INDIRECT LAND USE CHANGE (iLUC) WITHIN LIFE CYCLE ASSESSMENT (LCA) – SCIENTIFIC ROBUSTNESS AND CONSISTENCY WITH INTERNATIONAL STANDARDS

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VERBAND DER ÖLSAATEN-
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The author was not engaged or contracted as official representative of his organization but acted as independent expert.

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Abbreviations

AGLINK	Worldwide Agribusiness Linkage Program
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CF	carbon footprint
CFP	carbon footprint of products
CGE	computable general equilibrium models
dLUC	direct land use change
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
g	gramme
GHG	greenhouse gas(es)
GTAP	Global Trade Analysis Project
ha	hectare
IFPRI	International Food Policy Research Institute
ILCD	International Life Cycle Data System
iLUC	indirect landu use change
IMPACT	International Model for Policy Analysis of Agricultural Commodities
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Center(s) of the EU
LCA	life cycle assessment
LEITAP	Landbouw Economisch Instituut Trade Analysis Project
LUC	land use change
MJ	megajoule
NA	not applicable
PAS	Publicly Available Specification
PE	partial equilibrium models
RED	EU Renewable Energy Directive
SETAC	Society of Environmental Toxicology and Chemistry
Tg	teragramme
UNEP	United Nations Environment Programme
WTO	World Trade Organization
yr	year

Executive Summary

The 'food versus fuel' debate and the discussion about the environmental performance of biofuels in general has led to the development of the concept of indirect land use change (iLUC) and the proposal to include iLUC factors into environmental assessments of biofuels.

While the science behind iLUC is still in its infancy, life cycle assessment (LCA) has matured over a few decades and is nowadays accepted internationally by all stakeholders as "…best framework for assessing the potential environmental impacts of products currently available (EU 2003)". The international standards ISO 14040/44 represent the constitution of LCA.

The core question of this study is, if and how iLUC can be included in the LCA or carbon footprints (CF) of biofuels in a scientifically robust and consistent way. While the currently published mainstream trend seems to demand the integration of iLUC factors into LCA and CF assessments and thereafter in regulations, this study seeks proof whether this is supported by the sober, critical and neutral perspective of science.

The study reveals that there is hardly any fact-based support for a scientifically robust and consistent inclusion of iLUC factors into LCA and CF. This statement is based on the following results:

I. Indirect land use change cannot be observed or measured.

II. The iLUC quantification is based on theoretical models that mainly rely on hypothetical assumptions and market predictions.

III. The economic LUC models cannot differentiate between direct (dLUC) and indirect land use change. There is no iLUC without dLUC. If every product on earth accounted for its dLUC, there is no iLUC – unless double-counted.

IV. They suffer from a number of deficiencies and do not address the allocation of greenhouse-gas-emissions from a particular agricultural field between the displaced and the displacing crop ('inter-crop-allocation'). However, this is necessary to avoid doublecounting respectively free-rider incentives.

V. There are basically no primary data available for iLUC calculations; there is hardly any resolution with regard to individual crops or regions. The data quality underlying iLUC factors is significantly lower than any other data used for LCA and CF.

VI. There is full agreement in the scientific community that iLUC factors are highly uncertain. The level of cruelty for characterizing the uncertainties goes from "significant" (Laborde et al. 2011) to "enormous" (Edwards et al. 2010).

VII. iLUC values found in the existing literature vary in enormous ranges:

a. for bioethanol from negative values (e.g. -116 gCO2e/MJ (Dunkelberg 2013) or -85 gCO2e/MJ (Lywood et al. 2009)) up to 350 gCO2e/MJ (Plevin et al. 2010).
b. for biodiesel from 1 gCO2e/MJ according to Tipper et al. (2009) up to 1434 gCO2e/MJ as the upper value of Lapola et al. (2010).

These ranges mean that just the iLUC factors can be either some 200% below or some 1700% above the fossil fuels value. The uncertainty range for iLUC factors is even larger than the substantial differences between the LCA data of all types of food from lentils via tomatoes, cheese and even chicken to beef and lamb.

VIII. The uncertainties are dominated by systematic rather than statistical errors. As a consequence, there is currently no way to determine which of the iLUC factors published is more right than any other. It is not only about the size of the numbers, it is even unclear whether the iLUC effect of certain biofuels is positive or negative.

IX. There is a trend of an erosion of iLUC factors over time. For US corn ethanol, the initial LUC effect was given as 104 gCO2e/MJ. Improvements in the model used resulted in large reductions - first to 32 gCO2e/MJ (which is the value used in California's Low Carbon Fuel Standard) and more recently to 15 gCO2e/MJ. If California's Low Carbon Fuel Standard used the most recent iLUC factor, most corn ethanol production would be able to meet the required emission reduction percentage of 10% compared with fossil fuels by 2020 while this is not the case with the current factor of 32 gCO2e/MJ (Wicke et al. 2012).

X. The lack of scientific robustness and consistency of iLUC models and their data make the provision of any single numbers for iLUC factors rather sham than substance – just data, but no information.

a. The current information content, reliability and integrity of exact iLUC factors are not on the quality level of robust scientific findings.
b. Any single figure published to date is more representative for the approach or model used than the crop or biofuel assessed.
c. The quality of iLUC factors is way below the quality of the material and energy flow data that are typically used for process-based attributional LCA. It makes no sense to add these data into one number.

XI. The lacking scientific robustness and consistency of iLUC is properly reflected in the existing international standards for LCA and CF.

a. None of the generic LCA or CF standards and guidelines studied[1] requires the mandatory inclusion of iLUC factors into the assessment.
b. Even the intention to include iLUC factors in the future is limited to only a few documents and tightly constrained by the condition that this requires a scientifically robust and internationally agreed method.

[1] ISO standards on life cycle assessment (ISO 14040, ISO 14044), EC Product Environmental Footprint Guide, ILCD Handbook, French Labelling Scheme, ISO draft standard on carbon footprinting (ISO DIS 14067), GHG Protocol Product Standard, PAS 2050, Japanese CF Specification, Korean CF Labelling Guideline

c. Even if this condition might be met at some point in the future, the standards still require to report iLUC separately from the core LCA or CF result due to the different quality of the data (ISO 14067 2012, GHG 2011).

d. Some standards provide clear indications for either the limited use of iLUC factors (for consequential LCA only) or the comprehensive use of iLUC factors (for all products) or even indirect effects in general (beyond indirect effects for land use).

XII. iLUC factors are a hasty reaction in method development and an arbitrary choice for decision-making.

a. The isolated application of iLUC for biofuels is scientifically not consistent. If it is a robust and meaningful concept, it has to be applied to all products, not only one - "iLUC for all or iLUC for none" (Laborde 2011).

b. For a fair comparison of biofuels with fossil fuels, the same rules have to apply. If iLUC is considered for biofuels as indirect effect, the indirect effects of fossil fuels have to be considered as well. For example, the indirect military GHG emissions from Middle Eastern petroleum are well within the range of iLUC-factor estimates for ethanol and raise the GHG intensity of gasoline according to Liska & Perrin (2009) by roughly two-fold.

c. A scientifically robust assessment of indirect effects cannot be limited to the arbitrarily chosen issue of land use change. Full scientific consistency requires "including all indirect effects or none". Any arbitrary selection of indirect effects is a value choice, not justified by science.

These facts should be acknowledged for any consideration of iLUC factors in LCA and CF for decision-making. Decision-makers in both private and public organizations need to appreciate the benefits of LCA. However, for a robust, sustainable and credible use of LCA the over-interpretation of LCA results without proper consideration of its gaps and limitations has to be avoided. ISO 14040/44 clearly indicates that an LCA is not a complete assessment of all environmental issues of the product system under study. LCA does not fail, if it cannot capture indirect effects like iLUC - provided this limitation is documented properly. LCA does fail and damages its credibility, integrity and reliability, if it pretends to be able to do so by adding speculative, low quality iLUC factors to otherwise robust LCA results. Due to the different nature of iLUC and the material and energy flows typically assessed in LCA, it is wise to address iLUC separately from LCA – at least for quite some time.

For the topic of indirect land use change, more focus and resources should be directed towards proactive mitigation of such effects rather than reactive iLUC factors. For LCA, there are much more robust policy applications to expand the fact-based domain in environmental policy making. They should be tackled first – for the sake of both environmental policy and LCA.

1. Introduction

Reducing the greenhouse gas emissions of the transport sector, particularly road transport, is one of the major challenges for policy makers when it comes to tackling climate change. With liquid fuels likely to remain the primary energy source for road transport for at least the next few decades, biofuels are widely recognised as one of the potential solutions for lowering the greenhouse gas emissions of transport (Ernst & Young 2011).

The perception of the environmental advantages of biofuels was originally positive and many stakeholders were supporting an increased development, production and use of biofuels. Public policy promoted the use of biofuels by tax incentives, subsidies and mandatory quota of biofuels in the overall fuel mix (e.g. in France, Germany, EU, United Kingdom and the United States).

However, this positive perception has recently changed substantially. Since the 'food vs. fuel" discussion is on the agenda some stakeholders switched their branding of biofuels from 'good' to 'evil'. The food vs. fuel issue describes the competition for crops (e.g. corn) to be used in either food (e.g. staple) or fuel (e.g. ethanol) products. It addresses the risk of diverting farmland or crops for biofuels production at the expense of the food supply on a global scale.

Such effects are addressed by the concept of land use change (LUC). LUC can be defined as change in the purpose for which land is used by humans (e.g. between crop land, grass land, forest land, wetland, industrial land). Change in the use of land at the location of production of the product being assessed is referred to as direct land use change (dLUC). Change in the use of land elsewhere is referred to as indirect land use change (PAS 2050 2011). The indirect land use change impacts of biofuels, also known as iLUC, relate to the unintended consequences of releasing greenhouse gas emissions due to land use changes around the world induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuels (Searchinger et al. 2008). It should be noted, that LUC has potentially effects on different environmental impacts, but the present debate on iLUC of biofuels mainly deals with global warming implications only.

The 'food or fuel' debate is international in scope, with valid arguments on all sides of the issue. There is disagreement about how significant the issue is, what is causing it, and what can or should be done about it (Ayre 2007, Worldwatch 2007, Inderwildi & King 2009, Neves et al. 2011). This controversy is also reflected by the different approaches in sector specific regulations on biofuels respectively food. There are so far two biofuel regulations from the United States of America that already require the inclusion of iLUC factors, i.e. the Low Carbon Fuel Standard (LCFS) in California (CARB 2010) and the Renewable Fuel Standard 2 (RFS2) of the United States federal government (EPA 2010). In Europe, the EU Renewable Energy Directive (RED 2009) from 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC take a different approach.

The RED has in Annex V rules for calculating the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators. They include direct land use change GHG emissions as annualised emissions from carbon stock changes caused by land use change as equal shares over 20 years. Indirect LUC is excluded, but the RED notes that the Commission should develop a concrete methodology to minimise greenhouse gas emissions caused by indirect land use changes: "To this end, the Commission should analyse, on the basis of best available scientific evidence, in particular, the inclusion of a factor for indirect land use changes in the calculation of greenhouse gas emissions and the need to incentivise sustainable biofuels which minimise the impacts of land-use change and improve biofuel sustainability with respect to indirect land use change (RED 2009)." The RED included the requests to updated reports on the iLUC-issue. Several reports have been prepared, but still no iLUC-factors are proposed for inclusion in the GHG calculation.

Another relevant policy initiative is the European Food Sustainable Consumption and Production (SCP) Round Table which is an international initiative whose vision is to promote a science-based, coherent approach to sustainable consumption and production in the food sector across Europe, while taking into account environmental interactions at all stages of the food chain (Envifood 2012). It is relevant because the discussion of LUC in general and especially of iLUC needs consistent approaches between the food and the fuel sectors.

The ENVIFOOD Protocol recognises that "…there are several different ways of accounting for LUC, which, if not harmonised, will give considerable variations. LUC takes place as a result of several drivers, which are not trivial to identify." The ENVIFOOD Protocol does not differentiate between dLUC and iLUC and addresses just total LUC (Envifood 2012).

The following sections describe this background of this study in more detail (section 1.1), followed by the definition of the overall target as well as research questions (section 1.2) and an outline of study approach including its third party review (section 1.3).

1.1. Background

To tackle the challenge described above, life cycle assessment (LCA) and indirect land use change (iLUC) of biofuels represent the background for this study. LCA is currently the most accepted tool to assess the environmental performance of products in Europe, around the globe and by all stakeholders, i.e. government, companies, NGOs, academia, etc (Finkbeiner 2013). The underlying standards ISO 14040/44 (ISO 14040 2006, ISO 14044 2006, Finkbeiner et al. 2006) are by far the most broadly accepted standards in the field and can be regarded as the 'mother' of almost all other standardization activities, such as the ILCD-Handbook (ILCD 2010), the UNEP-SETAC Life Cycle Initiative (UNEP 2013) or the derivative carbon footprint (CF) standards ISO 14067 (ISO DIS 14067 2012), GHG Protocol (GHG 2011), PAS 2050 (PAS 2050 2011), etc. They all take ISO 14040/44 as a basis and specify some general requirements – even though some do not go much beyond the original (Finkbeiner 2009, 2013). A detailed analysis of the provisions of all these standards with regard to the subject of this study is presented in section 3 of this report. Because stakeholders and policy makers use LCA results more and more for their decision making, they do not have to be aware only of the huge benefits of LCA, but also of the inherent methodological limitations and the fact, that certain environmental impacts are not covered by LCA.

The early environmental and carbon footprint assessments of biofuels did not address the 'food vs. fuel' issue. Recently, the integration of direct and indirect land use change effects into the life cycle and carbon footprint assessments of biofuels is proposed by several scholars as solution for this gap.

However, the current discussion of iLUC and the GHG reduction potential of biofuels have turned into a rather controversial issue (Wang & Haq 2008). The controversy about the environmental potential and performance of biofuels is further heated up by diverging political and business interests of different stakeholders who try to take advantage of the still rather unclear science for their respective positions. Even some representatives of the scientific community seem to be inclined to provide political advice in their papers – way beyond the fact-based 'proof' of their data and on a level that is usually not accepted by scientific journals.

As scientists we should bethink ourselves that changing horses in midstream does not really help. The scientific contribution to the debate should focus on integrity and soundness, not sense of mission. The real task and challenge for the scientific community is to determine the environmental and sustainability performance of biofuels as objectively and fact-based as possible. The main question of this study, i.e. if and how iLUC can be included in the life cycle assessments (LCA) or carbon footprints (CF) of biofuels, is one of the more relevant aspects of the debate in urgent need of a down-to-earth science-based answer which is robust.

1.2. Goal of the study and research questions

The overall target of the study is to perform a gap analysis to identify methodological and practical gaps for the integration of indirect land use change (iLUC) within life cycle assessment (LCA) in general and with a particular focus on biofuels. The main criteria for this assessment are scientific robustness and consistency with relevant international standards for LCA and CF.
The research questions to be tackled include:

- What are the requirements of international standards and guidelines with regard to the inclusion of iLUC into LCA respectively CF?

- How scientifically robust are the current approaches to determine iLUC compared to other factors determining LCA and CF results?

- Is the integration of iLUC into LCA and CF studies consistent with the internationally agreed principles and methodologies of these assessment tools?

