Indirect effects of biofuel production

Overview prepared for GBEP

A SUSTAINABLE ENERGY SUPPLY FOR EVERYONE

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Foreword

This report was prepared to provide input to discussion on the indirect effects of biofuel production and consumption in the Global Bioenergy Partnership (GBEP). Financial support was kindly provided by the United Kingdom's Department of Energy and Climate Change and the Dutch Ministry of Infrastructure and Environment. This document does not necessarily reflect the views of GBEP, the Government of the United Kingdom or the Government of the Netherlands.

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1 Introduction to indirect effects of biofuel production

Bioenergy plays an important role in decarbonising our economy and stimulating sustainable development. The production and consumption of bioenergy will have both direct and indirect effects. This chapter sets out the key indirect effects of bioenergy production and consumption and the main mechanisms causing these indirect effects. It thereby lays the foundation for the subsequent detailed analyses on the size of indirect effects and how these can be mitigated.

1.1 The importance of bioenergy

Bioenergy production has seen a sharp growth in recent years. Key drivers include reduction of greenhouse gas emission, energy security and rural development. While large scale bioenergy production has met concerns about sustainability, it is important to note that bioenergy will play an important role in a decarbonised economy. This is due to the fact that for several sectors with a large and growing energy demand few alternatives exist. This includes aviation, shipping, road freight transport and industries requiring high temperature heating. Furthermore, many developing countries are currently heavily reliant on traditional use of biomass for heating and cooking. A transition to more sustainable forms of bioenergy can help achieve development and climate change mitigation goals. Developing a successful and sustainable bioenergy sector is therefore of key importance to the decarbonisation of the economy and to sustainable development around the world.

1.2 Bioenergy and sustainability

While bioenergy is a key form of renewable energy for low carbon sustainable development, the recent increase in bioenergy production has led to concerns about the sustainability of such large scale production. Key concerns include deforestation for energy crops, greenhouse gas (GHG) emissions from land-use change, impacts on the local environment and competition with food. On the other hand, biofuel production can contribute to economic development and energy security, e.g. through job creation, value addition and displacement of fossil fuel imports. The effects of bioenergy production and consumption can be divided into direct effects and indirect effects.

1.2.1 Direct effects

The direct effects of bioenergy production and consumption are a direct result of the activities needed to produce the bioenergy, for example the effects of crop cultivation on soil, air and water. As long as the location of production and processing is known, these direct effects can be monitored. GBEP currently develops indicators for a wide spectrum of such direct effects, including economic, energy security, social and environmental effects.

One of the main direct effects is direct land-use change (LUC). A direct LUC occurs when new areas (e.g. forest areas or grasslands, see circles A in Figure 1-1) are taken into production to produce the additional feedstock demand for bioenergy. This can have both positive and negative consequences on aspects such as biodiversity, carbon stocks and livelihoods.

Direct LUC effects and other direct effects of crop production can generally be measured and attributed to the party that caused them. These properties make direct LUC relatively easy to control. The development of voluntary certification schemes such as the Roundtable on Sustainable Palm Oil and the Round Table on Responsible Soy aim to prevent negative direct effects from crop cultivation. However, as long as not all worldwide production is controlled by such certification schemes, effective enforcement of land-use planning, or alternative control mechanisms, such mechanisms are not able to fully control indirect effects.

1.2.2 Indirect effects

Much of the feedstock use for bioenergy today is sourced from existing plantations, especially since many of today's biofuel feedstocks are food and feed crops. In this case, no direct effects take place during the feedstock cultivation phase, but so-called indirect effects can take place. The main indirect effects of additional bioenergy feedstock demand are[1]:

- Indirect land-use change, explained in more detail below;
- Rise in agricultural commodity prices, with potential consequences for food security;
- Demand-induced yield increases – where the additional demand for the feedstock triggers additional yield increases (Ecofys 2009b).

The indirect effect that is currently dominating much of the debate on the sustainability of biofuels is indirect land-use change (ILUC). ILUC can occur when existing plantations (see circle B) are used to cover the feedstock demand of additional biofuel production. This displaces the previous productive function of the land (e.g. food production). This displacement can cause an expansion of the land use for biomass production to new areas (e.g. to forest land or to grassland, see circles B'and B'') if the previous users of the feedstock (e.g. food markets) do not reduce their feedstock demand and any demand-induced yield increases are insufficient to produce the additional demand. Where this indirect LUC will take place is uncertain and is out of control of the bioenergy sector.

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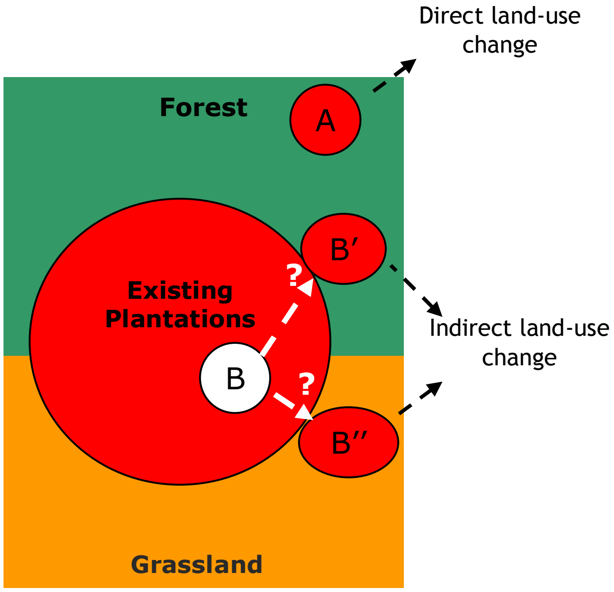
[1] For a detailled discussion on these indirect effects and a review of existing modeling work that aims to quantify the sizes of these idirect effects, see "Summary of approaches to accounting for indirect impacts" (Ecofys 2009b).

Figure 1 - 1: Illustration of the displacement mechanisms that may cause indirect land-use change. Adapted from (Dehue 2006)



1.2.3 Key characteristics of indirect effects

Since land requirements are a key concern for environmental, social and economic sustainability issues, controlling direct and indirect LUC effects is a major challenge to ensure a sustainable energy crop production. Several key characteristics of ILUC are summarised in the Box below. Any mechanism aiming to resolve indirect effects will need to take these complexities into account.

1.2.4 Note on direct LUC caused by food, feed and fibre sectors

This report is focussed on the indirect effects of bioenergy. It should be noted that unwanted effects from *indirect* LUC from bioenergy manifest itself through unwanted *direct* LUC for the production of agricultural products for other sectors such as the food and feed sector. Preventing unwanted direct LUC would thus eliminate unwanted indirect LUC altogether and is the optimal long term solution for unwanted LUC. However, because of the international characteristics of ILUC and the competition for land between different sectors, this mitigation measure requires global implementation for all land-based sectors to be effective. Until this is achieved, and if biofuels are to meet their policy goals such GHG savings, intermediate solutions will need to be implemented that acknowledge the lack of control of sustainability in other biomass consuming sectors.

Box 1: Key characteristics of indirect land-use change

- *Displacement effects act across national border.* Commodities such as palm oil, soy oil and sugarcane are traded on a global scale. Therefore, displacement effects act across borders. Achieving effective national land-use planning in some producing countries should therefore not be taken as full protection against indirect effects. If, for example, Indonesia were to prevent further deforestation through effective land-use planning, sourcing increasing amounts of palm oil from Indonesia for the energy sector may still cause indirect land-use change in other producing countries such as Malaysia.
- *Displacement effects act across substituting crops.* This is caused by the fact that different crops can substitute each other to some extent. For example, if the EU diverts more rapeseed oil production from food to feed then it is likely to increase its imports of vegetable oils. This could be rapeseed oil but could also be a different vegetable oil as different vegetable oils are to some degree substituting products. Thoenes (2007) states that "EU palm oil imports have already doubled during the 2000-2006 period, mostly to substitute for rapeseed oil diverted from food to fuel uses."
- *Competition for land connects also non-substituting crops.* Another reason why displacement effects act across crops is that different (non-substituting) crops can compete for the same agricultural land. A recent example of this occurred in 2008 when high maize prices led farmers in the US to plant more maize and less soy (USDA 2010), which could trigger soy expansion in other world regions.

1.3 About this report

This report intended to inform the GBEP workstream on indirect effects of bioenergy. Its aim is to provide an up-to-date insight into the science relating to ILUC from bioenergy: the mechanisms that cause ILUC; the various approaches to quantifying ILUC; the extent to which these approaches converge or diverge (and why); and the various approaches that are being developed to mitigate ILUC. A thorough understanding of this science will be important for the work of GBEP – namely the development of voluntary criteria and indicators for the effects of bioenergy production and consumption, including such criteria and indicators for the indirect effects of bioenergy production.

In order to provide an up-to-date insight into the science of ILUC, this report is structured as follows:

- Chapter 1 gives a general introduction into the mechanisms that cause indirect effects and discusses the key characteristics of such indirect effects. It lays the foundation for a more detailed analysis of ILUC in subsequent chapters.
- Chapter 2 reviews some of the key efforts to quantify the indirect effects of bioenergy production. It explains what the main approaches are to quantify indirect effects and quantitatively reviews a selection of existing ILUC quantification work. This quantitative review does not merely compare the

differences in outcomes but aims to explain those differences by looking at the underlying assumptions in more detail. This report thereby does not aim to identify the correct number for ILUC but aims to generate an understanding of what causes the studies to find different numbers, and what therefore are the key parameters that determine the size of ILUC. This again provides important insights for GBEP indicators for indirect effects.

- Chapter 3 reviews the mitigation options for unwanted indirect effects. It thereby provides an insight into what measures can be taken to prevent unwanted indirect effects from bioenergy production, over different time scales, by different actors.