- Can the proposal to integrate quantitative iLUC factors into life cycle based regulatory limit values be supported by scientific arguments?

1.3. Study approach and scientific third party validation

The overall target and research questions of the study are of methodological and generic nature. As a consequence, the study is performed as desk research addressing the broadly existing literature on iLUC and particularly focusing on an analysis of current standards and guidelines for LCA and CF. No case studies or calculation of new data are performed or intended, because they are not necessary or relevant for the research questions of the study.

The outline of the study starts with an introduction of the concepts and approaches for the integration of iLUC into LCA in section 2 followed by an analysis of the provisions in the international standards of LCA and CF with regard to iLUC in section 3. Based on that, section 4 provides the analysis and synopsis of the scientific robustness and consistency to integrate iLUC into LCA. Section 5 summarises conclusions and outlook.

The draft final report of the study was submitted to a scientific third party review to check and validate the statements and interpretations of the study with regard to the relevant standards and state-of-the-art LCA science. In the ISO standards for LCA, such a process is called critical review. However, critical reviews can be only performed for LCA case studies. Because the current study is a methodological analysis and no case study it cannot undergo a critical review for formal reasons. However, the nature and intent of the third party validation follows the principles and approach of the critical review process according to ISO 14040/44.

Prof. Dr. Walter Klöpffer was selected as independent third party reviewer. He is an internationally recognized expert for LCA and CF methodology and their international standards. He is one of the pioneers of LCA development and amongst others editor-in-chief of the leading scientific journal in this field, the International Journal of Life Cycle Assessment.

As part of the review process, Prof. Klöpffer provided questions and comments on the draft final report which were addressed and implemented during a revision of the study. A final review statement on the result of the third party validation can be found in section 7.

2. Concepts and approaches to integrate iLUC into LCA

In this section, the various concepts and approaches to quantify iLUC for the integration into LCA are introduced. First, the overall relevance of iLUC is discussed in section 2.1 followed by the definitions used in the study (section 2.2). Section 2.3 introduces the main concepts and approaches for iLUC quantification including economic and deterministic models. A comparison of these models is presented in section 2.4. Finally, the uncertainties and the current ranges of iLUC factors are summarized in section 2.5.

2.1. Relevance

Before the methods and approaches for the quantification of iLUC are discussed in more detail, some basic data and findings on the overall relevance of biofuel induced land use change are presented in this section. The controversy and heated debate about iLUC was fuelled by strong claims about the relevance of this issue by several authors. It was stated that "corn-based ethanol […] nearly doubles greenhouse emissions over 30 years and increases greenhouse gasses for 167 years (Searchinger et al. 2008)", that „dirty biofuels exacerbate climate change and lead to the destruction of rainforests (Greenpeace 2010)" or even that biofuel induced iLUC is "the champion of unintended consequences, and the road to hell […] paved with good intentions (Tansey 2011)."
Some of the main arguments for the fundamental criticism are

- Biofuel induced LUC is a relevant contribution to the global GHG emissions.
- Biofuels production will endanger the food supply on a global scale.
- Biofuels increase food prices
- Biofuels lead to increasing land use change and deforestation

It is not the intention at all to downplay the potential risks of the concerns raised with these arguments, but the current debate seems to be characterized by a rather hypercritical attitude. Therefore, some data given in the following paragraphs try to put the topic in a more sober perspective.

In contrast to the strong emphasis of some scholars, the magnitude of GHG emissions due to LUC from global biofuel production is still very small. Agricultural land expansion for food, feed, fibre, cattle ranching, fuel wood and timber (loggings) is much more relevant for LUC emissions. As shown in Figure 1, the current level of biofuel production contributes with just 6.6% to LUC emissions from permanent agriculture, which is about 1% of the total global LUC emissions (Fritsche & Wiegmann 2011).

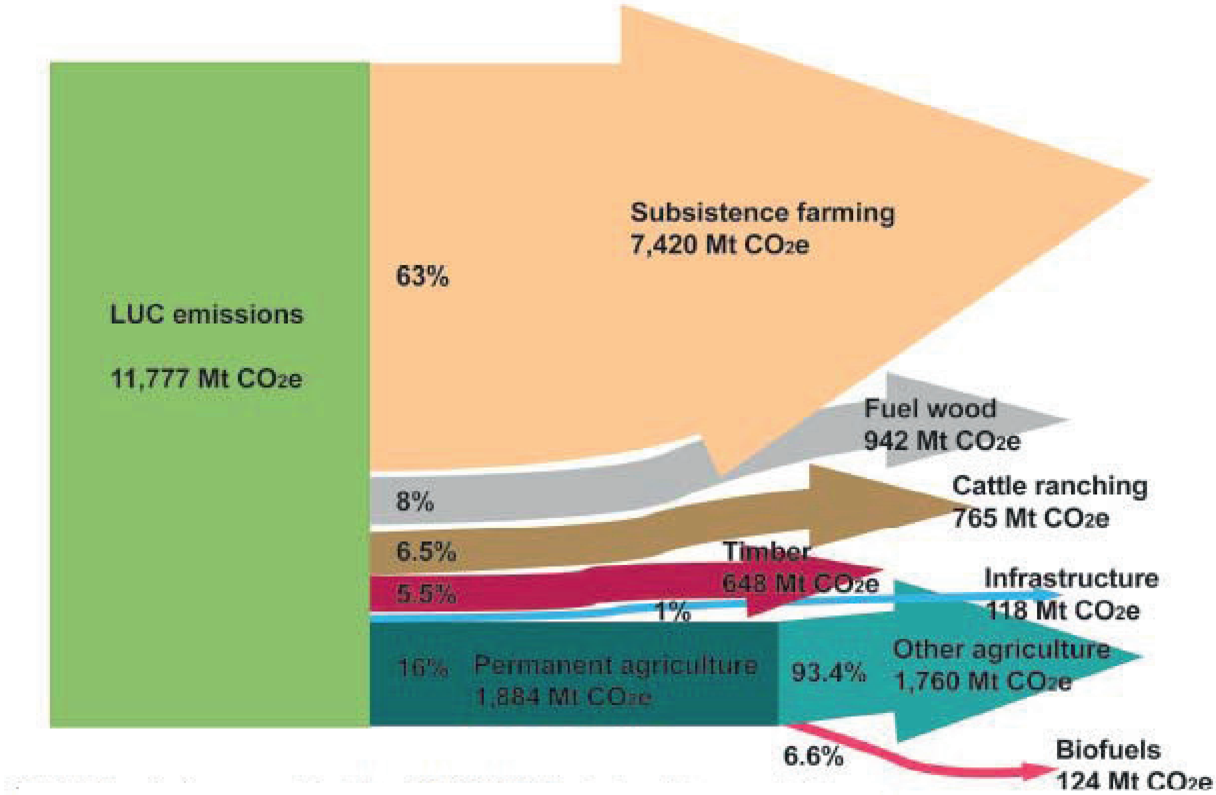
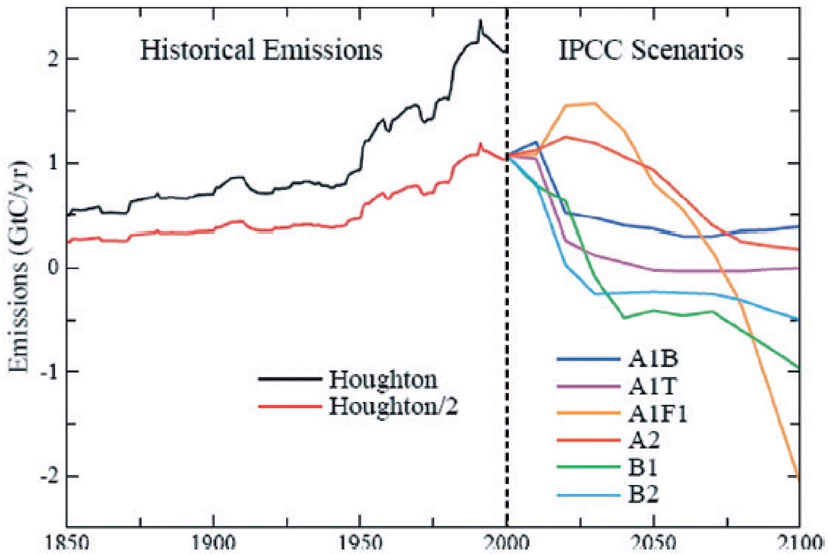


Figure 1: Causes of global LUC related GHG emissions, taken from Fritsche & Wiegmann (2011)

In addition, the overall trends in land use caused emissions are presented based on the Intergovernmental Panel for Climate Change (IPCC). Recent studies confirm that effects of urbanization and land use change on the global temperature record are negligible as far as hemispheric and continental-scale averages are concerned (IPCC 2007). Mathews & Tan (2009) show in Figure 2 the IPCC estimates of the future trends of net land use emissions. For a detailed description of the scenarios, we refer to the references given. Basically, the A1 scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and the rapid introduction of new and more efficient technologies. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The A2 scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The B1 scenario family describes a convergent world with the same global population as in A1, but with rapid change in economic structures toward a service and information economy. The B2 scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability (IPCC 2007). The historic data by Houghton are presented as such and with a reduction of 50%. The rationale of the 50% reduction scenario and the reason why the IPCC scenarios take it as a starting point is not explicitly addressed in the paper of Mathews & Tan (2009). However, for the key message of these data this is not decisive. Even if the unreduced Houghton data are taken as a starting point, LUC emissions are expected to fall substantially in the future - independent from the broad range of scenarios analysed, It should be stressed again, that the intention of this section is not to trivialize the topic of land use change, be it direct or indirect. However, the overall relevance of the topic has to be kept in mind while the quantification approaches and their results are presented later in this section. Before addressing this in section 2.3, some key definitions for the study are introduced.



Left side: estimate by Houghton of historical net land-use CO_2 emissions, and a 50% reduction of that estimate. Right side: IPCC scenarios for land use CO_2 emissions.[16]
Source: adapted from p. xiii, the supporting material of Hansen *et al.*[18]

Figure 2: Development of net land use change emissions, taken from Mathews & Tan (2009)

2.2. Definitions

It should be noted, that the term ‘indirect’ effects is used in different contexts for environmental issues. Within Environmental Impact Assessment (EIA), indirect impacts are defined as impacts on the environment, which are not a direct result of the project, often produced away from or as a result of a complex pathway. Sometimes referred to as second or third level impacts, or secondary impacts (EU 1999).

Within the context of environmental management systems indirect environmental aspect refers to an environmental aspect which can result from the interaction of an organisation with third parties and which can to a reasonable degree be influenced by an organization (EMAS 2009).

In the context of life cycle assessment, indirect effects are commonly used as a synonym for rebound effects. They include indirect consequences in a comprehensive way. Originally conceptualized for energy efficiency measures, the following effects can be distinguished: substitution effect, income effect, secondary effects, market-clearing price and quantity adjustments, transformational effects (Greening et al. 2000). Hertwich (2005) concluded that “the rebound effect, as defined in energy economics, is insufficient to describe the different secondary effects that are of interest in industrial ecology or sustainable consumption. Additional mechanisms and multiple environmental endpoints need to be considered. […] They include behavioral and technological spill-over effects, transformational effects, and positive and negative side effects, that is, environmental or other repercussions not directly addressed by the primary […] measure." The inclusion of indirect effects is far from common practice in LCA. They are supposed to be partly covered by consequential LCA (CALCAS 2009). The consequential, "change-oriented" or "market-based" life cycle inventory modelling aims at identifying the consequences that a decision has for other processes and systems of the economy. The consequential life cycle model is hence not reflecting the actual supply-chain, but a hypothetic generic supply-chain based on market mechanisms, and potentially including political interactions and consumer behaviour changes (ILCD 2010). This type of modeling has to be distinguished from the current, standard LCA practice of attributional or „accounting" life cycle inventory modelling which makes use of historical, fact-based, measureable data of known (or at least knowable) uncertainty, and includes all the processes that are identified to relevantly contribute to the system being studied (ILCD 2010).

With regard to this study, the particular subject of land use is addressed. Direct land use change occurs when a new activity occurs on an area of land. Direct land use change can be observed and measured. Indirect land use change (iLUC) occurs as an unintended consequence of land use decisions elsewhere. Indirect land use change cannot be directly observed or measured (Ernst & Young 2011). On a more technical level, the following definitions of the draft ISO standard on carbon footprinting (ISO DIS 14067 2012) are used for the purpose of this study:

direct land use change (dLUC):
change in human use or management of land within the boundaries of the product system being assessed

indirect land use change (iLUC)
change in the use or management of land which is a consequence of direct land use change, but which occurs outside the product system being assessed

The following section introduces the different iLUC quantification approaches and methods discussed today.

2.3. Overview iLUC quantification approaches[2]

Because agricultural trade is a globalised business today, the actual location where a natural ecosystem is converted to agricultural land can be far removed from the biofuel feedstock cultivation site (Delzeit et al. 2011); which makes it very challenging to link a specific biofuel feedstock cultivation measures to a specific iLUC. The occurrence of several indirect effects linked to biofuels production additionally complicates the quantification of GHG emissions induced by iLUC.

To address this challenge, two fundamentally different approaches have emerged. Complex economic models (computable general equilibrium (CGE) models or partial equilibrium (PE) models) as well as several simplified models have been developed. Simplified modeling is often referred to as deterministic or causal-descriptive modeling. The determination of iLUC can include regional information and data to varying extents; thus some authors refer to this as regional modeling when the spatial resolution is high (e.g. Lahl 2010). Regional models, however, are either economic or simplified models as well.

[2]This section is partly taken and adapted from the Elisa Dunkelberg´s draft dissertation "A case-study approach to integrating indirect land-use change into the carbon footprint of biofuels" which is supervised by the author of the study

2.3.1. Economic models

Economic models generally work with marginal changes in a mathematically modeled economic system. Economic equilibrium models consist of equations that define the quantitative relation between supply, demand, and price and a broad database (Di Lucia et al. 2012); they are generally complex and need large amounts of data. The basic assumption is that equilibrium in the economy is achieved when demand equals supply. Markets are assumed to be characterized by perfect competition. For iLUC, there are two kinds of economic models: CGE models study the entire global economy, while PE models focus on a specific sector such as agriculture. Both types of models are based on linear and nonlinear relations between prices, demand, and production; these relations are characterized by supply and demand elasticities that can be derived from statistic data and historical trends (Nassar et al. 2011).

Economic models, such as GTAP[3] (CGE) and IMPACT[4] (PE), have been developed independently from the biofuel or iLUC debate and researchers from various disciplines have constantly been adapting them to new contexts. Such models are typically applied in trade policy, but they are also used in development policy (e.g. Cardenete et al. 2012) and more recently in bioenergy policy. At around 2007 researchers in the field of economic modeling started to adapt the existing economic models in order to calculate iLUC effects. The first scientific paper on iLUC quantification based on economic modeling was published by Searchinger et al. (2008), who used a PE model to calculate the iLUC effect caused by maize-ethanol production in the USA.

Both PE models (e.g. IMPACT[4], FAPRI[5], AGLINK[6] and CAPRI[7]) and CGE models (e.g. GTAP[3] and LEITAP[8]) have meanwhile been used to project iLUC (Edwards et al. 2010). One of the important research institutes with regard to iLUC determination based on economic modeling is the International Food Policy Research Institute (IFPRI); IFPRI published two studies, in 2009 and 2011, respectively; in the 2009 study CGE models were used for the first time to assess the LUC impact of the EU's biofuels policy (Al-Riffai et al. 2010; Laborde 2011).

In order to assess iLUC, CGE and PE models generally take a marginal approach. Initially a baseline scenario is calculated with the model; then in a second step a scenario with a marginal extra demand for a specific biofuel is run (Edwards et al. 2010). Modelers often call the step of calculating the effect of a marginal extra demand for biofuels "giving the model a biofuel shock or policy shock"; this results in a projection of the effects of nationally increased biofuel demand on global commodity markets and on additional land requirements (Edwards et al. 2010).

Given that economic models do not distinguish between feedstocks grown on 'new" and those grown on 'old" land (Edwards et al. 2010), the results refer only to total LUC, including both dLUC and iLUC (Delzeit et al. 2011; Edwards et al. 2010). In a subsequent step, LUC are mapped to specific land-cover types (e.g. grassland, forest, etc.), based on historical patterns of LUC. Finally, biophysical models are used to project the GHG emissions from land-use conversion (Nassar et al. 2011). A comparison of the two scenarios allows GHG emissions to be attributed to a specific quantity of biofuels, so that the results can be expressed in g CO2e/ MJ. As this value includes emissions from both iLUC and dLUC,

[3] Global Trade Analysis Project
[4] International Model for Policy Analysis of Agricultural Commodities
[5] Food and Agricultural Policy Research Institute
[6] Worldwide Agribusiness Linkage Program
[7] Common Agricultural Policy Regionalised Impact Modelling System
[8] Landbouw Economisch Instituut Trade Analysis Project

adding this directly to the biofuels CF would cause double counting of dLUC (Delzeit et al. 2011). Modelers therefore separate dLUC and iLUC in the qualitative interpretation of the model's results. The assumptions made in setting up the baseline are crucial for the LUC results from both CGE and PE modeling. One important assumption refers to the elasticities, especially the so-called constant elasticity of transformation (CET) and the elasticity of land transformation. The latter characterizes the ease by which land is converted to another type of land use when the prices for agricultural commodities change (Delzeit et al. 2011).

A challenge in CGE modeling is creating a consistent dataset. The dataset normally used in CGE modeling is the social accounting matrix (SAM), which describes the transactions and inter-industry value flows between all economic agents within an economy and during a specific accounting period. Given that biofuel sectors are not part of the currently existing SAM and biofuel feedstock are often aggregated, one has to single out these feedstocks for LUC calculations based on assumptions (Delzeit et al. 2011).

The manner by which by-products are accounted for also has a crucial impact on the model results. Given that the models differ in how they take into account by-products, the results they provide in terms of LUC differ; in GTAP, for instance, by-products are accounted for by substitution based on relative prices; CAPRI accounts for them by means of physical replacement ratios (Edwards et al. 2010). According to Plevin et al. (2011) the following sequence of modeling steps is typical of studies that estimate the iLUC emissions induced by the expansion of biofuel production:

1. An economic equilibrium model is used to project the effects of increased biofuel production on global land and commodity markets, including

    a. how much additional land will be brought into production to compensate for land removed from other uses to produce biofuels and

    b. the approximate location of this land.

2. The resulting land use changes are mapped to specific land cover types based on historical patterns of land use change.

3. For each category of land cover conversion, the quantity and time profile of GHG emissions from land use conversion are estimated.

4. To calculate the CF in grams of CO_2e per MJ of biofuel, the emissions induced by the expanded biofuel production are attributed to a quantity of fuel, usually defined with reference to a time period of fuel production.

The robustness of the resulting iLUC factors is discussed in section 4.2, because there is significant uncertainty inherent in each of these modeling steps (Plevin et al. 2010).

2.3.2. Deterministic models

Deterministic models are simplified calculations based on a set of explicit assumptions. In contrast to economic models, deterministic models generally do not model prices, but use assumptions about how the agricultural systems respond to an increase in biofuel feedstock production. They generally use cause-and-effect assumptions to describe system behavior (Bauen et al. 2010). The logic is that an additional biofuel demand has an impact on the broader agricultural system, which has an impact on LUC, which finally leads to GHG emissions. Assumptions used to describe the market reactions and LUC are mainly based on an analysis of historical data on trade, land use, and LUC (Nassar et al. 2011). One example of a deterministic model is the iLUC factor developed by the Institute for Applied Energy (Öko-Institut) in Germany (Fritsche et al. 2010). The model is built on statistical trade data as well as various assumptions. A crucial assumption in this model is that iLUC can be estimated by looking at the exported products relevant for the bioenergy sector, e.g. soy and palm oil. Calculations are based on 2005 product exports, but the authors only consider the key regions Argentina, Brazil, the EU, Indonesia, Malaysia, and the USA; in 2005 these countries were responsible for more than 80% by mass of the global trade of the chosen commodities (Fritsche et al. 2010).

The authors calculate the area needed to produce these products by dividing the mass of traded commodities by the respective country-specific yields. The sum of all land use for agricultural exports, each country's proportionate share is calculated as the "world mix." As a next step, the additional area required is combined with country-specific assumptions about the dLUC associated with the production of the export commodities. Based on the conversion factors from IPCC, the interim results are then weighted according to each country's share in the "world mix," resulting in an iLUC factor of 270 t CO2/ha or 13.5 t CO2/ (ha * yr) when allocating the LUC emissions over 20 years (Fritsche et al. 2010). These calculations suggest that one ha of bioenergy feedstock production displaces one ha of previous production; however, the displacement is assumed to be lower because of further yield increases and the use of vacant areas. Assuming average yield increases of 1% per yr until 2030, the maximum iLUC factor will only be 75% of the theoretical iLUC factor. The authors suggest three different levels of 25%, 50%, and 75%, as they anticipate that even higher increases in efficiency are possible and assume that a share of the expansion occurs on degraded lands (Fritsche et al. 2010).

Plevin et al. (2010) introduced another deterministic model in order to characterise iLUC. For this purpose, the authors include four main parameters in their model:

- net displacement factor (NDF – ha of converted land per ha of biofuels),
- average emission factor (t CO2/ ha),
- production period (yr), and
- fuel yield [MJ/ (ha*yr)].

The objective of their approach was not to determine the most realistic iLUC factors for specific biofuels, but rather to characterize plausible boundaries for iLUC emissions by considering various probability distributions using Monte Carlo simulations (Plevin et al. 2010).

Lahl (2010) developed a simplified method addressing criticism that other models do not properly consider the effects of state regulation on the global agricultural market, which can take the form of subsidies, customs duties, and trade restrictions such as bans on import and export. The target thus was to include iLUC effects due to domestic trade, which, according to Lahl (2010), is quantitatively more important than global trade and had not been previously considered. Lahl (2010) suggested a method for regional modeling that starts with an estimation of all LUC within a specific country and for a specific period. As a next step, country-specific CO2 emissions (ERLUC) are then calculated for the respective carbon stocks in vegetation and soil, before and after conversion. In order to calculate the share of the various biofuels in total emissions, the change in biofuel production is divided by the change in agricultural production in total and multiplied by ERLUC. Next, the portion of total emissions due to dLUC is subtracted, and finally, the remaining emissions are allocated to the "originator," which can be separate farms or regions. In some cases correction factors for by-products or transnational effects can be included (Lahl 2010).

Another deterministic model has been developed by E4tech on behalf of the United Kingdom Department of Transport (Bauen et al. 2010). The causal-descriptive methodology was tested with five different biofuel feedstocks: sugarcane, palm oil, rapeseed oil, soy oil, and wheat. For each feedstock Bauen et al. (2010) calculated various iLUC factors based on different scenarios and assumptions. The motivation for the study was not to present an average iLUC factor, but to find differences in the iLUC risk between various feedstocks and to understand the uncertainties of iLUC.

In order to estimate appropriate market responses, Bauen et al. (2010) used statistical analysis of historical trends, market analysis, expert inputs, and a literature review concentrating their analysis on the market responses to product substitution (substitution of biofuel feedstock in other markets by other suitable products), area expansion and yield increase. Where product substitution was found to occur, a substitution ratio between the biofuel feedstock and the substituting product was determined based on the literature and expert interviews; the additional demand for the substituting product and its land use impact are then calculated based on this ratio. In order to calculate the area needed for additional feedstock production it is necessary to estimate what portion of the feedstock will be covered by increased yields and what portion will be covered by expansion of agricultural area. Based on Lywood et al. (2009), Bauen et al. (2010) calculated the shares based on the relationship between historic changes in yield and land use for various regions and crops. In order to determine the displacement, the authors base their calculations on average yields and not marginal yields. This means they assume that the production of a specific non-biofuel crop will require the same area with the additional biofuel production as without it (Bauen et al. 2010). The following section 2.4 compares the deterministic models described here with the economic models described above in section 2.3.1.

2.4. Comparison and analysis of iLUC approaches[9]

The previous section 2.3 introduced the existing approaches for the quantification of iLUC factors. This section analyses these approaches with regard to their strengths and weaknesses. For the analysis, a set of criteria that a robust iLUC-quantification method should fulfill were defined. The chosen criteria were structured into three categories: general requirements, ability to account for various indirect effects, and ability to account for regional heterogeneity.

General requirements:

– Level of detail (e.g. in the characterization of the agricultural sector)
– Ability to provide for a sensitivity analysis

[9]This section is partly taken and adapted from the Elisa Dunkelberg´s draft dissertation "A case-study approach to integrating indirect land-use change into the carbon footprint of biofuels" which is supervised by the author of the study

– Timeliness of data
– Applicability with regard to data availability
– Applicability with regard to time required for data collection
– Transparency and traceability
– Avoidance of double counting (separation of dLUC and iLUC)

Additional indirect effects:
– Supply of by-products (e.g. fodder crops)
– Efficiency gains (e.g. increase in productivity and in emissions from fertilization)
– Changing diets (e.g. due to changed prices)
– Changing total fuel and energy demand (e.g. due to changed prices)
– Changes in household incomes (e.g. causing a change in product consumption)

Regional heterogeneity (regionalization):
– Biophysical aspects:
  • Carbon fluxes (above and below ground soil carbon contents)
  • Current and expected productivity (yields)
  • Expected productivity due to the implementation of compensation measures

– Aspects of land use:
  • Amount of unused area in specific regions
  • Regional specification of LUC
  • Land-cover monitoring or use of statistical data on historic and current land use

– Political, economic and cultural aspects:
  • National legislation with regard to land use (e.g. ecosystem protection)
  • Land tenure and ownership
  • Regional specific management practices
  • Societal preferences (e.g. regarding willingness to cultivate specific crops)
  • Trade incentives and trade barriers

Table 1 presents the analyses, how the different types of approaches fulfill these criteria. The types of approaches considered are economic models (CGE and PE) and several different deterministic models. Within the group of CGE and PE models, specific models such as GTAP, LEITAP, FAPRI or IMPACT are not differentiated here as this would require more detailed knowledge and deeper insight into economic modeling. Both groups, however, exhibit characteristic advantages and disadvantages with regard to the set of criteria and they differ significantly from all deterministic models (see Table 1).

A general disadvantage of CGE models is that they do not capture the agricultural sector in the same detail as PE models (Delzeit et al. 2011). Laborde (2011) concedes, for example, that the IFPRI model MIRAGE does not yet capture either multi-cropping or crop rotation despite their significant influence on land-use patterns. This is the advantage of PE models – they represent the agricultural sector in greater detail; however, they are not linked to other sectors. As a consequence and unlike CGE modeling, the interactions with energy prices or fertilizer and chemicals cannot be taken into account.

The level of detail in deterministic modeling strongly depends on the specific approach and the purpose of its development. Fritsche et al. (2010), for instance, aim to provide a simplified approach which is not characterized by a high level of detail. The simplified model of Plevin et al. (2010) also does not aim to capture the agricultural sector in great detail – its purpose was to show the impact of uncertainty on iLUC factors in general. Bauen et al. (2010) and Lahl (2010), however, both aspire to describe market relations as well as regional conditions in more detail.

Table 1: Analysis and comparison of several iLUC quantification approaches

(+ criteria fulfilled; O criteria not fulfilled, but generally possible; – criteria not fulfilled)

	CGE	PE	Fritsche et al. (2010)	Bauen et al. (2010)	Lahl et al. (2010)
General requirements					
Level of detail	low	high	low	high	high
Option sensitivity analysis	+	+	+	+	+
Timeliness of data	low	low - high	low	high	high
Data availability	medium	medium	high	medium	medium
Time for data collection	high	high	low	high	high
Transparency and traceability	–	–	+	+	+
Separation dLUC and iLUC	–	–	+	+	+
Additional indirect effects					
By-products	o	o	allocation	system expansion	allocation
Efficiency gains	o	o	+	+	indirectly
Changing diets	o	o	–	–	–
Changing energy demand	o	o	–	–	–
Changing household income	o	o	–	–	–

	CGE	PE	Fritsche et al. (2010)	Bauen et al. (2010)	Lahl et al. (2010)
Regionalisation					
Carbon fluxes	o	o	IPCC	Winrock	IPCC
Current productivity	o	o	FAO	FAO	best data available
Expected productivity	o	o	vague estimation	more precise estimation	indirectly
Potential productivity	o	o	vague estimation	partly	–
Unused area	o	o	vague estimation	partly	o
Specification of LUC	CET	land price elasticities	statistical data	statistical data	statistical data
Land-cover monitoring	o	o	–	–	o
Statistical data on LUC	o	o	+	+	o
Legislation towards land use					
Land tenure and ownership	–	–	–	–	–
Management practices	–	–	–	–	–
Societal preferences	–	–	–	–	–
Trade incentives and barriers	+	+	–	+	+

Nassar et al. (2011) proved the strong influence that the choice of reference year has on the results. Given that deterministic models mainly use statistical data on LUC from previous years in order to forecast the prospective LUC, the extent and type of forecasted LUC depends strongly on the chosen reference years (Nassar et al. 2011). This effect accounts mainly for countries with rather variable LUC rates. Nassar et al. (2011) gives Brazil as an example, where the deforestation rate was much higher between 2004 and 2007 than between 2007 and 2009. Depending on the period chosen for the iLUC calculation, iLUC in Brazil would thus be high or low (Nassar et al. 2011). This influence of the choice of reference year on the average CO2 emission factor is valid for every model that predicts prospective LUC using historical data.

The time required for data collection and preparation is assumed to be substantial for all types of models. For CGE modeling much time is devoted to data disaggregation and preparation. When applying deterministic approaches, more time is needed for data collection. The model of Fritsche et al. (2010) represents an exception, given that it largely draws on export data provided by FAOSTAT.

Low traceability and transparency for those not familiar with economic modeling in general, and the specific model in particular, are disadvantages of PE and CGE models (Wing 2004). Deterministic models show advantages with regard to transparency and traceability; however, the trade-off for this is less detail and lack of capability to model of complex interactions.