Focus on GHG emissions from ILUC from biofuels

This report discusses the indirect effects of bioenergy production and consumption. This chapter introduced the three main indirect effects (indirect LUC – with effects on biodiversity, GHG emissions and other environmental, social and economic factors; changes in agricultural commodity prices; and demand-induced yield increases). It should be noted however that most work on indirect effects has focussed on the GHG emissions from ILUC from liquid biofuel production. Especially Chapter 2 will therefore contain much more information on the GHG emissions from ILUC than on the other indirect effects, although section 2.4.1. focuses on biodiversity losses. Also, the focus of the reviewed literature is on liquid biofuels specifically as opposed to bioenergy in general.

2 Quantitative review of work on pathway-specific indirect effects

In this section, we give a quantitative review of work on pathway-specific indirect effects. As this is a complex issue, we first present a summary of our key findings in Section 2.1. Section 2.2 and 2.3 explain the methodologies used for quantification of the indirect effects and the key assumptions they rely on. Section 2.4 introduces the studies we reviewed in this report. Section 2.5 provides the detailed results of the quantitative review and explains the differences found between studies. Section 2.6 draws a conclusion on the current state of pathway-specific quantification of indirect effects.

2.1 Key findings

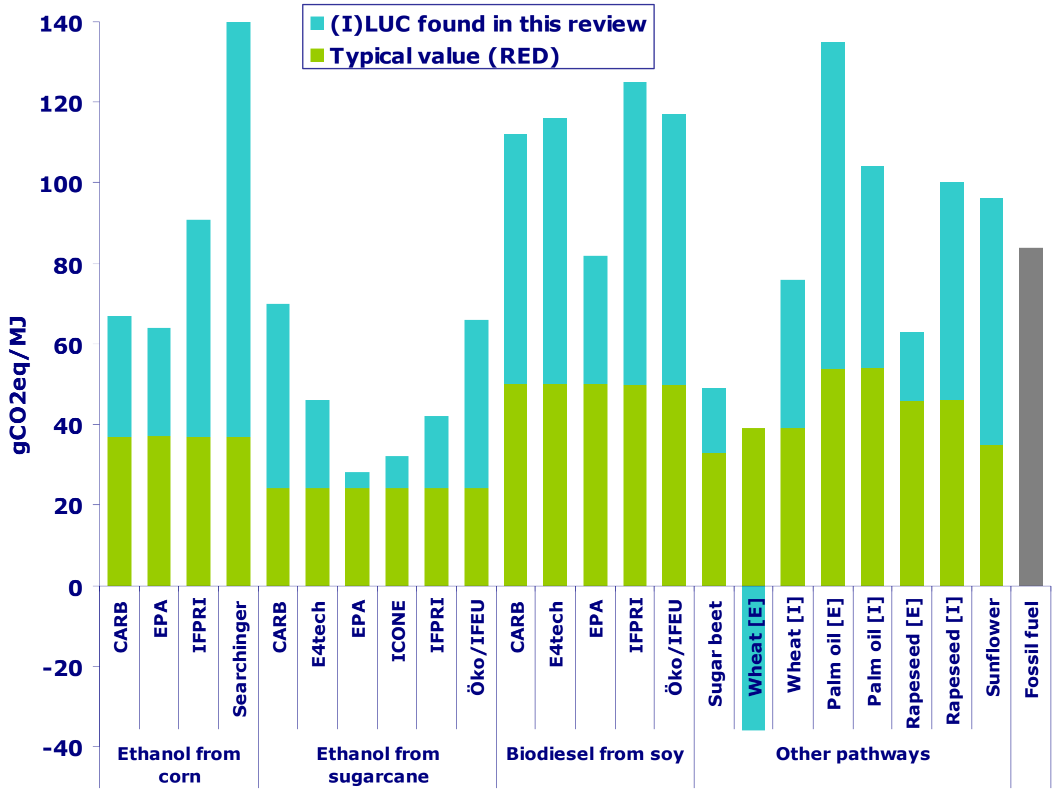


Figure 2 - 2 Graphical representation of the emissions caused by (I)LUC, direct and indirect land use change, for different biofuel pathways and different studies. For reference, typical non-land-use change emissions for the different pathways and a fossil reference from the EU Renewable Energy Directive (RED) have been added. Pathways labeled [E] are from the E4tech study, pathways labeled [I] are from the IFPRI study. Note that (I)LUC emissions found for ethanol from wheat in the E4tech study are negative.

Using Figure 2 - 3, we present our key findings for this quantitative review:

1. ***Within each pathway, there is no clear consensus on the size of total emissions from direct and indirect land-use change***. A slight trend can be seen where sugarcane generally has the lowest emissions from land-use change (4-46 gCO_2eq/MJ), followed by corn (27-103 gCO_2eq/MJ, with the second highest value being 54 gCO_2eq/MJ), followed by soy (32-75 gCO_2eq/MJ). In the other pathways, a similar trend is visible: ethanol pathways score better than biodiesel pathways. However, due to the large ranges in the results it would be premature to draw firm conclusions, based on the studies reviewed in this report, on the (I)LUC from ethanol versus biodiesel.
2. The ***differences*** between specific studies within a certain pathway ***are attributable to differences in quantification methodology and key assumptions*** on e.g. co-products, agricultural intensification, reduced demand in other sectors and carbon stocks of converted land, as described in Sections 2.2 and 2.3.
3. ***These differences can be made reasonably clear by our framework for quantitative comparison of intermediate results*** as presented in Section 2.5. Unfortunately, in many instances the data to derive these intermediate results are not available and, more importantly, a clear explanation of the causes of the differences between feedstocks is not given by the authors. An exception to this rule was the E4tech study, which contained a very transparent and well documented causal-descriptive approach.
4. In general, most studies find the emissions from ***(I)LUC for most pathways to be significant when compared to e.g. a fossil reference value*** of 80-90 gCO2eq/MJ fuel. An exception to this rule is the ethanol from wheat scenario in the E4tech study, that finds negative (I)LUC emissions. However, the assumptions and errors made in that scenario (see Section 2.5.4 for details) are critically discussed in Section 2.6 of this review.

2.2 Quantification of indirect effects

Different methods are used to quantify the indirect effects of biofuels. Most do follow a general four-step approach though. This is described in Section 2.2.1. This approach can be executed using equilibrium modelling or a causal-descriptive approach. These are described in Section 2.2.2 and 2.2.3.

2.2.1 Stepwise approach for quantification of indirect effects

Indirect effects occur through a series of market mechanisms, as described in Section 1.2. This means that they cannot be quantified by direct monitoring. Therefore, studies on quantification of indirect effects always use a quantification framework that estimates future indirect effects, e.g. an equilibrium model or a causal-descriptive approach.

Each study has its own exact methodology for quantification of indirect effects of additional biofuel demand. However, a general four-step approach is commonly found in these methodologies. This approach is visualized in Figure 2 - 3.

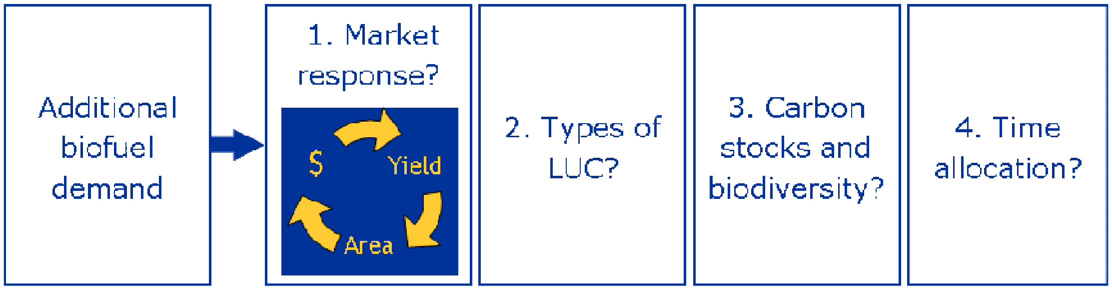


Figure 2 - 3 Four-step approach to quantifying the indirect effects of additional biofuel demand. In the reviewed studies the focus was on the greenhouse gas emissions caused by indirect land use change.

First a certain additional biofuel demand to be analyzed is chosen. Usually this is based upon a certain biofuel mandate, but it can also be based on general market expectations on competition with other fuels. In the studies reviewed in this report pathway-specific indirect effects were investigated. This means that the additional biofuel demand is supplied in whole by one biofuel pathway to calculate the indirect effects of that pathway specifically. A pathway always consists of a certain fuel and feedstock and sometimes of a specific region, e.g. production of ethanol from sugarcane in Brazil. Then the market response to this demand is calculated by modelling expected interdependent changes in commodity prices, crop yields and cropland areas due to the additional biofuel demand. In other words, the additional biofuel demand will come from one of three sources: 1) an additional yield increase that results from the additional biofuel demand, 2) an increase in agricultural land, and 3) a reduction in consumption in other sectors (step 1 in the above figure).

The area expansion, after correcting for additional yield increases and co-products, is the component causing a LUC. To further quantify the effects of this LUC, information is gathered on types of LUC (step 2 in the above figure) and the corresponding changes in carbon stocks and biodiversity (step 3 in the above figure). Finally, a time horizon, to which these indirect impacts are allocated and, in certain studies, a discount rate are chosen in order to enable comparison on, for example, a per year or per MJ fuel basis (step 4 in the above figure).

The approach visualized in Figure 2 - 3 can be used to quantify different indirect effects of biofuels. This is further explained in Table 2 - 1. As the focus of the reviewed studies was on the greenhouse gas emissions caused by ILUC, these studies do not contain specific analysis of food/feed consumption and biodiversity impacts.