Another disadvantage of economic modeling is that dLUC and iLUC cannot be differentiated (Delzeit et al. 2011); this has to be done through interpretation of the results. Adding the iLUC factors gained by economic modeling for the CF of biofuels without separating dLUC and iLUC beforehand leads to double counting and should thus be avoided. Deterministic models, on the contrary, usually allow for a distinction between dLUC and iLUC.

The main advantage of CGE models is that they are able to cover several types of indirect effects at the same time, e.g. changes in other sectors such as the food sector. Although this is generally possible with most of the economic models, scenarios with changing demands for food, intermediates, or fuel are not always conducted. Laborde (2011) notes, for instance, that in the most recent iLUC calculation of the IFPRI, the analyses of the impact of changing food demands have been very limited. As a contrast to economic models, deterministic models usually do not offer the possibility to model different kinds of indirect effects at the same time. Such effects can be partially considered by applying rather rough assumptions.

One difference between CGE and PE models is the way they handle and predict LUC. CGE models mainly work with the constant elasticity of transformation (CET), i.e. how easily land moves to another type of land use when the prices for agricultural commodities change (Delzeit et al. 2011). GTAP, for instance, distinguishes between three types of land use: cropland, pasture land, and accessible forests. The elasticity of land transformation finally depends on the share of total returns on these land types. A common criticism of CGE modeling is the coarseness of the land-use groups (Delzeit et al. 2011). LUC modeling in PE models normally relies on own- and cross-price elasticities for land demand used for specific crop cultivations. These individual land demands compete with each other so the displacement of agricultural uses can be calculated. Deterministic models rely on rather rough assumptions to describe how the agricultural system is going to respond to an increase in biofuel feedstock production.

Most of the existing models, economic and deterministic, only partially consider regionally specific characteristics such as local LUC, specific carbon stocks, land tenure and ownership systems, management practices, societal preferences, and trade incentives and barriers.

In comparison to CGE models, PE models generally allow a greater degree of regionalization given that they refer to the agricultural sector in a specific country. Thus regional economic links and regional data, for example, expected yield developments, can be considered in more detail than in CGE modeling.

Whether regional conditions are considered in deterministic models depends again largely on the specific model and its aim. While Lahl (2010) and Bauen et al. (2010) explicitly aim to consider regional data and information, Fritsche et al. (2010) prefer to provide an easily implementable and universally applicable methodology without regional differences. Regional factors such as economic and political factors were emphasized as being of particular importance for the occurrence of iLUC by Lahl (2010) and Delzeit et al. (2011).

This discussion reveals that the current approaches to quantify iLUC factors are fundamentally different with regard to methods and scope. In addition, none of the current approaches is even close to satisfy all the scientific criteria formulated at the beginning of this section. As a consequence, the current iLUC quantification approaches contain substantial uncertainties and the resulting iLUC factors for one and the same type of biofuel differ enormously. The uncertainty and the broad range of results for iLUC are addressed in more detail in the following section 2.5.

2.5. Current ranges of iLUC factors and uncertainties

There is broad consensus in the scientific community that the current iLUC estimations are highly uncertain. Even those authors that argue for the use of iLUC factors in LCA and CF calculations as well as in policy making admit that they are skating on thin ice. The first IFPRI study concluded that indirect land use changes were a valid concern, but that the degree of uncertainty regarding their magnitude was large (Al-Riffai et al. (2010). In the updated IFPRI study Laborde (2011) conceded that "the range of uncertainty on the overall LUC emissions is significant" and that the degree of uncertainty of LUC computation is "very large" when it is calculated on the crop/country level (Laborde 2011). Plevin et al. (2010) estimated that the range for emissions from indirect land-use change (iLUC) from US corn ethanol expansion was 10 to 340 g CO2/MJ and confirmed that "iLUC is the most uncertain component of the GWI [= CF] for biofuels (Plevin et al. 2010)."

Edwards et al. (2010) use in a study for the European Commission Joint Research Centre even stronger wording and talk about "enormous uncertainties […] in LUC estimates." A recent review article in the Journal of the Royal Society Interface describes the challenge in estimating land-use change effects of biofuel expansion as "a number of different modeling and biofuel scenario projection issues […and] uncertainty in a wide range of factors" (Sanchez et al. 2012). In a study for the UK Department for Transport Bauen et al. (2010) concluded that "price modelling is inherently uncertain [and] iLUC modelling is complex and uncertain for several reasons. First, it is about projecting impacts in the future, which is inherently uncertain. Second, iLUC models cannot be validated or calibrated against historic data: indirect land use change is not an observable parameter, as so it has not been measured historically. This means that high uncertainty and debate exist around the exact cause and effect relationships that lead to land use change. Thirdly, there are uncertainties associated with the estimates of carbon stocks associated with different land types, and the carbon stock losses associated with land use change (Bauen et al. 2010)." As a consequence, they refrain from providing an average or "central" iLUC factor because of this large degree of uncertainty.

Wing (2004) characterizes the economic models – which are nowadays adapted for iLUC calculations - as black boxes with output values that cannot be "meaningfully traced to any particular features of their data-base or input parameters, algebraic structure, or method of solution" (Wing 2004).

Last, but not least, the IPCC states in their recent Special Report on Renewable Energy Sources and Climate Change Mitigation that the "models used to estimate iLUC effects vary in their estimates of land displacement. Partial and general equilibrium models have different assumptions and reflect different time frames, and thus they incorporate more or less adjustment. […They] suggest that any iLUC effect strongly (up to fully) depends on the rate of improvement in agricultural and livestock management and the rate of deployment of bioenergy production" (IPCC 2011). Another issue that has been recently addressed is the influence of the chosen temporal reference as discussed in the baseline time accounting approach of Kløverpris & Müller (2013).

Based on this variety of sources there is no doubt that the uncertainty of iLUC quantification approaches and their results is a severe issue. There is full agreement in the scientific community that the uncertainty is way beyond a level that is usually aimed for in quantitative science. The only scientific difference occurs in the level of cruelty for characterizing the uncertainties – which goes from "significant" (Laborde et al. 2011) to "enormous" (Edwards et al. 2010). Another big difference occurs then in the political consequences proposed, but this is outside the scientific arena – even though some scientists with a sense of mission still play an active role in it. Despite the limited knowledge and uncertainties described above, several authors still dare to provide 'exact' iLUC factors and propose their implementation in regulations (e.g. Fritsche & Wiegmann 2011), while others focus more on scientific integrity and refrain from providing single, more or less arbitrary numbers for iLUC-factors which are prone to be (mis)used out of context (Bauen et al. 2010).

This general discussion on uncertainties explains, why the different iLUC estimations of different authors for one and the same biofuel reveal such enormous differences. Due to the lacking robustness of the assessments and the fact, these uncertainties are mainly due to systematic rather than statistical errors, there is currently no way to determine which of these results is more right than any other. The issue is not only about the size of the numbers, it is even unclear whether the iLUC effect of certain biofuels is positive or negative.

Figure 3 from the EU Commission study of Edwards et al. (2010) gives an impression of the potential ranges of values. It should be noted, that the error bars just relate to one of the different sources of uncertainty, the soil C emissions. An average value of 40 t C/ha for soil C emissions were used as a baseline. IPCC default values report 38 to 95 tC/ha following land cover conversion for EU and agricultural areas in North America. The error bars represent the maximum range using 95 tC/ha (value also used in Searchinger et al. 2008), and the minimum derived from an emission factor of 10 tC/ha (used in FAPRI-CARD calculations with GREEN-AGSIM reported to the JRC) (Edwards et al. 2010). Overall, the results range from basically no LUC up to 800 g CO2/MJ.

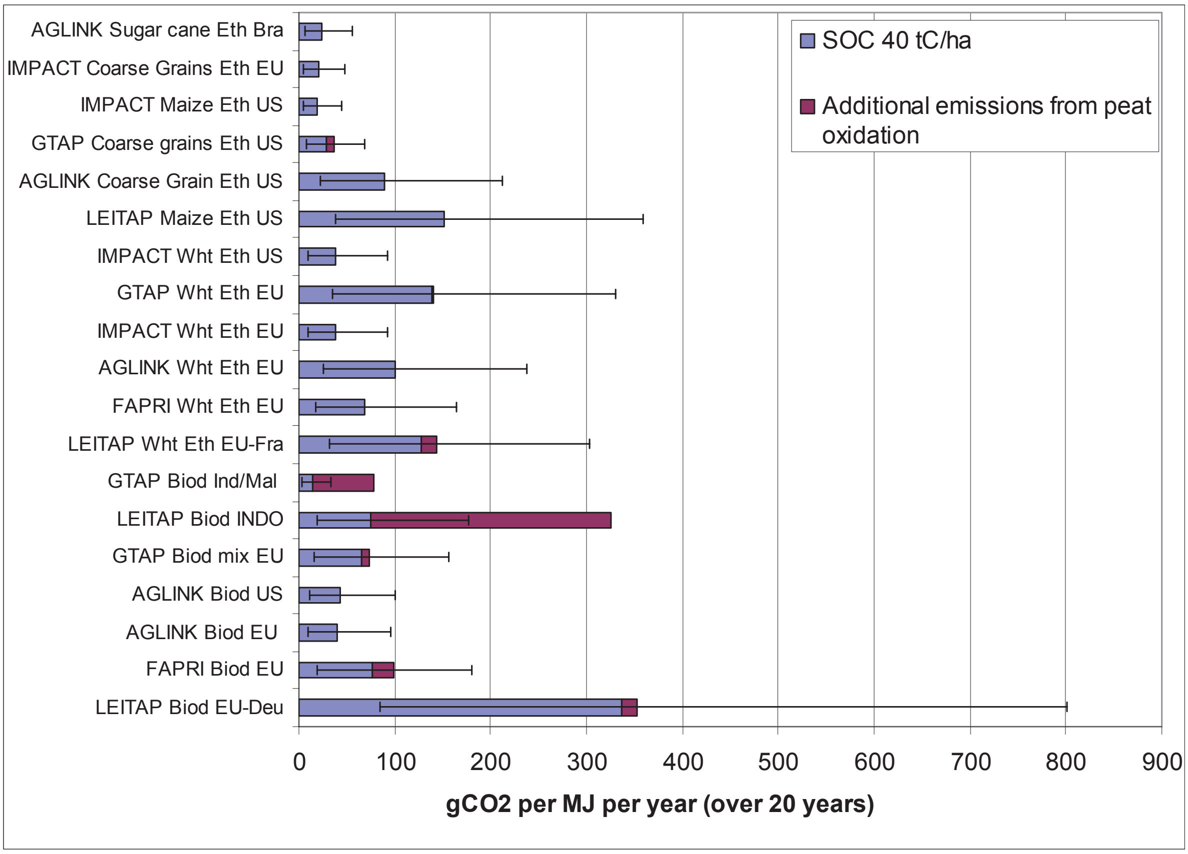


Figure 3: Rough indication of GHGs assuming 40 tC/ha over 20 years, taken from Edwards et al. (2010)

For iLUC factors, the range of values for different scenarios found in the existing literature varies for bioethanol from negative values (e.g. -116 gCO2e/MJ (Dunkelberg 2013)) or -85 gCO2e/MJ (Lywood et al. 2009) up to 350 gCO2e/MJ (Plevin et al. 2010). For biodiesel, the range starts currently with a value close to zero (1 gCO2e/MJ according to Tipper et al. (2009)) and goes up to 1434 gCO2e/MJ as the upper value of Lapola et al. (2010).

Last, but not least, there is an interesting trend in the development of iLUC estimations based on economic models over time. Even though the time series is still short and all the uncertainties discussed above obviously apply to this trend as well, it is striking that the iLUC estimations are getting smaller over time.

Figure 4 shows that the first study from 2008 by Searchinger et al. (2008), which contributed to bringing the whole issue on the agenda, has by far the highest value with over 100 g CO2/MJ ethanol. Two years later, several studies produced a wide range of iLUC factors for ethanol, but they are all below 50 g CO2/MJ ethanol. The most recent studies from 2011 calculate even smaller values and fluctuate all around 10 g CO2/MJ ethanol. If this trend continues, the resulting iLUC factors may get negative values fairly soon – a development that several authors applying deterministic models already suggest (e.g. Lywood et al. 2009).

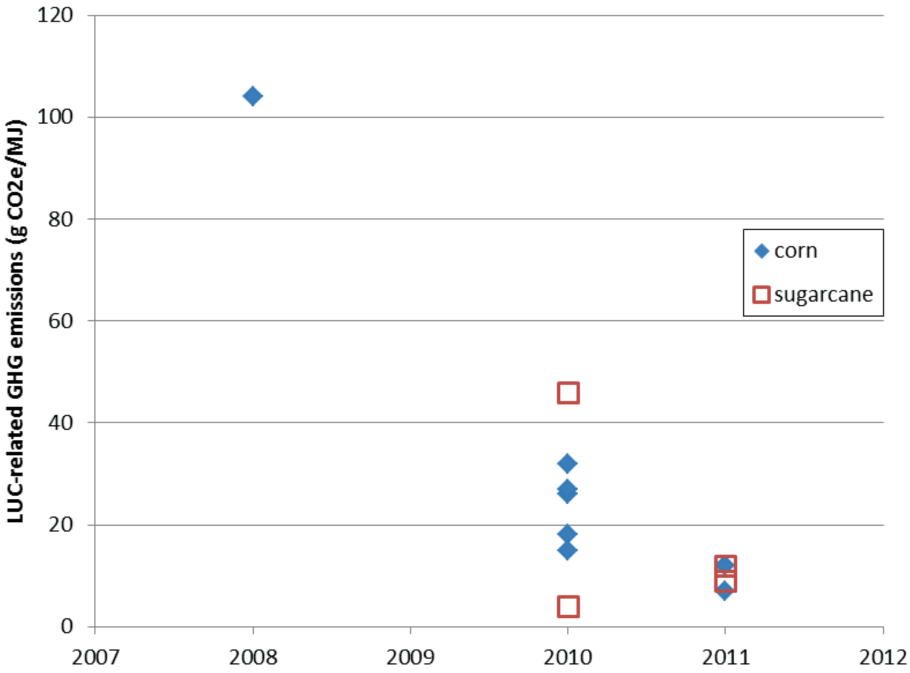


Figure 4: Development of iLUC factors (economic models) for ethanol, data from Wicke et al. (2012)

The observation of the erosion of iLUC factors over time is also addressed in the recent review article in Biofuels by Wicke et al. (2012). They describe that "…progress in developing and refining the analysis […] has been made in the course of 2009, 2010 and 2011. With respect to corn ethanol production, the initial LUC effect of US corn ethanol was given as 104 g CO2-equivalent per megajoule. […] However, the development and improvements of the Global Trade Analysis Project (GTAP) bioenergy model from Purdue University have resulted in a large reduction in the estimates of LUC related GHG emissions (first to 32 g CO2e/MJ used in California's Low Carbon Fuel Standard and more recently to 15 g CO2e/MJ). If California's Low Carbon Fuel Standard LUC emission factor of corn ethanol was to be adjusted accordingly, most corn ethanol production would be able to meet the required emission reduction percentage of 10% compared with fossil fuels by 2020 while this is not the case with the current factor of 32 g CO2e/MJ. […] Also Al-Riffai et al. (2010) and, most recently, Laborde (2011) have found significantly lower values for corn ethanol than originally proposed (Wicke et al. 2012)."