Table 2 - 1 Details of the methodology to quantify the indirect effects of biofuels. As the focus of the reviewed studies was on the GHG emissions caused by ILUC, these studies do not contain specific analysis of food/feed consumption and biodiversity impacts.

Step	***Description***	***Reviewed impacts***
1. Market response	Global agroeconomic equilibrium models or causal-descriptive approaches are used to assess the effect of additional biofuel demand, for example by introducing a biofuel mandate, on the market. Effects to accommodate the biofuel demand are usually separated in three categories: • Expansion of agricultural land. • Intensification of agricultural production; e.g. higher yield per harvest, increased number of harvests per year • Higher commodity prices, crowding out consumers of the same commodity in other markets, leading to reduced consumption, e.g. for food/feed.	**Information on global food/feed prices and food/feed consumption**
2. LUC	From step 1, it is known what amount of expansion of agricultural land can be expected. Also, the location is usually available on a country/region level. In this step a prediction is made on which types of land will be converted to agricultural land. One method used for this purpose is satellite analysis of historical LUC trends.	
3a. Biodiversity 3b. Carbon stocks	Once the amount and the type of LUC is known from steps 1. and 2., the biodiversity and carbon stocks impacts can be assessed, making use of information sources on the carbon stocks and biodiversity values present in the LU-types that are converted – e.g. IPCC data-sources on carbon stocks. For the carbon impact, an additional step is needed, see step 4.	**Information on biodiversity loss**
4. Time allocation	Although the carbon emissions quantified in step 3b largely take place upon conversion, they are usually allocated to the GHG balance of biofuels over time. Different allocating mechanisms have been suggested. Different discount rates have also been suggested to allow comparison of emissions occurring over different time periods.	**Information on life cycle GHG balance**

2.2.2 Methodologies using global agro-economic equilibrium models

In many cases where indirect effects of additional biofuel production are assessed, global agro-economic equilibrium models are used. These models predict the market response to additional biofuel demand by calculating equilibrium states for the global market using a complex set of mathematical equations that relate to e.g. international trade, agricultural economics and policy and energy markets. Underlying these equations is a vast set of assumptions e.g. on trade elasticities, agricultural yield developments and demands from other sectors such as the food sector.

By comparing scenarios with and without the additional biofuel demand, they deduce changes in the system that can be attributed to the additional biofuel demand. An advantage of this approach using equilibrium models is that it is very comprehensive. A disadvantage is that the complex nature of the models can make their assumptions and results rather non-transparent.

It is also important to remark that the land-use changes identified by the models implicitly contain both direct and indirect land-use changes. These two effects can not be separated in the models. This is caused by the way the models operate: land-use changes are measured by comparing the land use in the additional biofuel scenario to the land use in the reference scenario. The model does not explicitly specify whether the land that underwent a land-use change is now in use for biofuel feedstock production or for other purposes such as food production. Therefore, the nature of the land-use change could be either direct or indirect. However, it is certain that all land-use changes were directly or indirectly triggered by the additional biofuel demand, as that is the only difference between scenarios. Following from this observation is that when ILUC is mentioned in a model study or a study reviewing model studies, actually a total of direct and indirect land-use change is meant. We will refer to this as (I)LUC.

Studies that use equilibrium models can use either general or partial equilibrium models. General equilibrium models calculate an equilibrium state for a system including all (relevant) economic markets. Partial equilibrium models calculate an equilibrium state for one specific sector, e.g. the energy sector or agricultural sector. The state of all other sectors is assumed constant. General equilibrium models are therefore more comprehensive, but can in turn also include more uncertainties in assumptions.

2.2.3 Methodologies using a causal-descriptive approach

In an effort to reduce the intransparency caused by some agro-economic equilibrium models, other methodologies use a causal-descriptive approach. This is a bottom-up approach where a causal chain of events following the additional production of biofuels is constructed. Assumptions that lead to the steps of this chain of events are backed by historic data, projections for the future or expert opinions. This makes these approaches more transparent and more easily discussed. A drawback is that these approaches require some amount of simplification as they lack the comprehensive scope and the computational power of the agro-economic equilibrium models.

Causal-descriptive approaches can have a retrospective or a predictive nature. For example, in the ICONE study introduced in Section 2.4 the authors looked back at a historical period and tried to assign the observed land-use changes to biofuels and other drivers of agricultural development. In the E4tech study and in the ILUC Factor approach by the Öko-Institut and IFEU, both are also introduced in Section 2.4, the authors try to analyse possible future land-use change scenarios using a causal chain of events. An advantage of the retrospective approach is that in principle one only needs historical statistics, without the need for making future predictions. At the same time, this could also be a weakness, as it makes the implicit assumption that historical trends reflect future trends, which is not necessarily correct due to changes in e.g. technology and policy.

2.3 Key assumptions in quantifying indirect effects

From the methodology of quantification presented in Section 2.1, it becomes clear that each methodology is a complex computational framework with its own regional divisions and assumptions. These differences in methodology setup and assumptions lead to differences in outcomes ranging from minor to major. The main assumptions associated with each of these steps are thus determining factors in the eventual outcomes. These are discussed here along the lines of the four methodological steps described in Table 2 - 1:

1 Market response to additional biofuel demand

This step contains the following main assumptions to quantify the resulting cropland expansion, intensification of production and reduction of demand in other sectors.

- The **choice of feedstock** for the additional biofuel demand; e.g. including biofuel pathways with a high biofuel yield per hectare or biofuels from residues and wastes leads to lower land-use change.
    - Choosing biofuel pathways with a high biofuel yield per hectare means that in principle less area is needed to accommodate the additional biofuel demand and thus that indirect impacts are lower. As biofuel yields per hectare from high yielding pathways can be multiple times higher than those of low yielding pathways this can have a large effect. However, co-products should be taken into account as well; this is discussed in the next assumption. This report focuses on pathway-specific indirect effects, so every pathway's effect is quantified separately.
    - Choosing biofuel pathways from residues and wastes that put no strain on the economic system, so no indirect impacts occur. This absence of indirect impacts of residues and wastes is a model assumption. In practice, some feedstocks classified as residue or waste in the EU Renewable Energy Directive (RED) can have indirect effects.[2] An example would be tallow from animal rendering, which can currently be used as process fuel by the renderers as well as for oleo-chemical applications. If that tallow were now to be used for biofuel production, the renderers would need a replacement process fuel, for example heavy fuel oil. In this report, no biofuel pathways from residues and wastes are included.

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[2] Recently a report was issued by the UK Renewable Fuel Agency on this matter: Ecometrica, Methodology and Evidence Base on the Indirect Greenhouse Gas Effects of Using Wastes, Residues, and By-products for Biofuels and Bioenergy, November 2009.

- Treatment of **co-products** of biofuel production.
    - Most biofuel feedstock crops do not only have biofuel as an end-product, but also produce one or more co-products. For example, corn used for ethanol production also yields residual dry distiller's grains and solubles (DDGS) commonly used as animal feed. In soy biodiesel production the biofuel co-product, soy meal commonly used as animal feed, is even the main product in terms of volumes. These co-products can be accounted for by assuming they displace a certain amount of other commodities on the markets, usually animal feed. Assumptions on what product is displaced and where and how this displaced product would have been produced, have a significant effect on the outcome of the methodology. For example, the DDGS from corn ethanol production is often assumed to replace one third of the original corn demand for biofuels.
- **Relation between agricultural intensification and commodity prices and/or demand**.
    - This relation determines the amount of additional biofuel demand that is met through additional agricultural intensification. Any amount met this way does not need to be met by cropland expansion and thus no (I)LUC occurs for that amount. Note that intensification may also lead to changes in GHG emissions. The studies reviewed in this report do not take this into account.
    - This relation is very difficult to quantify: historical data on yield and prices are distorted by many other factors, making it extremely challenging to identify the actual causal relationship between demand or price increases on the one hand and yield increases on the other hand. Studies on this matter are often inconclusive.
- **Relation between food/feed demand and commodity prices**.
    - This relation determines the amount of additional biofuel demand that is met through reductions in food/feed demand. Any amount met this way does not need to be met by cropland expansion and thus no (I)LUC occurs for that amount. In addition, it determines the indirect impacts on food /feed consumption.
- **Relative yield of new land taken into production**
    - Some studies assume[3] that the land best suited for agriculture is already in production. Any land that is used for cropland expansion therefore has a lower average yield than current cropland, which increases the amount of land expansion needed.

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[3] Exact assumptions on this issue and their effect in the methodology are often unclear.

2 <u>LUC caused by cropland expansion</u>

- Assumptions of **types of LUC caused by cropland expansion**.
  - Since carbon stocks and biodiversity values between different land types, e.g. forest, grassland, savannah, can differ significantly, the type of land-use change assumed to occur because of cropland expansion is a key parameter in quantifying indirect impacts. Conversion of specific high-carbon subcategories of these land types such as wet- and peatlands are not included in all studies. This can cause uncertainties in the carbon stock values found in step 3.

    Many studies rely on historical satellite data for their assumptions on the type of land that is converted by expanding cropland. It should be noted that the reliability of such satellite data, and especially their suitability to observe land-use change is questioned by some experts.
  - Secondary indirect effects can occur in the cattle sector, which is not included in all methodologies. For example, when a biofuel is produced from sugarcane previously used for the food sector, sugarcane might expand onto pasture used for cattle grazing. This cattle pasture might in turn be replaced by pasture expansion into a forested area. This secondary effect is only quantified when the methodology accounts for these changes in the cattle sector.

3 <u>Current carbon stocks and biodiversity values of land used for cropland expansion</u>

- Assumptions on **carbon stocks and biodiversity values** of land types affected by cropland expansion.
  - Even when the types of LUC are known from the second step, the carbon stock and biodiversity value of the land affected by LUC is still an important assumption, as different values are used within the different model studies. Some studies also include foregone carbon sequestration of land taken into crop production that would otherwise likely have increased in carbon stock, e.g. young forests or fallow cropland.

4 <u>Time allocation of GHG emissions of LUC</u>

- Assumptions on **time allocation of GHG emission effects**.
  - Most GHG emissions of LUC occur soon after the conversion of land takes place, for example by burning the original vegetation. However, in the final result of the GHG life cycle analysis of the biofuel, these emissions from LUC need to be allocated over time to the biofuel produced on the land. The amount of years chosen for that varies between the studies and often no clear rationale provided. This amount of years chosen commonly varies between 20 to 100 years, and has a significant effect on the indirect GHG impacts of biofuel. In addition, some studies incorporate discussion on discount rates that can be used to attach gradually less value to GHG emissions and/or savings as they occur later in time. This is comparable to the use of discount rates for the value of money in time in economic theory.

Quantification of these assumptions and their effect on model outcomes, where possible, forms the core of the quantitative comparison made in Section 2.5.

2.4 Overview of reviewed quantitative work on indirect effects

In this report, only studies are included that have performed pathway-specific quantification of indirect effects. The reviewed studies, their character and the way their results are reviewed are presented in the list below and Table 2 - 2:

- CARB, California's Low Carbon Fuel Standard (LCFS) Final Statement of Reasons, December 2009
- E4tech, A causal descriptive approach to modelling the GHG emissions associated with the indirect land use impacts of biofuels, Final Report, November 2010.
- EPA, Renewable Fuel Standard Program (RFS2) Final Rule, March 2010
- ICONE, An Allocation Methodology to Assess GHG Emissions Associated with Land Use Change, Final Report, September 2010
- IFPRI, Global trade and environmental impact study of the EU biofuels mandate, March 2010
- Öko-Institut and IFEU, the ILUC Factor contained in Sustainable Bioenergy: Current Status and Outlook, March 2009
- Searchinger et al., Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change, Sciencexpress, February 2008

Table 2 - 2 Character of the reviewed studies and the way they were used in this review.

Study	**Character**	**Use in this review**
CARB	Equilibrium model study with results for ethanol from sugarcane and corn and biodiesel from soy use in the US.	Quantitative review on corn (Section 2.5.1), sugarcane (2.5.2) and soy (2.5.3).
E4tech	Causal-descriptive study with results for use ethanol and biodiesel in the EU from a variety of pathways. See Table 2 - 3 for the specific scenario per crop included in this study.	Quantitative review on sugarcane (Section 2.5.2), soy (2.5.3), palm oil, wheat and rapeseed oil (all 2.5.4).
EPA	Equilibrium model study with results for ethanol from sugarcane and corn and biodiesel from soy use in the US.	Quantitative review on corn (Section 2.5.1), sugarcane (2.5.2) and soy (2.5.3).
ICONE	Causal-descriptive study with results from ethanol from sugarcane in Brazil.	Quantitative review on sugarcane (2.5.2).
IFPRI	Equilibrium model study with results for use of ethanol and biodiesel in the EU from a variety of pathways.	Quantitative review on corn (Section 2.5.1), sugarcane (2.5.2) and soy (2.5.3) and other pathways (2.5.4).
Öko-Institut/IFEU	Causal-descriptive study with a generalised methodology that can be used for a variety of pathways.	Quantitative review on sugarcane (2.5.2) and soy (2.5.3).
Searchinger	Equilibrium model study with results for ethanol from corn use in the US.	Quantitative review on corn (Section 2.5.1).

In the E4tech study different scenarios are presented for each pathway. They can have significantly different results on GHG emissions from indirect land use change. These scenarios differ on the assumptions used as input, for example on co-product effect, land use change types and carbon stocks. In the E4tech study none of these scenarios is presented as most likely or most accurate. However, we had to choose one of the scenarios for each pathway to include in this review.

We did this by including the scenario that had the most common denominators in its assumptions. For example, if there are five scenarios for a certain pathway, and four of them assume historical deforestation rates to continue, we chose to include one of those four. By applying this logic to all the different assumptions of the scenarios, we were able to select a scenario with the most common denominators in its assumptions for each pathway. These scenarios, including a short description of their most important assumptions are listed in Table 2 - 3.

Table 2 - 3 Overview of the scenario included in this review per pathway from the E4tech study. Please refer to the E4tech study for more details.

Pathway	Scenario	Most important assumptions
Biodiesel from palm oil	4	No demand induced yield increase; Historical deforestation rates; 33% of expansion on peat land; single plantation lifetime.
Biodiesel from rapeseed oil	1	High share produced in EU; inclusion of demand induced yield increase; no displacement of Ukrainian food rapeseed; historical deforestation rates; 100% use of rapeseed meal as animal feed; high substitution values for co-products.
Biodiesel from soybean oil	1	China: 50%/50% substitution of soy oil by palm oil and rapeseed oil; high emission factor scenario used for palm oil.
Ethanol from wheat	4	Increased production all in EU; high demand induced yield increase; historical deforestation rates; 100% use of DDGS as animal feed.
Ethanol from sugarcane	7	Low demand projections; some production in USA and Africa; inclusion of demand induced yield increase; historical pasture displacement in Brazil attributed to sugarcane expansion; historical deforestation rates.

2.4.1 Quantifying biodiversity losses

All studies reviewed in this report focus on the GHG emissions from (I)LUC resulting from an additional demand for biofuels. None of the studies includes a detailed analysis of the impacts of (I)LUC on biodiversity. However, as explained in Section

2.2.1 indications on the impacts on biodiversity are available from the existing studies. After all, all of the reviewed studies, except the ILUC-factor from the Öko -Institute, provide the following information:

- The amount of (I)LUC that takes place, usually on a country/region level (step 2 in the 4-step process described in Section 2.2.1). This information is summarised for each crop in each study in the tables of Section 2.5 in ha/toe.
- The type of land converted as a result of (I)LUC (step 3 in the 4-step process described in Section 2.2.1. Combined with the information on the country/region where the (I)LUC takes place, this provides information on the type of biome or ecosystem that is converted.

Therefore, even though the reviewed studies did not explicitly analyse the impacts on biodiversity, they contain valuable information on the potential biodiversity impacts of additional biofuel demand.

Another indication of the impacts on biodiversity of additional biofuel demand is given by the recent "Rethinking Global Biodiversity Strategies" (PBL 2010). While this study is not specifically focussed on the impacts of biofuels or bioenergy it does find in its results that increasing the amount of bioenergy, without additional measures to minimise impacts on biodiversity, has a negative impact on global biodiversity by 2050 even if it reduces global warming. Interestingly the study also finds that if additional measures are taken alongside bioenergy, such as additional yield increases, the total impacts on biodiversity are positive.

To increase the understanding of the impacts of biofuels on biodiversity, it is recommended that future biofuel/bioenergy (I)LUC studies attempt to quantify these biodiversity impacts next to the impacts on GHG emissions.

2.5 Review of pathway-specific indirect effects – understanding the differences

This section provides the quantitative review of indirect effects for different pathways: ethanol from corn (Section 2.5.1), ethanol from sugarcane (Section 2.5.2), biodiesel from soy (Section 2.5.3) and biofuels from other pathways (Section 2.5.4).

2.5.1 Ethanol from corn

The review is split in three stages: first, we provide a condensed but comprehensive overview of quantitative results from all studies in our review in one table. Then we explain the details of each study. Finally, we explain the differences between studies, using the details described earlier.

Summary of important results and assumptions of the reviewed studies

The table on the next pages summarizes the key results and assumptions of the various studies.

Table 2 - 4 Pathway-specific results from different studies on GHG emissions from (I)LUC for ethanol from corn. Please refer to the text for detailed discussion of the reviewed studies and their differences.

ETHANOL FROM CORN	Unit	CARB (LCFS)	EPA (RFS2)	IFPRI	Searchinger
Treatment of co-products					
	-	25-45% displacement of original feedstock by co-products.[4]	Included in the model.[5]	Included, but replacement rates are unclear.	33% displacement of original feedstock by co-products.
Additional demand from biofuels for energy crops results in					
Biofuel-induced agricultural intensification	%	Included, with a significant but unquantifiable effect. (Rough estimate: ~50%)[6]	Included for both crops and pastures.[7]	Included, but extent unclear.	0% (assumption)
Reduced demand in other sectors	%		Included. (Estimate for total mandate: ~10%)[8]	Included, but extent unclear.	20% (estimate[9])
Cropland expansion	%	Included, but extent unclear. (Rough estimate: ~50%)[6]	Included, but extent unclear. (Rough estimate: ~90%)[10]	Included, but extent unclear.	80%
Extent of cropland expansion					
Cropland expansion	ha/toe	0.15	0.26	Unspecified.	0.38

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[4] The co-product is assumed to replace corn on a ~1:1 weight basis. As generally 25%-45% of the corn ends up in the co-product, this range is used to estimate the co-product displacement effect.

[5] The co-product is assumed to replace a combination of corn and soy meal on a 1:1 to 1.2:1 weight basis. The effect of this replacement is endogeneously calculated in the model.

[6] From communication between Ecofys and the authors we know this is included. They estimated that these effects would be significant, which is supported by the sensitivity of the final outcome of the study to changes in assumptions in these areas. Based on data reported in the study (corn yield of 151.3 bushel/acre; ethanol yield of 2.8 gallon/bushel) and assuming a 1/3 co-product displacement, we calculated a very rough estimate of ~50% for these two effects combined.