The same observation is even reflected in the assessment of available iLUC literature in the recent IPCC Report on Renewable Energy (IPCC 2011). The report indicated "that initial models were lacking in geographic resolution, leading to higher proportions than necessary of land use assigned to deforestation, as the models did not have other kinds of lands (e.g., pastures in Brazil) for use. While the early paper of Searchinger et al. (2008) claimed an iLUC factor of 0.8 (losing 0.8 ha of forest land for each hectare of land used for bioenergy), later (2010) studies that coupled macro-economic to biophysical models tuned that down to 0.15 to 0.3 (see, e.g., Al-Riffai et al. 2010, IPCC 2011)."

This section discussed the uncertainties and the current ranges of iLUC factors and concludes the introduction of the various concepts and approaches to quantify iLUC for the integration into LCA. Before the scientific robustness and consistency of these approaches is further analysed in section 4, the current provisions in international standards of LCA and carbon footprinting are provided in the following section 3.

3. Provisions in international standards of LCA and CF

This section provides an overview on the provisions in relevant international standards in the field of LCA and carbon footprinting with regard to indirect effects, particularly indirect land use change. They are categorized into generic LCA related standards and guidelines as well as generic carbon footprint standards and guidelines. It goes beyond the scope of this analysis to discuss all currently existing documents. A selection was made based on the relevance for the product system biofuels and the global level of application. The following standards and guidelines are analyzed:

- Generic LCA standards and guidelines
  - ISO standards on life cycle assessment (14040 2006, ISO 14044 2006)
  - EC Product Environmental Footprint Guide (PEF 2012)
  - ILCD Handbook (ILCD 2010)
  - French Labelling Scheme (ADEME 2009)

- Generic carbon footprint (CF) standards and guidelines
  - ISO draft standard on carbon footprinting (ISO DIS 14067 2012)
  - GHG Protocol Product Standard (GHG 2011)
  - PAS 2050 (PAS 2050 2011)
  - Japanese CF Specification (METI 2009)
  - Korean CF Labelling Guideline (KEITI 2010)

3.1. ISO 14040 and ISO 14044

The leading international standards for LCA do not contain any explicit provisions with regard to the inclusion of direct or indirect land use change within the global warming impact of land use changes. When the last revision of the standards was completed in 2006 (Finkbeiner et al. 2006), the discussion on dLUC and iLUC was not yet existing. At that time, the impact category land use was only discussed as a proxy for biodiversity impacts.

However, after the revision there were regular inquiries with all national standardization bodies and stakeholders on areas that may require revisions to these core standards of LCA. The last one was completed and discussed in 2012. Neither any of the 67 national standardization bodies nor any of the prominent international liaison organizations like the Food and Agriculture Organization of the United Nations (FAO), the World Business Council for Sustainable Development (WBCSD), Consumer International (CI) or the Society of Environmental Toxicology and Chemistry (SETAC) requested the inclusion of indirect effects into the standard as the spirit and basic understanding of these standards clearly focus on direct and primary material and energy flows which can be unambiguously attributed to a product system. In the absence of specific provisions in the standards, this is substantiated with some paragraphs of the standard that implicitly convey this notion.

The preference for methodologies that can be justified based on natural science is contained in one of the principles of ISO 14040, i.e. the priority for a scientific approach. The principle says that "decisions within an LCA are preferably based on natural science. If this is not possible, other scientific approaches (e.g. from social and economic sciences) may be used or international conventions may be referred to. If neither a scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, then, as appropriate, decisions may be based on value choices."

While the principle is open for other approaches, the provisions for the system boundary, product system and unit processes are more restrictive. Methodologically speaking, the inclusion of LUC for modeling greenhouse gas emissions is a question of the system boundaries which define the product system. ISO 14040 says that "LCA is conducted by defining product systems as models that describe the key elements of physical systems." The standard further elaborates this view by stating that "the system boundary defines the unit processes to be included in the system. Ideally, the product system should be modelled in such a manner that inputs and outputs at its boundary are elementary flows. […] The choice of elements of the physical system to be modelled depends on the goal and scope definition…" The product system and its unit processes as core objects of any LCA study are defined physically and as such do not intent to cover non-physical, indirect market effects like iLUC.

If not covered by the system boundary and product system as such, one could argue that iLUC could be seen as an allocation issue (see also section 4.2). In reality, the land conversion is performed by the farmer whose crops were displaced by the biofuel crop. In a standard LCA approach, this would be fully accounted as dLUC for this farmer. However, if an LCA of a "displaced crop" is performed, all or some of its dLUC could be allocated to the "displacing crop" in the sense of

dLUCnet (displaced crop) = dLUCgross (displaced crop) – iLUC (displacing crop).

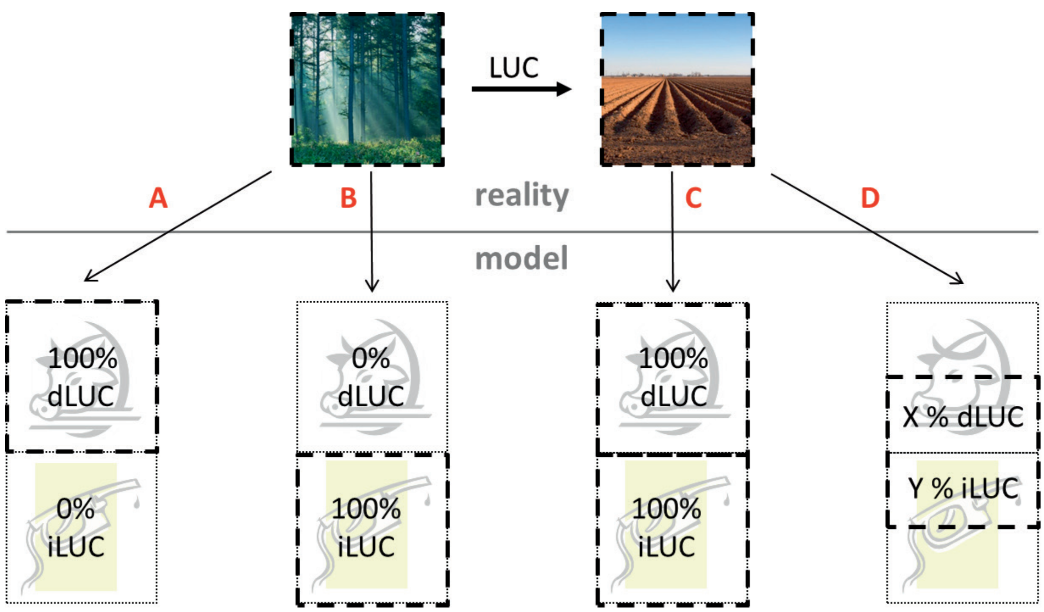


Figure 5: Schematic options for inter-crop-allocation and associated model results

Figure 5 shows the different modeling options schematically. What happens in reality is presented in the upper part of Figure 5. In the real world, only land use change can be observed, shown here for the example of the conversion of forest to agricultural land. There are several possibilities to model this process in LCA – depending on the allocation choices of the burden generated by the LUC. The LUC burden can be either allocated to the direct process responsible for physically cutting down the forest. This would be then dLUC shown here for example for cattle farming. The LUC burden could be also allocated indirectly to a process that is assumed to be actually responsible for the cattle farmer's action to cut the forest. This would be then iLUC shown here for the example of biofuel production. The physical reality and the physical allocation are shown in case A in Figure 5. In case A, the direct physical action takes 100% of the burden and as a consequence, there is 0% of iLUC. The second case B shows the allocation choice of the proponents of the iLUC concept, even though they do not present it as an allocation choice. If all the burden of the dLUC of the displaced crop (e.g. here the feed for cattle) is accounted for as iLUC of the displacing crop, the resulting net dLUC of the displaced crop is zero. This can be only done based on economic assumptions and is inconsistent with attributional LCA. This case provides obviously also wrong incentives because the cattle farmer who is actually cutting the natural forest (physical reality!) gets a free rider ticket to do so. The cattle farmer cutting the forests gets zero burden because he is not found guilty and exculpated from the LUC at the indirect expense of someone else (here: biofuel producer).

Case C represents the case of double-counting. In this case the area for which LUC occurred is allocated to both cattle and biofuels. As a result, there is 100% dLUC and 100% iLUC, which is obviously not consistent with the standard´s requirement to avoid double-counting. The last case D is proposed here as explicit 'inter-crop-allocation'. Transparency requires making an explicit allocation choice for the LUC burden. If iLUC is supposed to be considered at all, this allocation is required to avoid double-counting and wrong free-rider incentives. There are – as usual – different allocation procedures available, but the condition they have to fulfill is clearly, that the total allocated burden has to be 100%. A further example for the topic of inter-crop allocation is presented in section 4.2.

According to ISO 14044 the specific requirements on the inventory phase and the data do not really support such an indirect, economically driven allocation procedure. The standard says that "the inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics." It is further clarified that "the same calculation procedures should be consistently applied throughout the study." While the LCI typically is calculated based on direct physical data of material and energy flows, the macroeconomic calculations of indirect effects is clearly a different kettle of fish.

When it comes to data and data quality, the requirements of ISO 14044 are quite clear: "When data have been collected from public sources, the source shall be referenced. For those data that may be significant for the conclusions of the study, details about the relevant data collection process, the time when data have been collected, and further information about data quality indicators shall be referenced. If such data do not meet the data quality requirements, this shall be stated." For the impact assessment, "the LCA [shall] take into account the following possible […] sources of uncertainty: a) whether the quality of the LCI data and results is sufficient to conduct the LCIA…"

The quality, the specificity, the level of transparency and the reproducibility of the existing iLUC data as shown in the previous section 2 obviously fail to comply with the requirements of ISO 14044 – unless the scope definition of a particular case study would accept such simplistic and error-prone data quality. However, the standard requires consistency between scope and goal. As a consequence, the informative value of such a study would be reduced to such a low level that it might be interesting for academic exercises, but meaningless for decision-making.

Overall, a similar interpretation has been published by the EU-funded Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability (CALCAS). They conclude in their Blue Paper that "Standard ISO-LCA does not take into account economic relations. [...] Inclusion of meso- and macro-economic models (modelling in terms of labour, capital, economic growth, spending etc.) is definitely beyond what is mentioned in ISO-LCA, and also what is done in typical LCA-studies nowadays (CALCAS 2009)."

Because ISO 14040 and ISO 14044 represent the "constitution of LCA" (Finkbeiner 2013), they were discussed here in some more detail in order to fill the gap of explicit provisions on iLUC with interpretations of the implicit intent of them.

3.2. EC Product Environmental Footprint (PEF) Guide

The European Commission's "Roadmap to a Resource Efficient Europe" proposes ways to increase resource productivity and to decouple economic growth from both resource use and environmental impacts, taking a life-cycle perspective. One of its objectives is to: "Establish a common methodological approach to enable Member States and the private sector to assess, display and benchmark the environmental performance of products, services and companies based on a comprehensive assessment of environmental impacts over the life-cycle (‚environmental footprint')" (PEF 2012). The European Council invited the Commission to develop supporting methodologies and the PEF Guide is the result of this process.

The PEF Guide defines that "greenhouse gas emissions that occur as a result of direct land use change shall be allocated to goods/services for 20 years after the land use change occurs using the IPCC default values table.[...] greenhouse gas emissions that occur as a result of indirect land use change shall not be included."

Further details are given in an annex. The annex specifies the calculation approach for dLUC in more detail and justifies the exclusion of iLUC: "These indirect effects can be assessed by economic modelling of the demand for land or by modelling the relocation of activities on a global scale. The main drawbacks of such models are their reliance on trends, which might not reflect future developments, and their commonly basis on political decisions. No widely accepted provisions exist for the calculation of emissions resulting from indirect land use change, so no specific recommendations or guidance are supplied here. These shall not be assessed in the PEF study."

3.3. ILCD Handbook

The ILCD Handbook is a series of technical documents providing guidance for good practice in Life Cycle Assessment in business and government. The development of the ILCD has been coordinated by the European Commission and has been carried out through a broad international consultation process with experts, stakeholders, and the public (ILCD 2011).

The ILCD says about indirect land use change, that it is not consistent with attributional LCA, but that it is "…an aspect under consequential modelling." The ILCD Handbook also gives additional guidance, that iLUC has to be modeled comprehensively and not only including primary effects of displacing crops: "One example for secondary consequences is that the marginally increased price of the displaced crop (and potentially to some degree even of land intensive goods in general) might be an incentive for achieving higher yields by use of more fertilisers and better management. This might partly off-set/reduce the need for an indirect land use change and less land needs to be changed elsewhere than the amount now used for the biofuel." It is also stressed, that the iLUC approach, if used, has to be applied consistently for all product systems and not only for biofuels: "Note that in the logic of consequential modelling this applies to all land uses, including food production, industrial plants, private homes etc…."

The ILCD Handbook acknowledges that currently no scientifically robust methods exist to quantify iLUC: "As no widely accepted provisions exist for indirect land use, but such are still under development by several organisations, no specific provisions are made at this point. The appropriate way how to integrate indirect land use changes is hence to be developed for the specific case, in line with the general provisions of consequential modelling. This is unless specific provisions would be published under the ILCD. Such provisions might be part of a future supplement."

3.4. French Environmental Footprint (BPX 30-323)

The French law Grenelle provided the framework for developing a general methodology for French environmental product labeling. It goes beyond just requiring a carbon footprint for each product category, because BPX 30-323 provides general guidelines for product-specific multi-criteria communication in line with ISO 14040/44. Additionally, BPX 30-323 includes guides for certain PCRs, and the Agency for Environment and Energy Management (ADEME) has begun development of a public database containing generic data.

France is currently conducting national testing research on consumer product environmental information with 168 participating companies.

With regard to LUC, the requirements are consistent with ISO/DIS 14067 (see section 3.5) as the quantification of direct land use change is referred to the IPCC methodology while indirect land use change is not included until an internationally agreed method has been established.

3.5. ISO DIS 14067

ISO DIS 14067 is the carbon footprint standard of the International Organization for Standardization (ISO). It is not yet published in its final form as it currently still has the status of a Draft International Standard (DIS), but the requirements on land use change summarized below are not expected to change significantly.

ISO DIS 14067 says in paragraph 6.4.9.4, that "When significant, the GHG emissions and removals occurring as a result of direct land use change (dLUC) shall be assessed in accordance with internationally recognized methods such as the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories and included in the CFP. LUC GHG emissions and removals shall be documented separately in the CFP study report. If site-specific data are applied, they shall be transparently documented in the CFP study report. Indirect land use change (iLUC) should be considered in CFP studies, once an internationally agreed procedure exists. All choices and assumptions shall be justified and documented in the CFP study report."

3.6. PAS 2050:2011

PAS 2050 from the British Standards Institute received some international relevance, because it was one of the first national carbon footprint standards. The original version from 2008 was revised in 2011. PAS 2050 addresses the inclusion and treatment of land use change by the requirement that "the GHG emissions and removals arising from direct land use change shall be assessed for any input to the life cycle of a product originating from that land and shall be included in the assessment of GHG emissions of the product." The PAS 2050 provides some guidance for a specific assessment and some default land use change values in an annex.