[7] Both the use of pastures and that of cropland can be intensified in the model in response to demand/price changes. The magnitude of this effect is not clear from the data, but could very well be significant. As an example: international pasture reduction equals 33% of cropland expansion in the corn scenario. As this effect could also partially be caused by reduced demand for cattle products, it can not only be attributed to pasture intensification.

[8] The study provides data for global reduced food consumption for the total RFS2 mandate. Based on this data we made a rough estimate on the size of this reduction relative to the additional production of land-using biofuels.

[9] This value was an estimate as reported by Searchinger during personal communication with Ecofys in 2009 and is therefore indicative.

[10] Based on data reported in the study (corn yield of 183 bushel/acre; ethanol yield of 2.6 gallon/bushel) and assuming a 1/3 co-product displacement, we calculated a very rough estimate of ~10% for biofuel-induced agricultural intensification and reduced demand in other sectors combined. This means ~90% of cropland expansion.

ETHANOL FROM CORN	Unit	CARB (LCFS)	EPA (RFS2)	IFPRI	Searchinger
GHG effect of cropland expansion					
Weighted average of emissions from crop expansion	tCO2eq/ha	244	126	Unspecified.	351
Project horizon for emissions from (I)LUC	Years	30	30	20	30
Emissions from (I)LUC	gCO_2eq/MJ fuel	30	27	54	103
Emissions from (I)LUC (assuming a standardized project horizon of 20 years; for comparison only)	gCO_2eq/MJ fuel	45	41	54	155

Detailed discussion of reviewed studies

CARB

The CARB study includes a co-product replacement for corn, where the resulting co-product is assumed to replace corn used as animal feed.

The modelling done in the study also accounts for the effects of biofuel-induced agricultural intensification and reduced demand in other sectors. We expect that these effects are significant from communication with the authors, from their sensitivity analysis and from the relatively low value of 0.15 ha/toe cropland expansion. It is unclear how large these effects are. A very rough estimate based on the available data indicates that they could combine to compensate ~50% of additional biofuel demand.

The model includes a land-use module that automatically identifies the type of land being converted to cropland as either "forest land" or "pasture land". For corn it is found that ~20% of cropland expansion occurs on forest land and ~80% on pasture land. It is not clear from the data whether this includes any cattle knock-on effect where displaced pastures are reclaimed in other areas. This leads to a moderate value for associated emissions of 244 tCO_2eq/ha. The emissions are allocated to a 30-year time period.

EPA

The EPA study includes a co-product replacement for corn, but this is not a pure replacement of corn itself. Instead, the co-product replaces a mix of corn and soybean meal. As this happens endogeneously in the model the exact effect cannot be derived from the available reports.

It is also clear that biofuel-induced agricultural intensification and reduced demand in other sectors are included in the model. Both cannot be quantified exactly based on the available reports, but are expected to play a significant role. For example, the study provides data for global reduced food consumption for the total RFS2 mandate. Based on this data we made a rough estimate on the size of this reduction relative to the additional production of land-using biofuels being ~10%. Biofuel-induced agricultural intensification occurs both on cropland and on pastures in the EPA model. The magnitude of this effect is not clear from the data, but could very well be significant. As an example: international pasture reduction equals 33% of cropland expansion in the corn scenario. As this effect could also partially be caused by reduced demand for cattle products, it cannot only be attributed to pasture intensification.

A very rough estimate based on the available data indicates that in total biofuel-induced agricultural intensification and reduced demand in other sectors in the corn scenario could combine to compensate ~10% of additional biofuel demand.

The resulting cropland expansion value of 0.26 ha/toe is in the middle of the range found in other studies and consists of separately quantified US ("domestic") and non-

US (“international”) cropland expansion. This is due to the fact that EPA used a combination of a model specific for the US and an international model for their calculations. For corn 42% of the expansion is domestic, 58% is international.

The GHG emission effect of cropland expansion found in the EPA study is very low compared to the other studies. The US model endogeneously calculates the GHG emission effect of domestic cropland expansion. For corn, negative emissions of -4 gCO_2eq/MJ are found, meaning that the land-use changes lead to carbon sequestration. The causes for this effect are unclear because they occur within the model and are not explained in detail by the authors.

The international model cannot endogeneously calculate the GHG emission effect of international cropland expansion. Therefore, satellite data is used to predict which land types are converted and Winrock data for carbon stocks of these land types are used to calculate the associated emissions. For corn, relatively large conversion of high carbon stock biomes in the Brazilian Amazon are found, leading to significant emissions.

On average, combining domestic and international land-use changes, a relatively low value of 126 tCO_2eq/ha is found. The time horizon for the emissions is set at 30 years.

IFPRI
No detailed intermediate results are available for the pathway-specific calculations performed by IFPRI. Therefore, no breakdown or discussion of their 54 gCO_2eq/MJ value can be provided. The exception is the projection on time horizon for the emissions at 20 years, where the other studies use 30 years. If a 30-year horizon were to be used, the value would be 36 gCO_2eq/MJ.

Communication with the author indicated that IFPRI may perform an updated analysis on pathway specific ILUC values for EU biofuel demand. We hope this updated version will provide more insights in the assumptions and intermediate results of the study, which will allow for a better comparison with other studies.

Searchinger
Searchinger finds a relatively high value of 103 gCO_2eq/MJ ethanol fuel. Two important reasons for that are his assumption that there will be no biofuel-induced agricultural intensification and the relatively high carbon stocks he assumes for converted land. In his paper he explains these two assumptions:

1 The study assumes that potential agricultural intensification due to higher demand and/or price is neutralised by the yield loss associated with the taking into production of marginal lands that are less suitable for agriculture.
2 Searchinger assumes that all deforestation historically found in a certain area is caused by cropland expansion, provided that cropland expansion has historically

been larger than deforestation. Through this assumption the study finds large LUC in forested areas, which are high in carbon compared to other land types.

Matching comparison and discussion of the reviewed studies – understanding the differences

All studies find significant GHG emissions associated with (I)LUC for ethanol from corn, with the results spanning 27 – 103 gCO_2eq/MJ ethanol fuel. Within this range of values, Searchinger finds a particularly high value. Two important reasons for that are the study assumes that any biofuel-induced agricultural intensification is cancelled out by lower yield on the new land taken into cultivation, and the relatively high carbon stocks assumed for converted land.

The IFPRI, CARB and EPA values, when compared on a 30 year time horizon, are relatively similar at 36, 30 and 27 gCO_2eq/MJ respectively. No details are available for the IFPRI analysis, so we cannot comment on the way this value was achieved.

When comparing the details of the CARB and the EPA value it is striking that, although they reach a similar end value, the intermediate values are quite different. The EPA cropland expansion is almost twice as high as that of CARB: 0.26 ha/toe instead of 0.15 ha/toe. The reason for this cannot be pinpointed as co-product replacement, biofuel-induced agricultural intensification and reduced demand in other sectors all occur endogeneously in the model. Not enough detailed data are available to analyse their effect in the two studies.

The difference in cropland expansion values is compensated by the EPA value for emissions per hectare of cropland expansion being about half that of CARB: 126 tCO_2eq/ha instead of 244 tCO_2eq/ha. The low value for EPA can be explained by the fact that a significant part of the cropland expansion occurs in the US, which leads to a negative emission effect, meaning that the land-use changes lead to carbon sequestration. As this happens endogeneously in the model, the precise reasons cannot be explained. These negative emissions compensate for the non-US land use changes, which cause significant emissions in the forest biomes of the Amazon, leading to the overall low value of 126 tCO_2eq/ha.

2.5.2 Ethanol from sugarcane

The review is split in three stages: first, we provide a condensed but comprehensive overview of quantitative results from all studies in our review in one table. Then we explain the details of each study. Finally, we explain the differences between studies, using the details described earlier.

Summary of important results and assumptions of the reviewed studies

Table 2 - 5 Pathway-specific results from different studies on GHG emissions from (I)LUC for ethanol from sugarcane. Please refer to the text for detailed discussion of the reviewed studies and their differences.

ETHANOL FROM SUGARCANE	Unit	CARB (LCFS)	E4tech	EPA (RFS2)	ICONE	IFPRI[11]	Öko-Institut/IFEU (ILUC Factor)
Treatment of co-products							
	-	Co-products are all used for process energy, no agricultural feedstock replacement.	Co-product is used for energy generation.[12]	Co-product is used for energy generation.[13]	Not considered.	Co-products only have economic value, no agricultural feedstock replacement.	Included, as gross yield numbers are used.[14]
Additional demand from biofuels for energy crops results in							
Biofuel-induced agricultural intensification	%	Included, with an unquantifiable effect. (Rough estimate: ~0%)15	26%	Included for both crops and pastures.16	92%	29% (Total mandate: 33%)	50%17
Reduced demand in other sectors	%		0% (Excluded)	Included. (Estimate for total mandate ~10%)18		8% (Total mandate: 24%)	
Cropland expansion	%	Included, but extent unclear. (Rough estimate: ~100%)15	74%	Included, but extent unclear. (Rough estimate: ~40%)19	8%	64% (Total mandate: 44%)	50%

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[11] No detailed intermediate data was presented for the sugarcane pathway-specific calculations in the IFPRI study. However, as 69% of the increased demand for biofuels from energy crops in IFPRI's EU mandate scenario included in the same report was met by sugarcane, some indicative values could be derived from that scenario. In this column, these indicative sugarcane-specific values are presented where possible. Behind them, between brackets, are the same values but then pertaining to the total mandate including all biofuel pathways in their EU mandate scenario.

[12] The co-product credit therefore materialises by replacement of fossil energy sources, outside the scope of the land-use analysis.

[13] The co-product credit therefore materialises by replacement of fossil energy sources, outside the scope of the land-use analysis.

[14] The ILUC Factor methodology uses gross cropland yields. This means that the yield of all products from one hectare, including co-products is used for the calculations. The GHG effects are thus automatically allocated to both products and co-products on an energy content basis.

[15] From communication between Ecofys and the authors we know this is included. They estimated that these effects would be significant for the combination of all pathways. For sugarcane specifically, the contribution might be low: based on data reported in the study (cane yield of 75.13 ton/ha) and an assumed ethanol yield of 0.075 ton ethanol/ton cane and assuming no co-product displacement, we calculated a very rough estimate of ~0% for these two effects combined.

[16] Both the use of pastures and that of cropland can be intensified in the model in response to demand/price changes. The magnitude of this effect is not clear from the data, but could very well be significant. As an example: international pasture reduction equals 38% of cropland expansion in the sugarcane scenario. As this effect could also partially be caused by reduced demand for cattle products, it can not only be attributed to pasture intensification.

[17] This number is derived from the "medium ILUC risk level" used in the ILUC Factor methodology. In addition to biofuel-induced agricultural intensification and reduced demand in other sectors, it also includes use of "set-aside and abandoned land" which the authors deem to have no associated ILUC.

[18] The study provides data for global reduced food consumption for the total RFS2 mandate. Based on this data we made a rough estimate on the size of this reduction relative to the additional production of land-using biofuels.

[19] Based on data reported in the study (ethanol yield 600 gallon/acre) and assuming no co-product displacement, we calculated a very rough estimate of ~60% for biofuel-induced agricultural intensification and reduced demand in other sectors combined. This means ~40% of cropland expansion.

ETHANOL FROM SUGARCANE	Unit	CARB (LCFS)	E4tech	EPA (RFS2)	ICONE	IFPRI[11]	Öko-Institut/IFEU (ILUC Factor)
Extent of cropland expansion							
Cropland expansion	ha/toe	0.29	0.22	0.14	0.03	Unknown. (Total mandate: 0.11)	0.13
GHG effect of cropland expansion							
Weighted average of emissions from crop expansion	tCO2eq/ha	202	125	34	380	Unknown. (Total mandate: 133)	270
Project horizon for emissions from (I)LUC	Years	30	30	30	30	20 (Total mandate: 20)	20
Emissions from (I)LUC	gCO2eq/MJ fuel	46	22	4	8	18 (Total mandate: 18)	42
Emissions from (I)LUC (assuming a standardized project horizon of 20 years; for comparison only)	gCO2eq/MJ fuel	69	33	6	12	18	42

Detailed discussion of reviewed studies

CARB

The modelling done in the study accounts for the effects of biofuel-induced agricultural intensification and reduced demand in other sectors. It is unclear from the documentation how large these effects are. As the cropland expansion found by CARB is relatively large compared to the other studies, it can be expected that these effects are smaller than the 37-92% found in the other studies. Indeed, a very rough estimate based on the available data indicates that in total biofuel-induced agricultural intensification and reduced demand in other sectors do not have a significant compensation effect (~0%) in the sugarcane scenario.

The model includes a land-use module that automatically identifies the type of land being converted to cropland as either “forest land” or “pasture land”. For sugarcane it is found that ~30% of cropland expansion occurs on forest land and ~70% on pasture land. It is not clear from the data whether this includes any cattle knock-on effect where displaced pastures are reclaimed in other areas. All emissions are allocated to a 30-year time period.

E4Tech

[We reviewed scenario 7 of the sugarcane scenarios of E4Tech, please refer to Section 2.4 for details.]

The E4tech study includes no co-product replacement for sugarcane that affects the land-use calculations as the co-product (bagasse) is used to generate energy.

Biofuel induced agricultural intensification plays a significant role, resulting in a 26% reduced need for area expansion. This intensification was based on a combination of the Lywood (2009a) method for certain regions with an estimate for regions where this method was deemed unfeasible. The use of the Lywood method can lead to high values for biofuel induced agricultural intensification, as explained in Section 2.6.1.

Analysis of reduced demand in other sectors was not included in the E4Tech work, so by default contributes 0%.

The scenario reviewed by us includes a knock-on effect for pasture displaced by sugarcane in Brazil, leading to an expansion of pasture in other regions of Brazil.

The resulting area expansion is in the middle of the range of other studies at 0.22 ha/toe. The emissions caused by this expansion are on the lower end of the range of the other studies at 125 tCO_2eq/ha. This low number is partly caused by an error in the carbon stock numbers for land converted to pasture in Brazil (as a result of pasture displacement by sugarcane). The effect of this error is that the ILUC value of Brazilian sugarcane ethanol is underestimated by 50%. Note that Brazil supplies only 55% of total additional sugarcane ethanol in the scenario reviewed by us, so the error in the average emissions per hectare of land converted is less than 50%. As discussed in more detail in Section 2.6.8, the effect on the average ILUC emissions from sugarcane ethanol is between 3 and 10 gCO_2eq/MJ according to the authors. Furthermore, the carbon stock numbers are based on Winrock data that found medium levels of deforestation. Combined with the error mentioned above and the fact that sugarcane is treated as a perennial crop leading to more carbon sequestration than annual crops, the overall value for the emissions per hectare is relatively low.

The reviewed E4Tech-scenario finds a midrange value of 22 gCO_2eq/MJ GHG emissions from (I)LUC associated with sugarcane from ethanol. When the error in the carbon stock numbers used in Brazil is taken into account, the value is 25-32 gCO_2eq/MJ.

EPA

The EPA study includes no co-product replacement for sugarcane that affects the land-use calculations as the co-product is used to generate energy. The co-product credit is applied in another step of the total emissions analysis.

Biofuel-induced agricultural intensification and reduced demand in other sectors are included in the model. Neither can be quantified exactly, but we expect they play a significant role. For example, the study provides data for global reduced food consumption for the total RFS2 mandate. Based on this data we made a rough estimate on the size of this reduction relative to the additional production of land-using biofuels being ~10%.

Biofuel-induced agricultural intensification occurs both on cropland and on pastures in the EPA model. The magnitude of this effect is not clear from the data, but seems significant. As an example: international pasture reduction equals 38% of cropland expansion in the sugarcane scenario. As this effect could also partially be caused by reduced demand for cattle products, it cannot only be attributed to pasture intensification.

A rough estimate based on the available data indicates that in total biofuel-induced agricultural intensification and reduced demand in other sectors in the sugarcane scenario could combine to compensate ~60% of additional biofuel demand. The resulting cropland expansion value of 0.14 ha/toe is in the middle of the range found in other studies.

The GHG emission effect of cropland expansion of 34 tCO_2eq/ha found in the EPA study is extremely low compared to the other studies. The model cannot endogeneously calculate the GHG emission effect of international cropland expansion. Therefore, satellite data is used to predict which land types are converted and emissions factors calculated by Winrock for carbon stocks of these land types are used to calculate the associated emissions. For sugarcane, the authors comment that these low values are "due largely to our projection that sugarcane crops would expand onto grassland in South and Southeast Brazil, which results in a net sequestration because sugarcane sequesters more biomass carbon than the grasslands it would replace”. No significant indirect effects of this expansion of sugarcane onto grasslands, such as the displacement of cattle which may lead to cattle expansion in the Amazon region, are observed in the EPA modelling.

As a last variable, the time horizon for the emissions is set at 30 years.

ICONE

The ICONE study is a retrospective causal-descriptive methodology that attributes historic deforestation of three types of forest biomes, observed in Brazil between 2005 and 2008 through satellite data, to the agricultural sector developments in the same period. The role of sugarcane is explicitly analyzed such that deforestation emissions can be attributed to the expansion of sugarcane for ethanol. In contrast to the agroeconomic models it distinguishes between direct and indirect LUC.

The ICONE study finds a relatively low value of 8 gCO_2eq/MJ GHG emissions from (I)LUC associated with sugarcane from ethanol. The main reason for the low value of GHG emissions from direct LUC is that sugarcane expansion rarely leads to direct conversion of natural vegetation. Satellite image data is presented as evidence for this. For the emissions for indirect LUC the situation is more complicated and is discussed below.

Important causes of the low value for emissions from indirect LUC have to do with methodological choices on calculating the indirect LUC emissions that the authors have made:

1. Crops/cattle displaced by sugarcane are first accommodated within the same region as where they are displaced by sugarcane by relocating them to land that has become available through yield increases or area reduction of other crops. Thereby, the crops/cattle displaced by sugarcane receive priority over crops/cattle displaced by other activities. The report does not explain this prioritization. This leads to the situation where indirect LUC caused by sugarcane only takes place within the region in which the sugarcane expands. These are typically the regions where little deforestation occurs, while most deforestation occurs in the Amazone where sugarcane does not expand directly. This results in the finding that sugarcane causes low emissions from ILUC.
   In summary, the situation arises that a) sugarcane predominantly displaces cattle, b) cattle predominantly expands in the Amazon region, but c) none of the expansion of cattle in the Amazon region is linked to the displacement of cattle by sugarcane.
2. Knock-on effects of crops/cattle displaced by sugarcane beyond the first displacement step are not included. For example, when sugarcane displaces corn, a part of the displaced corn may displace soy, which may be reclaimed in natural vegetation. This effect is not considered: only the first-step expansion of the displaced corn on natural vegetation is taken into account.

3 Crop/cattle displacements that cannot be explained using the prioritised relocation in the same region do not cause interregional/international ILUC. The report suggests that this is explained by yield increases in other regions but this is not entirely clear. In our review we therefore assumed this was compensated for through a combination of demand-induced agricultural intensification and/or reduced demand in other sectors.