The temporal cut-off for land use change is 20 years, or a single harvest period, prior to undertaking the assessment (whichever is the longer). The GHG emissions shall be allocated equally to each year of the period. The PAS contains a note that says "Indirect land use change refers to such conversions of land use as a consequence of changes in land use elsewhere. While GHG emissions also arise from indirect land use change, the methods and data requirements for calculating these emissions are not fully developed. Therefore, the assessment of emissions arising from indirect land use change is not included in this PAS. The inclusion of indirect land use change will be considered in future revisions of this PAS."

3.7. Japanese and Korean guidelines for carbon footprint

The Japanese and Korean carbon footprint specifications and guidelines are briefly addressed here, because they are among the documents that have been most widely applied by companies on a global scale.

The CFP pilot project by Japanese government has achieved various results, such as currently 73 approved CFP-PCRs (Product Category Rules; the rules for accounting CFP) and 495 approved CFP products (from about 100 companies), a database of emission factors (containing about 1,200 data entries for materials and forms of energy). In the Korean labeling scheme more than 360 goods and services have been approved for labelling.

With regard to iLUC, neither the Japanese Technical Specification TS Q 0010 "General principles for the assessment and labeling of Carbon Footprint of Products" nor the Korean guideline contain any specific provisions on the inclusion of iLUC.

Similar to ISO 14040 and ISO 14044 the absence of specific provisions can be interpreted in the sense, that the inclusion of iLUC into the CF calculation is not intended.

4. Analysis of scientific robustness and consistency

This section provides a synopsis of the LCA respectively CF specific requirements of standards and guidelines as presented in section 3 with the concepts and approaches to quantify iLUC as presented in section 2. By matching the application requirements with the current state of the scientific development, the scientific robustness and consistency will be discussed with regard to the methods (section 4.2), with regard to the data (section 4.3) and finally, with regard to the results (section 4.4). Before these more science oriented parts, the technical requirements of the relevant application standards are summarized in the following section 4.1.

4.1. Consistency with standard requirements and guidelines

The general overview of the current standards and guidelines for LCA and CF and an analysis of the applicable requirements with regard to iLUC were presented in section 3. An overview of these provisions and a comparison of the requirements are provided in this section.

The results of this analysis are presented mainly in the form of two tables (see Table 2 and Table 3). These tables provide a concise summary on five key aspects with regard to their provisions on iLUC and LCA, i.e. if the inclusion of iLUC factors

- is mandatory,
- is intended once a robust method exists,
- is restricted to consequential LCA,
- requires the assessment of all other indirect effects and
- requires the iLUC inclusion for all products.

The only difference between Table 2 and Table 3 is the rigour in the interpretation of the standards. Table 2 follows a strict formal interpretation of the standards and includes only those aspects which can be answered based on explicit text or the explicit absence of requirements. As a consequence, more than half of the table remains empty. However, based on a more comprehensive interpretation of the implicit intent of the standards most of these gaps can be filled. Table 3 shows the results including the implicit content.

Table 2: Overview iLUC requirements of standards and guidelines (explicit content only)

	iLUC inclusion mandatory	iLUC inclusion intended – if methods robust	if iLUC is included, restricted to consequential LCA	if iLUC is included, then also other indirect effects	if iLUC is included, then for all products
Generic LCA standards					
ISO 14040/44	no				
EC PEF Guide	no				
ILCD Handbook	no		yes	yes	yes
French Labelling Scheme	no	yes			yes
Generic CF standards					
ISO DIS 14067	no	yes			yes
GHG Protocol	no		yes		yes
PAS 2050	no	neutral			
Japanese CF Specification	no				
Korean CF Guideline	no				

Table 3: Overview iLUC requirements of standards and guidelines (including implicit content)

	iLUC inclusion mandatory	iLUC inclusion intended – if methods robust	if iLUC is included, restricted to consequential LCA	if iLUC is included, then also other indirect effects	if iLUC is included, then for all products
Generic LCA standards					
ISO 14040/44	no	no	NA	yes	yes
EC PEF Guide	no	NA	NA	yes	yes
ILCD Handbook	no	NA	yes	yes	yes
French Labelling Scheme	no	yes	NA	no	yes
Generic CF standards					
ISO DIS 14067	no	yes	NA	no	yes
GHG Protocol	no	no	yes	no	yes
PAS 2050	no	yes	NA	no	yes
Japanese CF Specification	no	no	NA	NA	yes
Korean CF Guideline	no	no	NA	NA	yes

NA means here 'not applicable' in the sense that there is not sufficient text in the standard to make a qualified assumption on the implicit intention of the documents.

It is obvious, that none of the generic standards and guidelines analysed have any mandatory requirement to include iLUC factors into the calculation of LCAs or CFs. Also the sector specific methodologies discussed do not require including iLUC factors at this stage. While currently none of the generic standards and guidelines has mandatory requirements some of them intend to include iLUC once a scientifically robust or internationally agreed method exists. This is explicitly addressed in ISO DIS 14067 (ISO DIS 14067 2012) and the French Labelling Scheme (ADEME 2009). On a more implicit level, the same intention could be assumed for PAS 2050 (PAS 2050 2011), while the remaining standards and guidelines have no content that implies the intention to include iLUC factors.

Two documents, the ILCD-Handbook (ILCD 2010) and the GHG Protocol Product Standard (GHG 2011), explicitly mention that the inclusion of iLUC is only consistent with a consequential modeling approach. The other standards do not address this aspect implicitly, because they basically build on the established attributional modeling approach.

It is only the ILCD-Handbook (ILCD 2010) again, that explicitly clarifies that if iLUC is included, all other indirect effects beyond land use have to be considered as appropriate for a consequential model. On a more implicit level, the same notion can be assumed for ISO 14044 (ISO 14044 2006) due to the generic consistency requirements and the EC PEF Guide (PEF 2012).

Last but not least, several standards clearly address that if iLUC is included, it has to be calculated for all products, not only for biofuels. It is interesting to note, that this interpretation applies to all analysed generic standards and guidelines on a more implicit level.

In summary, the inclusion of iLUC factors is currently not mandatory in any of the relevant generic LCA and CF standards and guidelines today. Even the intention to include iLUC factors in the future is far from mainstream and limited to only a few documents. In addition, some standards provide clear indications for either the limited use of iLUC factors (for consequential LCA only) or the comprehensive use of iLUC factors (for all products) or even indirect effects in general (beyond indirect effects for land use).

4.2. Scientific robustness and consistency of the methods

Some of the unresolved challenges and gaps with regard to scientific robustness and consistency of iLUC quantification methods have already been discussed in section 2. They include the facts

- that fundamentally different methods are applied to quantify iLUC,
- that all these methods rely on a large set of assumptions,
- that they react very sensitive to changes in the assumptions made,
- that all these models rely on market predictions,
- that all these methods rely on historic trends to model a presumably non-linear future change of the system,

- that the economic models cannot distinguish between iLUC and dLUC,

- that they do not really take into account the strong regional characteristics such as local LUC, specific carbon stocks, land tenure and ownership systems, management practices, societal preferences, trade incentives or barriers, because they cannot determine "iLUC with respect to any individual feedstock production activity since the displacement could
  - move previous agricultural production to areas outside of a country;
  - occur with significant time lags; and
  - be distributed through global trading. [The location at which iLUC may occur is unknown]. The 'non-locality' of indirect effect is a result of the 'non-locality' of global commodity markets" (Fritsche & Wiegmann 2011).

- that they often ignore the challenge of allocation of LUC to by-products,

- that they often ignore other compensation measures like yield increases or changing diets.

In this section some additional challenges for the scientific robustness and consistency of iLUC quantification will be elaborated, because they are not yet as broadly discussed as the topics above and because they take a focus beyond biofuels. However, it is probably not scientifically robust and consistent to develop a new methodological artefact like iLUC for an isolated application for biofuels. If it is a robust and meaningful concept, it has to be applied to all products, not only one.

This is basically the first additional gap to be discussed in a bit more detail here. The issue for scientific robustness and consistency means simply "iLUC for all, iLUC for none" (Laborde 2011). Laborde addressed this issue in the latest IFPRI-Report for the EU-Commission as policy issue: "policymakers who would like to introduce the LUC issue explicitly in the legislation have to consider this dilemma: "iLUC for all, iLUC for none" with potentially long-term consequences for impact assessment strategies. This argument may be used to discourage any LUC legislation in order to avoid opening Pandora's Box (Laborde 2011)." However, this is not only a political issue, but clearly an issue of scientific consistency. If iLUC is a valid scientific concept, it has to be applied for all products, at least all agricultural products.

If iLUC is applied for biofuels, it has to be applied for example for organic agricultural products as well. It should be noted, that organic agricultural products have different targets than biofuels. They are mainly driven by lower soil and biodiversity impacts rather than climate change issues. However, they are economically and as far as land use are concerned quite similar. Based on a study for FAO and according to the International Energy Agency, an estimated 14 million hectares of land were used for the production of biofuels in 2006. At the global level, the projected growth in biofuel production to 2030 ranges from 35 million to 54 million hectares of land depending on the policy scenario (Cotula et al. 2008). According to Willer (2012) the land used for organic agriculture was in 2006 twice as large for organic agriculture compared to biofuels, i.e. 30 million hectares in 2006 and has grown to 37 million hectares in 2010, which is already more than the lower end estimate of Cotula et al. (2008) for biofuels in 2030. Economically, the organic markets of the top ten countries in 2010 totaled 44.5 billion Euros, while a new report from Pike Research gives a value for the global biofuels market of 82.7 billion USD in 2011 (Pike Research 2012). Taking these economic data and the overall uncertainty of iLUC factors into account (see section 2.5), it seems a fair guess that iLUC factors for biofuels and organic crops are in the same order of magnitude. If the climate effects of biofuels are measured and challenged with iLUC factors, it is scientifically consistent to do the same with organic crops. Again, it is not the intention to ignore the beneficial aspects of organic agriculture on other safeguard subjects, but for the climate change assessment of agriculture and for the mitigation of undesired LUC, they are just as relevant as biofuels. If the inclusion of iLUC-factors is proposed for biofuels and scientific integrity is not ignored, they have to be included for all agricultural products.

An educative example for some other - presumably unintended - consequences of the methodological inconsistency can be demonstrated by the assessment of climate change mitigation or conservation measures that transform agricultural land into grassland or even forest. If for climate mitigation purposes forest is regrown on agricultural land, the iLUC concept assumes that then somewhere else forest is transformed into agricultural land. This would be treated as being the 'fault' of the conservation measure. As a consequence, it would have to carry the burden as iLUC factor and lead to basically no GHG reduction. As a consequence, the iLUC concept implies that conservation or afforestation measures make no sense as they may save CO2 directly, but emit it indirectly.

Another challenge for the scientific consistency of iLUC is the problem of double counting with dLUC. It is not the focus of this study to analyse the inclusion of dLUC into LCA and CF studies, but the estimation of dLUC is definitely more robust than iLUC, because it can be observed and measured, not just modelled. As presented in section 3, the inclusion of dLUC is much more supported in the international standards and guidelines than the inclusion of iLUC. What is even more important, every standard or every approach that proposes to include iLUC will definitely also propose to include dLUC. However, there is no iLUC without dLUC and as such this is a trivial case of double-counting. If every product on earth would account for its dLUC, there would be no iLUC – unless double-counted.

To address this challenge in a scientifically robust and consistent manner, an additional allocation procedure has to be introduced in the methodology, i.e. the allocation of LUC burdens between the displaced and the displacing crop (Finkbeiner 2012, Dunkelberg 2013). In order to avoid double-counting the following formula has to be applied

dLUCgross (displaced crop) = dLUCnet (displaced crop) + iLUC (displacing crop).

If all the gross burden of the dLUC of the displaced crop is accounted for as iLUC of the displacing crop, which is the standard approach of the proponents of the iLUC-concept, the resulting net dLUC of the displaced crop is zero. This is inconsistent and provides wrong incentives because the farmer who is actually cutting the natural forest (physical reality!) gets a free-rider ticket to do so.

The following example demonstrates that current iLUC methods, which do not perform this 'inter-crop-allocation', lead to either a free-rider effect or double counting. The example assumes that sugarcane ethanol production in Brazil displaces pasture land in the Amazônia Legal, followed by deforestation in order to generate new pasture land (Dunkelberg 2013).

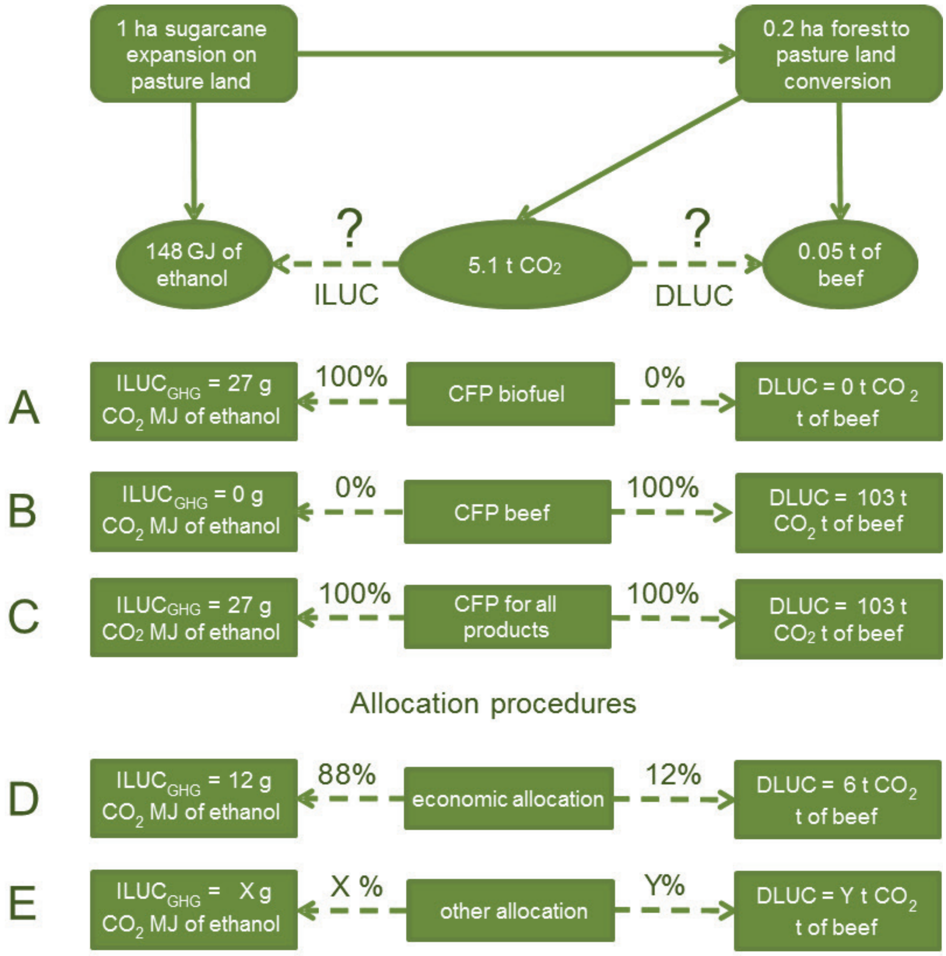


Figure 6: Inter-crop-allocation example of displaced and displacing crop, adapted from Dunkelberg (2013)

Figure 6 schematically shows the displacement effect caused by sugarcane area expansion of 1 ha, which is supposed to cause area expansion of 0.2 ha of pasture land for beef farming. Case A represents the results of current iLUC quantification approaches, i.e. all the burden is with ethanol. Cattle farming that directly transforms forested to pasture land is relieved from its responsibility for any LUC-induced CO2 emissions. "This can lead to a free-rider effect, as the party directly profiting from the final land use conversion is not held accountable for these LUC-induced CO2 emissions – not even in a scenario in which the product CF is used as a market incentive to reduce carbon emissions in the economy. [This approach could boost the sales of beef, because the accounting approach results in low-carbon beef. A beef farmer who actually clears rainforest gets a low carbon footprint label thanks to the iLUC concept!]. Thus, such an approach, in which all LUC emissions are allocated to the expanding biofuel feedstock, fails to provide a market incentive for LUC reduction that specifically addresses those directly benefitting from deforestation (Dunkelberg 2013)".

However, if an LCA of CFP of Brazilian beef is performed, the dLUC will be typically included in case B. If both are studied, the double-counting occurs (case C). If sugarcane expansion leads to a displacement of pasture land into the Amazônia Legal, emissions from deforestation will be included in the CF of meat produced on the newly generated pasture land and that of ethanol produced from sugarcane. This is not a consistent and robust solution by scientific standards and international LCA standards (ISO 14040 2006, ISO 14044 2006).

Inter-crop-allocation of LUC-induced CO2 emissions to both the displacing and the displaced agricultural activities is a feasible way to avoid double counting and at the same time to set incentives for avoiding LUC. Case D demonstrates exemplary values for economic allocation, but the choice of the proper allocation procedure can be done according to the standard or method used (generic case E). While the issues discussed so far remain on the level of indirect effects for land use change, a scientifically robust assessment of indirect effects cannot be limited to the arbitrarily chosen issue of land use. Full scientific consistency requires looking into all indirect effects of product systems – if indirect effects are included. The choice of "iLUC for all or iLUC for none" mentioned above needs to be complemented by the even more fundamental choice to "include all indirect effects or none". To include all indirect effects is a huge challenge and a further boost for increased uncertainty of the assessment, but any arbitrary choice to include selected indirect effects only is a pure value choice, not to be justified by science.

The relevance of this issue will be demonstrated by a few examples. The rebound effects of energy efficiency measures have been briefly addressed in section 3.1. If we do an LCA of an energy saving fridge, the indirect effects of spending the saved electricity cost would have to be considered. If a family spends this money to fly to an island for holidays instead of their usual biking tour, their energy saving fridge may have to get a malus of an indirect behavior change factor (could be called 'iBC-factor', which would add the emissions of the holiday flights to the burden of the fridge). The consequence could be the recommendation not to buy energy saving fridges. In addition, the electricity provider will sell the "displaced" electricity elsewhere and the energy saving fridge can be made responsible for the displaced use, too.

If we want to assess the LCA of renewable energy, e.g. from wind, the indirect effects may need consideration, too. Due to his new wind power plants, an energy provider may close a coal fired power plant. This will lead to a market effect that the coal will be cheaper due to lower demand. Therefore, the displaced use of coal may lead to an increased use of coal elsewhere. If the other low-budget energy provider produces the electricity not only with cheaper coal but also with lower efficiency, the "shutting down" of the coal fired power plant of the first energy provider has to take the indirect malus of even more CO2 emissions than his own shut-down power plant, because the shutting down was the cause for the worse provider to pitch in. As a conclusion, the use of wind power is discouraged.

Somewhat closer to the biofuel issue, Liska & Perrin (2009) provided an interesting example by estimating the indirect effects of US military expenditures and associated GHG emissions, as far as they are related to the protection of oil exports from the Middle East. Liska & Perrin (2009) assumed "that 10% of total US GHG emissions were due to the military, and if only 26% of those operations were for protection of oil supplies (assuming no expenditures for the Iraq war), total indirect military emissions would equal 187 TgCO2e /yr. These indirect military emissions would add 98 gCO2e /MJ to gasoline produced from Middle Eastern petroleum and raise the GHG intensity of gasoline from this source by roughly two-fold." This value is well within the range of iLUC-factor estimates for ethanol. If iLUC-factors are supposed to be added to biofuels for regulatory purposes like in the RED, the reduction targets have to consider the indirect emissions for the fossil fuel benchmark values as well.

The discussion reveals that the current iLUC quantification methods are still in their infancy, rather theoretical and not well-thought-out. There needs to be significant progress in all the issues raised in this section before quantitative iLUC factors can be seriously recommended for decision-making. European environmental policy is unfortunately far from implementing life cycle based decision-making, despite the robustness and standardization achieved in attributional process-based LCA. The usual argument is that the methods and data are not yet robust enough. Compared to standard LCA application, the uncertainty and arbitrariness of iLUC factors is orders of magnitude larger. It seems rather strange that EU policy wants to implement iLUC factors, while they typically oppose stringent LCA based regulation as too 'dangerous'. This is neither consistent nor responsible, it is harum-scarum.

4.3. Scientific robustness and consistency of the data

The methodological gaps and inconsistencies discussed in the previous section are often linked to associated gaps and inconsistencies with regard to the data used for iLUC quantification. This section, however, will focus on some particular data issues which have not been explicitly addressed before.

It is generally agreed, that the quality of key underlying datasets for iLUC is in many cases low (Wicke et al.2012), that the data used are rather old (Dunkelgerg 2013) and that the time reference of the data used has a strong influence on the results (Nassar et al. 2011). Nassar et al. (2011) mention Brazil as an example, where the deforestation rate was much higher between 2004 and 2007 than between 2007 and 2009. Depending on the reference year chosen iLUC in Brazil would thus be either high or low (Nassar et al. 2011).

Obviously land use data play an essential part in land use change modelling. "There are a variety of datasets of global land use, derived from satellites or agricultural inventories. These datasets give markedly different results […] there are doubts about the reliability of different datasets (EU 2010)." For a robust determination of iLUC, data for all land classes available for agriculture must be used and not only arbitrarily chosen types of land as is the case in most analysed studies (Djomo & Ceulemans 2012). Djomo & Ceulemans (2012) concluded from a recent review of 43 iLUC studies that "data on crop yield are very crucial for the modeling of iLUC. They are also sources of inconsistencies among the analysed studies."

For most of the input data to the iLUC models, verification or validation is either not possible due to their theoretical nature or has not been performed. In such a case, transparency of the data selected or assumed is of utmost importance. However, as confirmed by an in-house literature review of the European Commission "the reports assessed in this review are generally not explicit enough for the purposes of this review as regards data and methodology. It has not been possible to make a full comparison of the modelling choices made because in many cases, the reports do not reveal what these choices are. […] The literature contains little explicit discussion of the methodological and data issues involved. Each study tends to use its own assumptions without mentioning, let alone critically evaluating, others (EU 2010)."

Another set of data that underlie iLUC factors are strongly influenced by market predictions. The common failures of market predictions are easily observed in the news every day. The assumption of a proportionality of economic data with environmental data is debatable and leads to artefacts. The economic models assume that a demand of 2 EUR has twice the environmental burden of 1 EUR. Independent from economies of scale, this also means that a cheaper biofuel has less iLUC than an expensive biofuel, even if they need the same amount of land to be grown on. The coarseness and quality of data underlying iLUC factors is way below the material and energy flow data that are typically used for process-based attributional LCA. It makes no sense, to add these data into one number. Therefore, several standards require to report iLUC – if at all – separately from the core LCA or CF result (ISO DIS 14067 2012, GHG 2011).

On a very fundamental level, iLUC data suffer from epistemological limitations, because it is empirically impossible to observe or detect them physically. Those LUC impacts that are observed in the real world cannot be connected to a particular biofuel by any experimental method. Therefore, one must rely on models that are only valid within a certain context. From the theory of science it follows that statements based on iLUC (and LCA in general) are impossible to prove. It is even very difficult to falsify them, but this is at least theoretically possible (Finnveden 2000).

In conclusion, it is not only the modeling that makes iLUC factors uncertain, it is also the data used. Because appropriate, especially region and crop specific data are missing and because of the low quality economic data, documentation and transparency of the chosen datasets is crucial for assessing scientific robustness and consistency, but often lacking.

4.4. Scientific robustness of the results

The lack of scientific robustness in both methods (section 4.2) and data (section 4.3) obviously propagates into a broad and uncertain range of results at the borderline of arbitrariness. To put this huge span of uncertain results into perspective, the range of the currently published iLUC estimates is presented against the carbon footprint of a full range of different food products and chemicals/materials. For the comparison with chemicals/materials, about 100 different chemicals/materials[10] representing a diverse set of material groups like metals (excluding precious metals), plastics, energy carriers, inorganic substances, organic substances and minerals were taken from the GaBi 5 professional database (GaBi 2013). The data for food products included amongst others lentils, tomato, milk, tofu, broccoli, rice, potatoes, eggs, chicken, tuna, pork, beef and lamb.

Figure 7 shows the differences in carbon footprint for these different kinds of food groups according to Hamerschlag (2011). If we just take the production emissions, the total range is from about 500g CO2e/kg of food in the case of lentils, tomatoes or potatoes up to some 36000g CO2e/kg of food in the case of lamb.

To depict the ranges of iLUC on the same scale as shown for the food groups, the published values of g CO2e/ MJ as shown in section 2.5 were converted into CO2e/ kg using roughly the lower heating values of ethanol (approximately 30 MJ/kg) and diesel (approximately 42 MJ/kg) respectively. The reference values for fossil fuels were taken in the range from the RED value of about 84 g CO2e /MJ (RED 2009) and the 90 g CO2e /MJ value of Laborde (2011).

[10] Cadmium, Magnesium, 1,3-Butadiene, Acetic acid, Acetone, Acrylonitrile-Butadiene-Styrene Granulate, Aluminium ingot, Aluminium sheet, Ammonium chloride, Argon (liquid), BF Steel billet / slab, Bisphenol A, Carbon dioxide, Carbon monoxide, Caustic soda, Chlorine, Cumene, Cyclohexane, Epoxy Resin, Ethanol, Ethene, Ethyl benzene, Ethylene glycol, Ethylene Propylene Diene Elastomer (EPDM), Ferro nickel, Formaldehyde, Formic acid, Glass fibres, Glycerine, Hydrochloric acid mix, Hydrogen cyanide, Hydrogen fluoride, Hydrogen, Hydrogen peroxide, Isopropanol, Lead, Lime, Limestone, Limestone hydrate, Maleic anhydride, Methane, Methanol from natural gas, Natural rubber, Nitric acid, Nitrogen, Oxygen, o-Xylene, Phenol, Polyamide 6 Granulate, Polyamide 6.6 Granulate, Polybutadiene granulate, Polycarbonate Granulate, Polyester Resin unsaturated, Polyethylene High Density Granulate, Polyethylene Low Density Granulate, Polyethylene Terephthalate Granulate, Polymethylmethacrylate granulate, Polyphenylene sulfide granulate, Polypropylene granulate, Polystyrene granulate, Polyvinyl Alcohol Granulate, Polyvinylchloride granulate, Propene, Sheet Moulding Compound, Soda, Stainless Steel slab, Styrene, Sulphuric aci, Tin plate, Toluene, Urea, Hard coal, Lignite, Diesel, Gasoline, Kerosene, Natural gas, Sulphur, Copper, Nickel, Silicon, Tin, Aluminium hydroxide, Aluminium ingot, Ammonia, Benzene, Brass, Polyurethane flexible foam, Polyvinylidene chloride, Sodium chloride, Zinc, Sodium sulphate, Ferro chrome, Ferro manganese, Manganese

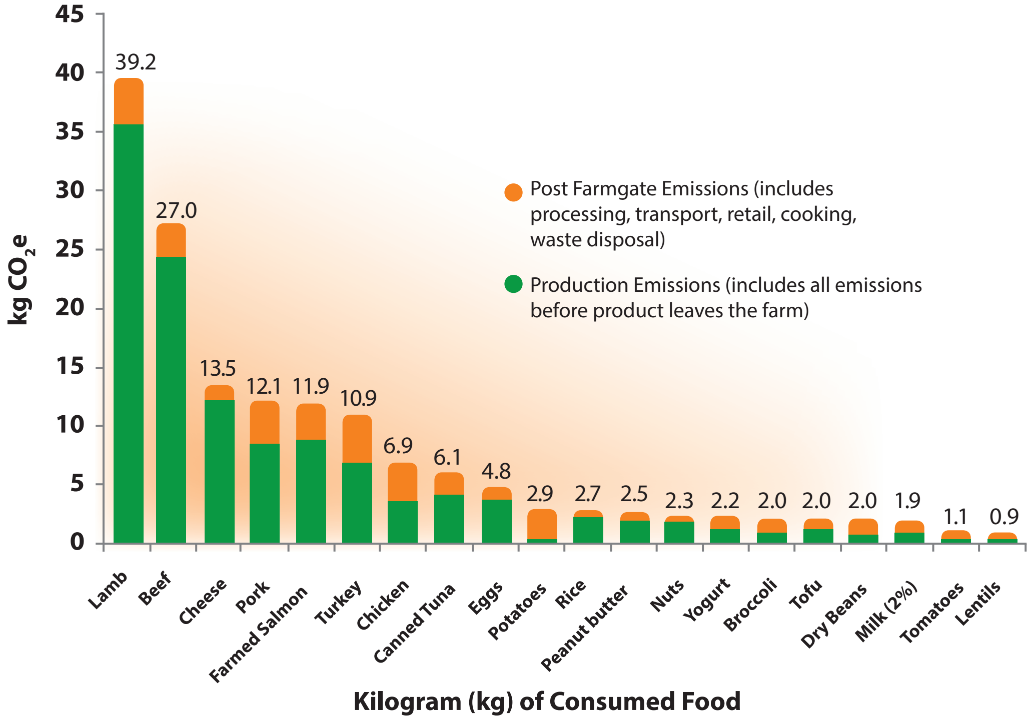


Figure 7: Carbon footprint of different types of food, taken from Hamerschlag (2011)

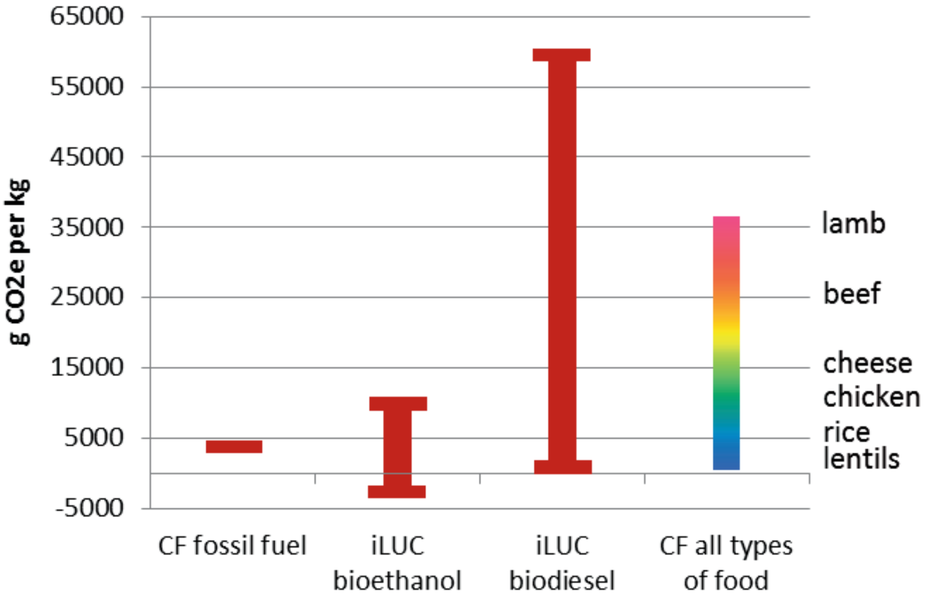


Figure 8: Ranges of iLUC factors put into perspective with fossil fuels and all types of food [data taken from RED (2009), Laborde (2011), Dunkbelberg (2013), Plevin et al. (2010), Tipper at al. 2009), Lapola et al. (2010), Hamerschlag (2012)]

The result shown in Figure 8 is quite remarkable. It shows that the ranges for the iLUC factors published are enormous. Based on these values, just the iLUC factor of biofuels (notwithstanding their GHG values for agricultural production, fuel production, etc.) can be either some 200% below or some 1700% above the fossil fuels value. This means that just based on iLUC, biofuels can either lead to an absolute reduction of GHG emissions twice as high as the emissions from fossil fuels or they can lead to an emission that is seventeen times higher than those from fossil fuels.