The above methodological choices have an even larger effect due two underlying choices the authors have made:

1 All yield increases for crops other than sugarcane are attributed to reducing the pressure caused by expansion of sugarcane. This is an unconventional choice as other methodologies explicitly or implicitly exclude these business-as-usual yield increases as they are not a result of the additional biofuel demand. This can for example be done by using a baseline scenario in an equilibrium model study. In addition, the applied business-as-usual yield increases found in the used 2005-2008 period are much higher than historical trends.

2 Over the chosen timeframe of the study (2005-2008), contrary to other historical timeframes and predictions for the future, Brazilian cropland for crops other than sugarcane decreased significantly. As this reduction in cropland is not clearly compensated for in the methodology by e.g. a loss of exports or a comparison with a baseline scenario, this leaves significant room for accommodating the sugarcane expansion. In addition, the reduction in cropland of other crops means there was relatively low pressure of cropland expansion on deforestation, leading to low deforestation numbers.

A few examples of the results of applying this methodology to the South-East region of Brazil, which has the majority of all the sugarcane expansion, are:

1 Sugarcane partially expanded on corn cropland. First, a ~15% correction caused by business-as-usual yield increase is used to reduce the amount of actually displaced cropland. Then, it is observed that only 3% of the corn expansion took place on natural vegetation, meaning that a very small share of the sugarcane expansion on corn cropland is found to have led to deforestation: ~2.5%. No further knock-on effects of the displaced corn displacing other crops/cattle are taken into account. In total, the relatively low number is a result of the methodological choices of regional prioritization, business-as-usual yield increases, not considering of knock-on effects and the used timeframe.

2 Sugarcane partially expanded on soy cropland. First, a ~20% correction caused by business-as-usual yield increase is used to reduce the amount of actually displaced cropland. Then the authors conclude that the amount of new land taken into production for soy in the region is only ~15% of the amount of soy cropland displaced by sugarcane in the region. Following calculations of conversion of natural vegetation therefore only take into account this small amount of new land taken into production for soy. This implicitly means that there is a sharp reduction in regional soy production, which in other methodologies usually leads to reduced exports and/or increased imports in turn leading to interregional or international displacement, but this is not taken into account.

The mentioned methodological choices lead to a relatively very low value for cropland expansion due to additional biofuel demand: 8% of the additional demand is covered by cropland expansion into natural vegetation or only 0.03 ha/toe of biofuel. This implies that the other 92% must have come from either yield increases on cropland and/or pastures caused by the additional biofuel demand or a reduction in consumption in other sectors[20]. Although the GHG emissions per hectare of this crop expansion are relatively high, which can be expected as only high carbon stock forested biomes were considered, the resulting value for GHG emissions from (I)LUC is relatively low at 8 gCO2eq/MJ fuel.

IFPRI

No detailed intermediate results are available for the pathway-specific calculations performed by IFPRI. However, in the case of sugarcane indicative trends can be derived from the EU RED mandate scenario calculated in the same IFPRI study. This is because ethanol from sugarcane provides 69% of the increased demand for biofuels from energy crops in that scenario. Therefore, it can be assumed that trends observed in that scenario might be indicative of those in the pathway-specific sugarcane scenario21. However, these intermediate values, displayed where available in Table 2 - 5 should only be interpreted as an indication.

The values show that the end result of the sugarcane pathway-specific calculation and that of the total EU mandate calculation are equal: 18 gCO_2eq/MJ. In both scenarios, biofuel-induced agricultural intensification and reduced demand in other sectors play a significant role in reducing the need for cropland expansion, although less for sugarcane than for the total mandate.

The amount of cropland expansion per unit of biofuel and GHG emissions per converted hectare are unknown for the pathway-specific calculation. As the end result is the same as in the total mandate scenario, their product should be equal to that of the total mandate scenario. We can speculate that, due to the relatively high yield of sugarcane, the sugarcane cropland expansion per unit of fuel will not be much higher than that of the total mandate. This means that the GHG emissions per converted hectare are likely to be somewhat similar to the 133 tCO_2eq/ha found in the total mandate scenario, which is a low value compared to other studies. This is potentially caused by the absence of a knock-on effect of pastures. This means that the potential

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[20] All land that is not considered natural vegetation in the study is considered being either cropland or pasture. This means that any expansion of cropland not leading to a change in natural vegetation should lead to a reduction in pasture. This reduction in pasture should be accomodated by pasture yield increases or reduced demand for products coming from the pasture.

[21] This implies that we assume that increased sugarcane production in the EU mandate scenario has no or limited interaction with the production of other crops.

reclamation of pastures that are displaced by (sugarcane) cropland may not be comprehensively included in the IFPRI study.

Öko-Institut/IFEU (ILUC Factor)

The ILUC Factor is a simple and transparent methodology for calculating GHG emissions associated with ILUC. It derives a standard value of 270 tCO2eq/ha for average emissions of one hectare of crop expansion, based on historic trade and land-use change patterns and literature carbon stock values. Then it makes an assumption on the "ILUC risk level": how likely it is that one hectare of displaced crops will lead to land-use change, as other effects like demand-induced yield increases, reduced demand in other sectors and use of "set-aside and abandoned land" will not cause ILUC according to the methodology.

There is no set value for this risk level in the methodology, it is only reported that it will be between 25-75%, with 50% being the "medium level". We have chosen to use this medium level values throughout this report. Furthermore, the ILUC values change slightly over time as yield and trade data change. We report the 2010 ILUC values. Finally, we report the ILUC values for the case where the crop is grown on land previously used as cropland. The latter choice ensures that the reported values are independent of the direct LUC effect that takes place in growing the biofuel crop, making it suitable for comparison with the results of the other studies.

After all these values have been determined, the only difference between pathways is the yield per hectare of the crop used as feedstock. As sugarcane is a relatively high yielding crop it has, for the ILUC Factor, relatively low GHG emissions from land-use change. It should be noted that the actual pathway-specific value is very dependent upon the choice of the ILUC risk level, for which little argumentation is provided.

Matching comparison and discussion of the reviewed studies – understanding the differences

There is a significant range in GHG emissions associated with (I)LUC for ethanol from sugarcane, with the results spanning a 4 – 46 gCO_2eq/MJ ethanol fuel.

The EPA and the ICONE study find the lowest values: 4 and 8 gCO_2eq/MJ ethanol fuel respectively. On an abstract level this has the same cause. Both studies find that sugarcane expands mainly on low carbon stock grassland in Brazil and find that this expansion on pasture leads to very little knock-on effects in high carbon stock areas such as primary forest. Due to a difference in methodology, this shows in different ways in Table 2 - 5. For ICONE, conversion of natural vegetation in forest biomes to cropland is considered and is found to be very low in size (0.03 ha/toe) but high in emissions per hectare (380 tCO_2eq/ha). For EPA, a much higher expansion number (0.14 ha/toe) is found, but this is mainly expansion on grasslands. Therefore, the average emissions per hectare number is low (34 tCO_2eq/ha). Both are a representation of a similar effect.

The IFPRI study, especially when it is considered that they use a 20-year time horizon, also has a low value of (I)LUC emissions of 18 gCO_2eq/MJ fuel. The lack of detailed data makes it difficult to analyse the causes. Estimations from the total mandate scenario in that study, where sugarcane plays a large role, indicate that a relatively low number for average emissions per hectare cropland expansion (estimate from total mandate: 133 tCO_2eq/ha) could play a role. This could be caused by the absence of a cattle displacement knock-on effect. A recent report by JRC (2010) indicates that IFPRI might have significantly underestimated the loss of below- and aboveground carbon.

The E4tech study is in the middle of the range of the found values with emissions of 22 gCO_2eq/MJ fuel. This follows from the fact that most assumptions chosen as input for the causal-descriptive model are in the middle of the range of those of other studies. Note that the E4tech study accidentally used the wrong carbon stock numbers in Brazil. Correcting for this error would lead to a higher ILUC value, as discussed in section 2.6.8.

The ILUC Factor and CARB studies are at the higher end of the range. When both are compared on a 30-year time horizon basis, they have emissions of 28 and 46 gCO_2eq/MJ fuel respectively. The ILUC Factor result is very transparent, but heavily depends on the assumption of the ILUC risk level. We chose to use the medium level here. The CARB result is mainly high because of a relatively high number for cropland expansion at 0.29 ha/toe. This likely has to do with a limited effect of biofuel-induced agricultural intensification and reduced demand in other sectors, compared to EPA and ICONE, but this could not be derived from the data. Combined with the middle of the range value for average emissions per hectare cropland expansion (202 tCO_2eq/ha) this leads to the highest emission value per unit of biofuel.

2.5.3 Biodiesel from soy

The review is split in three stages: first, we provide a condensed but comprehensive overview of quantitative results from all studies in our review in one table. Then we explain the details of each study. Finally, we explain the differences between studies, using the details described earlier.

Summary of important results and assumptions of the reviewed studies

The table on the next pages summarizes the key results and assumptions of the various studies.

Table 2 - 6 Pathway-specific results from different studies on GHG emissions from (I)LUC for biodiesel from soy. Please refer to the text for detailed discussion of the reviewed studies and their differences.

BIODIESEL FROM SOY	Unit	CARB (LCFS)	E4tech	EPA (RFS2)	IFPRI	Öko-Institut/IFEU (ILUC Factor)
Treatment of co-products						
	-	Implicitly included.[23]	Included, with a 55% effect.[22]	Implicitly included.[23]	Included, but replacement rates are unclear.	Included, as gross yield numbers are used.[24]
Additional demand from biofuels for energy crops results in						
Biofuel-induced agricultural intensification	%	Included, with a significant but unquantifiable effect.[25]	7%	Included for both crops and pastures.[26]	Included, but extent unclear.	50%[27]
Reduced demand in other sectors	%		0%	Included. (Estimate for total mandate: ~10%)[28]	Included, but extent unclear.	
Cropland expansion	%	Included, but extent unclear.	94%	Included, but extent unclear.	Included, but extent unclear.	50%

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[22] This means: 55% of the emissions otherwise attributed to the pathway are compensated by the emission savings caused by the co-product.