This uncertainty level of several orders of magnitude is significantly broader than the range of all different types of food as shown in Figure 8. With the uncertainty level of iLUC, it would be impossible to differentiate between low carbon footprint types of food like lentils or tomatoes and high carbon footprint types of food like red meat.

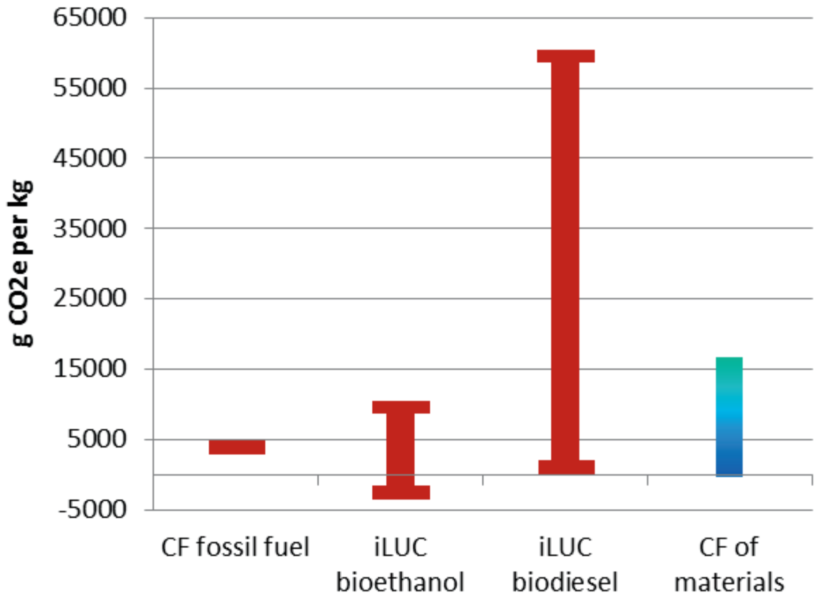


Figure 9: Ranges of iLUC factors put into perspective with fossil fuels and a set of 100 chemicals/ materials [data taken from RED (2009), Laborde (2011), Dunkbelberg (2013), Plevin et al. (2010), Tipper at al. 2009), Lapola et al. (2010), GaBi (2013)]

The same type of comparison for a set of some 100 different chemicals/materials (see footnote 10 for details) is shown in Figure 9. The result is basically the same, but the resulting range for the chemicals/materials is even smaller than the range for different types of food shown in Figure 8. The lowest number is -400 g CO2e/ kg for the production of natural rubber (includes biogenic CO2 uptake) and the highest number is the production of 1 kg of nickel with about 16600 g CO2e/ kg. It is even more striking here, that the highest estimate for iLUC of biodiesel is almost four times as high as the production of nickel, while the lowest iLUC estimate for ethanol is almost a factor of 10 lower than the production of rubber.

In conclusion, the enormous ranges of the currently published iLUC factors result in several orders of magnitude of differences compared their fossil alternatives. This clearly indicates the absence of any scientific robustness for claiming a particular iLUC factor. The relevance and uncertainty of these ranges gets quite obvious when they are put into context of the CF ranges available for different chemicals/materials and all types of food. While there are significant and robust differences between the different chemicals/materials and food groups, the uncertainty range for iLUC factors is even larger than the substantial differences between chemicals/materials and food. As a consequence, the provision of any single figure for iLUC factors is rather sham than substance – just data, but no information. Any single figure published to date is more representative for the approach or model used than the crop or biofuel assessed. Due to the lack of scientific robustness of methods and data, there is currently no real limit to calculate any number for iLUC. The current information content, reliability and integrity of exact iLUC factors are not on the quality level of scientific findings.

5. Conclusions and outlook

LCA can assist in identifying opportunities to improve the environmental performance of products at various points in their life cycle. Moreover, it enables informing decision-makers in industry, government or non-governmental organizations. In this final section, the overall findings with regard to the integration of iLUC factors in LCA or CF assessments are summarized. First, some general answers to the research questions formulated for this study are presented in section 5.1. In the final section 5.2, some proposals and perspectives on the future development with regard to iLUC are presented as an outlook.

5.1. Summary of results

The previous sections of the report contain the detailed results of this study. In this section some high level answers to the research questions formulated for the study (see section 1.2) are provided. What are the requirements of international standards and guidelines with regard to the inclusion of iLUC into LCA respectively CF?

The inclusion of iLUC factors is currently not mandatory in any of the relevant generic LCA and CF standards and guidelines. Even the intention to include iLUC factors in the future is far from mainstream, limited to only a few documents and tightly constrained by the condition that this requires a scientifically robust and internationally agreed method. In addition, some standards provide clear indications for either the limited use of iLUC factors (for consequential LCA only) or the comprehensive use of iLUC factors (for all products) or even indirect effects in general (beyond indirect effects for land use). How scientifically robust are the current approaches to determine iLUC compared to other factors determining LCA and CF results?

There is agreement in the scientific community that the uncertainty of current iLUC factor is way beyond a level that is usually aimed for in quantitative science. It was shown that the ranges for the iLUC factors published are really enormous. Just the iLUC factor of biofuels (notwithstanding their GHG values for agricultural production, fuel production, etc.) can be either some 200% below or some 1700% above the fossil fuels value. It can be positive or negative value. This clearly indicates the absence of any scientific robustness for claiming a particular iLUC factor. The relevance and uncertainty of these ranges gets quite obvious when they are put into context of the CF ranges available for different chemicals/materials and all types of food. While there are significant and robust differences between the different chemicals/materials and food groups, the uncertainty range for iLUC factors is even larger than the substantial differences between a set of chemicals/materials and food. The provision of any single figure for iLUC factors is rather sham than substance – just data, but no information. Any single figure published to date is more representative for the approach or model used than the crop or biofuel assessed. The uncertainty of the iLUC factors is also much larger than other elements of LCA and CF.

Is the integration of iLUC into LCA and CF studies consistent with the internationally agreed principles methodologies of these assessment tools?

LCA and CF are mainly based on actual material and energy flows and have a 'priority for a scientific approach' principle. This is very different from iLUC, which is a theoretical, hypothetical value based on market predictions and a number of assumptions. The data quality is significantly different. Therefore, iLUC factors should be reported separately and not be added to the results of LCA and CF.

Just considering iLUC for biofuels is also not consistent with the LCA methodology and principles. If iLUC is considered at all, it has to be considered for all products. For real consistency, even all indirect effects of product systems have to be considered in LCA, not just indirect effects of land use change. However, this is then not anymore the largely fact-based LCA we all know today.

On a more technical level, the iLUC methodologies are still very coarse and not well thought-out. Some simple methodological principles like the avoidance of double-counting or allocation issues are largely ignored. As an example, inter-crop-allocation between displaced and displacing crop is proposed here to avoid some of the existing methodological flaws.

Can the proposal to integrate quantitative iLUC factors into life cycle based regulatory limit values be supported by scientific arguments?

Even according to the politically motivated IFPRI-study for the EU-Commission by Laborde (2011), iLUC for biofuels is not a consistent policy tool. His latest report says that "introducing a LUC component into biofuel legislation will lead to the question of why LUC measurements are not introduced for other policies that can have larger land use impacts (e.g. CAP reform, trade negotiations). Overall, mitigation strategy requests need to be consistent across a wide range of policies, and there is no a priori reason to think that biofuel production-related emissions are more adverse than those generated by other agricultural production. Taking a discriminatory approach to agricultural production based on its use will be inefficient and potentially unsustainable in both political and legal (e.g. WTO) ways (Laborde 2011)."

This study confirmed that there needs to be significant progress in many issues before quantitative iLUC factors can be seriously recommended for decision-making. European environmental policy is unfortunately far from implementing life cycle based decision-making, despite the robustness and standardization achieved in attributional process-based LCA. The usual argument is that the methods and data are not yet robust enough. Compared to standard LCA application, the uncertainty and arbitrariness of iLUC factors is orders of magnitude larger. It seems rather strange that EU policy wants to implement iLUC factors, while they typically oppose stringent LCA based regulation as too 'uncertain'. This is neither consistent nor responsible.

"Although regulators are rapidly pushing ahead, the underpinning science for estimating indirectly caused emissions due to biofuel production is currently in its infancy (Liska & Perrin 2009)." It is strongly supported, if policy is as fact-based as possible. However, current iLUC factors are not fact-based. If they are used in the context of LCA and CF, they do not make the policy any better, but damage the reliability, integrity and credibility of LCA and CF. It is up to any public policy body to legislate biofuels the way they want. However, it is not acceptable if LCA is misused as witness of the prosecution in this context. There are much more robust policy applications for LCA and they should be implemented first.

The proponents of the consequential LCA approach specifically propose it for policy making. This should be handled with care. If the uncertainty of consequential LCA is proven to be generally in the same order of magnitude as for the iLUC factors, it needs a proper qualifier to be clearly distinguished from largely fact-based attributional LCA.

5.2. Outlook

The critical assessment of the current scientific robustness and consistency of iLUC does in no way imply that further research of iLUC effects and quantification approaches is not recommendable. It rather confirms the research needs in this area. It is by scientific standards still a very new topic anyway - proven by the fact that the issue of LUC-carbon intensity of biofuels appeared in the scientific literature only since 2008 (Djomo & Ceulemans 2012).

If further research achieves a better understanding of iLUC, scientifically robust and consistent iLUC quantification factors might be reconsidered as a potential element to be included in LCA and CF. However, taking into the account the rudimentary understanding as of now, this will take significant time and patience.

In parallel, the notion of Zilberman et al. (2010) should be further elaborated who qualified iLUC as "a second-best solution to a first-class problem". Along the same lines Faaij (2012) concluded that "iLUC is a reactive concept while we actually want to be proactive in avoiding it altogether […] defining iLUC factors has received most attention versus very limited focus on mitigation of iLUC." Some proposals on mitigation have been made by Wicke et al. (2012) and research resources and efforts should be spent on these topics with priority.

Despite the fact that LCAs are probably the best method to identify the environmental performance of products currently available, this study identified a still significant number of methodological gaps and challenges when it comes to addressing iLUC. These methodological gaps and choices have an obvious influence on the results of LCA studies using iLUC factors. Several gaps are inherent in the nature of iLUC and the LCA method as such; others can be addressed by future scientific work and progress.

Value choices can be scientifically informed, but they remain value choices. On a scientific level, it can only be checked, if these value choices are made consistently. Decision-makers in both private and public organisations need to appreciate the benefits of LCA. However, for a robust, sustainable and credible use of LCA the over-interpretation of LCA results without proper consideration of its gaps and limitations should be avoided, especially when it comes to iLUC. LCAs should be seen as one relevant element of environmentally motivated decision making, but as ISO 14040 puts it *„An LCIA shall not provide the sole basis of…overall environmental superiority or equivalence, as additional information will be necessary to overcome some of the inherent limitations in the LCIA."*

It is common practice that not all environmental aspects can be integrated into LCA and other tools like risk assessment or environmental impact assessment are used for such particular questions. Due to the different nature of iLUC and the material and energy flows typically assessed in LCA, it is probably wise to try to address and mitigate iLUC separately from LCA – at least for quite some time.

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7. Third party review statement

The land use change issue (LUC) has recently been much discussed in considering the Life cycle assessment (LCA) of product systems depending on soil: agriculture, biofuels, forests, meat production etc. These and other systems compete about the available, finite areas and it is not at all clear which products should be preferred under environmental aspects. In that situation, decision makers are well advised to use advanced assessment methods, especially LCA (ISO 14040:2006 and 14044:2006). In addition to these environmental LCA standards, methods restricted to the assessment of global warming (the Global warming potential (GWP) or "carbon footprint" (CF) caused by greenhouse gases (GHG)) have gained attention recently. ISO DIS 14067:2013 provides a draft standard. The same is true for the British pre-standard PAS 2050:2011 and several private initiatives, all based on the environmental standards cited above.

Since major economic changes tend to show (often unexpected) secondary effects, which may offset the original goal of a change, modifications of the original method of land use assessment (based on direct land use change (dLUC)) have been proposed and – prematurely – even been suggested for decision making. These modified methods try to include potential secondary effects of iLUC into the analysis. It has been the challenging task of this study to explore the scientific basis of such proposals, the model calculations which are used to substantiate iLUC and the limits set by the international standards. The results are sobering for the supporters of the inclusion of iLUC into the decision making at the present status of method development.

The main questions to be answered by this study are:

- **Do models exist which can be used to predict iLUC with the necessary accuracy?**

Several models (economic and deterministic) were analysed and shown to be not or only partially useful. Major drawbacks are that iLUC is often not distinguished from dLUC and that not enough data are available. The existing models could only serve as a starting point for the development of models useful for LCA. The present models also produce highly divergent "iLUC factors".

- **Do the existent LCA and CF standards require the inclusion of iLUC?**

They do not. The study is adamant in this regard. The iLUC belongs to a group of phenomena called "rebound effects". These can be treated in principle by the "consequential" LCA approach. Consequential LCA is based on (economic) scenarios in addition to an LCA as basis, whereas the (conventional) LCA, also called attributive LCA, is based on actual material and energy flows using the most recent data available. Since the reaction of the economy to any changes (here: land use) is not known, assumptions have to be made making any results questionable.
Some documents admit that iLUC calculations may be useful in the future, once a robust and internationally acknowledged method will be worked out.

- **Are the methods proposed so far robust and scientifically defensible?**

Examples are given where double counting can occur and the distinction between dLUC and iLUC is not always straightforward. Much more work will be necessary to develop a future methodology, as requested by some standards and other documents.

Conclusion:

The study is based on most recent literature and in-depth knowledge of the standards to be used for modelling and other relevant documents.
I strongly suggest taking into account the results of this study in any further measures with regard to iLUC modelling and its use in LCA for decision making.

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