[23] In the EPA and CARB models, the vegetable oil market and the oil meal market are separate. The model extracts soybean oil from the vegetable oil market for production of biodiesel. This can lead to extra soy production, including additional soy meal, but could also be compensated for by e.g. an increase in production of palm oil.

[24] The ILUC Factor methodology uses gross cropland yields. This means that the yield of all products from one hectare, including co-products is used for the calculations. The GHG effects are thus automatically allocated to both products and co-products on an energy content basis.

[25] From communication between Ecofys and the authors we know this is included. They estimated that these effects would be significant, which is supported by the sensitivity of the final outcome of the study to changes in assumptions in these areas. Unfortunately no conclusive quantification of these effects could be made from the available data.

[26] Both the use of pastures and that of cropland can be intensified in the model in response to demand/price changes. The magnitude of this effect is not clear from the data, but could very well be significant. As an example: international pasture reduction equals 19% of soy cropland expansion. As this effect could also partially be caused by reduced demand for cattle products, it can not only be attributed to pasture intensification.

[27] This number is derived from the "medium ILUC risk level" used in the ILUC Factor methodology. In addition to biofuel-induced agricultural intensification and reduced demand in other sectors, it also includes use of "set-aside and abandoned land" which the authors deem to have no associated ILUC.

[28] The study provides data for global reduced food consumption for the total RFS2 mandate. Based on this data we made a rough estimate on the size of this reduction relative to the additional production of land-using biofuels.

BIODIESEL FROM SOY	Unit	CARB (LCFS)	E4tech	EPA (RFS2)	IFPRI	Öko-Institut/IFEU (ILUC Factor)
Extent of cropland expansion						
Cropland expansion	ha/toe	0.31	0.16	0.94	Unspecified.	0.21
GHG effect of cropland expansion						
Weighted average of emissions from crop expansion	tCO2eq/ha	253	465[29]	43	Unspecified.	270
Project horizon for emissions from (I)LUC	Years	30	30	30	20	20
Emissions from (I)LUC	gCO_2eq/MJ fuel	62	66	32	75	67
Emissions from (I)LUC (assuming a standardized project horizon of 20 years; for comparison only)	gCO_2eq/MJ fuel	93	99	48	75	67

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[29] This value is for the actual expansion of palm oil and rapeseed oil needed to substitute the soy oil used for biofuels. It excludes any influence of the co-products. When these are taken into account, the value is 505 tCO_2eq/ha.

Detailed discussion of reviewed studies

CARB

The oil meal co-product is included in the modelling as a replacement for livestock feed. However, it is not clear what effect this has on the amount of cropland expansion needed for biofuel production.

The modelling done in the study also accounts for the effects of biofuel-induced agricultural intensification and reduced demand in other sectors. It is unclear how large these effects are.

The model includes a land-use module that automatically identifies the type of land being converted to cropland as either “forest land” or “pasture land”. For soy it is found that ~30% of cropland expansion occurs on forest land and ~70% on pasture land. It is not clear from the data whether this includes any cattle knock-on effect where displaced pastures are reclaimed in other areas. All emissions are allocated to a 30-year time period.

E4tech

[We reviewed scenario 1 of the soy oil scenarios of E4Tech, please refer to Section 2.4 for details.]

The E4tech study assumes that all soy oil needed for biofuel production will come from soy oil previously used for food applications. As E4tech did not include the potential for reduced demand in other sectors in their study, this soy oil is completely substituted by other vegetable oils. Their analysis finds this to be 75% of palm oil and 25% of rapeseed oil. For the effects of these substitution they thus use a weighted average of the effects found in their palm oil and rapeseed oil analysis (refer to Section 2.5.4 for details on these analyses). Therefore, the soy oil (sub)results are heavily influenced by those of palm oil.

This means that:

- The co-product effect is large. It compensates for 55% of the land use emissions caused by increased palm and rapeseed oil production. This is because both palm oil and rapeseed oil receive significant credit for their co-products that displace other vegetable oils and animal feed as discussed in more detail in sections 2.6.3 and 2.6.4.
- The additional yield effect is modest at 7%, as E4tech assumes no biofuel demand-induced yield increase for palm oil.
- The required cropland expansion is low compared to the other studies at 0.16 ha/toe as palm oil has a high yield.
- The emissions from this crop expansion are high compared to the other studies at 505 tCO_2eq/ha as E4tech assumes that the palm expansion takes place in Indonesia and Malaysia including expansion on forest land.

- The end result of 66 gCO_2eq/MJ biofuel is comparable to that found by most other studies.

EPA

The EPA study includes a co-product markets for soy, but in an implicit way. In the model, the vegetable oil market and the oil meal market are separate. The model extracts soybean oil from the vegetable oil market for production of biodiesel. This can lead to extra soy production, including additional soy meal, but could also be compensated for by e.g. an increase in production of palm oil.

It is also clear that biofuel-induced agricultural intensification and reduced demand in other sectors are included in the model. Both cannot be quantified exactly, but could very well play a significant role. For example, the study provides data for global reduced food consumption for the total RFS2 mandate. Based on this data we made a rough estimate on the size of this reduction relative to the additional production of land-using biofuels being ~10%. Biofuel-induced agricultural intensification occurs both on cropland and on pastures in the EPA model. The magnitude of this effect is not clear from the data, but could very well be significant. As an example: international pasture reduction equals 19% of cropland expansion in the soy scenario. As this effect could also partially be caused by reduced demand for cattle products, it cannot only be attributed to pasture intensification.

The resulting cropland expansion value of 0.94 ha/toe is very high compared to other studies. Due to the lack of detailed data on the effects that reduce the need for cropland expansion, this cannot be explained. The total cropland expansion value consists of separately quantified US ("domestic") and non-US ("international") cropland expansion. This is due to the fact that EPA used a combination of a model specific for the US and an international model for their calculations. For soy 53% of the expansion is domestic, 47% is international.

The GHG emission effect of cropland expansion found in the EPA study is extremely low compared to the other studies. The US model endogeneously calculates the GHG emission effect of domestic cropland expansion. For soy, negative emissions of -8 gCO_2eq/MJ are found, meaning that the land-use changes lead to carbon sequestration. The causes for this effect are unclear because they occur within the model and are not explained in detail by the authors.

The international model cannot endogeneously calculate the GHG emission effect of international cropland expansion. Therefore, satellite data is used to predict which land types are converted and Winrock coefficients for carbon stocks of these land types are used to calculate the associated emissions. Analogously, the EPA methodology takes into account the 30-year carbon sequestration provided by cropland and pasture that is abandoned from agricultural use (e.g. as a result of biofuel-induced pasture intensification). The 2007 average land cover, as determined by the same satellite data, is used as a proxy for the land type that abandoned land reverts to. No analysis is provided to test the latter assumption but it has a significant and reducing effect on the ILUC emissions value for biodiesel from soy because these two different uses of satellite data can lead to large differences between the emission/sequestration factors for converted/reverted land in the same region. For example, when 1 hectare of cropland or pasture expansion occurs in the Brazilian Amazon, it is assumed that 54% of this expansion takes place in forested areas. When 1 hectare of cropland or pasture is abandoned in the same region, 83% of it is expected to revert back to forest.

In the case of soy, a very large reduction of pasture area in the Amazon biome is found. This leads to large amounts of carbon sequestration in the Amazon. This factor, combined with the negative emissions associated with domestic land-use change, lead to a value of 43 tCO_2eq/ha, which is extremely low compared to the other studies.

As the amount of land-use change at 0.94 ha/toe is large, the total emission effect is still significant at 32 gCO_2eq/MJ biofuel using a time horizon for the emissions of 30 years.

IFPRI

No detailed intermediate results are available for the pathway-specific calculations performed by IFPRI. Therefore, no breakdown or discussion of their 75 gCO_2eq/MJ value can be provided. The exception is the projection on time horizon for the emissions at 20 years, where several of the other studies use 30 years. If a 30-year horizon were to be used, the value would be 50 gCO_2eq/MJ.

Öko-Institut/IFEU (ILUC Factor)

The methodology of the ILUC Factor is explained in detail in Section 2.5.2. It is argued there that, after choosing the same reference year 2010 and the same ILUC risk level of 50%, the crop yield is the only remaining variable.

From the results for soy, we see that the assumed crop yields from soy are lower than those of sugarcane, as the GHG emissions associated with (I)LUC are higher at 67 gCO_2eq/MJ fuel. The projection on time horizon for the emissions is 20 years, where several of the other studies use 30 years. If a 30-year horizon were to be used, the value would be 45 gCO_2eq/MJ.

Matching comparison and discussion of the reviewed studies – understanding the differences

All studies find significant GHG emissions associated with (I)LUC for biodiesl from soy, When all results are compared on a 30-year time horizon basis, they span a range of 32 – 62 gCO_2eq/MJ biodiesel fuel.

EPA finds the lowest value at 32 gCO_2eq/MJ. In a way this is remarkable, as EPA finds by far the highest number for cropland expansion at 0.94 ha/toe. This is completely compensated by the extremely low average value for emissions per hectare of cropland expansion: 43 tCO_2eq/ha. This value is largely influenced by two effects. First, a significant part of the cropland expansion occurs in the US which leads to a negative emission effect, meaning that the land-use changes lead to carbon sequestration. As this happens endogeneously in the model, its precise reason cannot be identified. In addition, international land-use change leads to a very large reduction of pasture area in the Amazon biome. The EPA methodology assumes that this area previously used as pasture will, when it is not used as cropland, largely revert to forest[30]. This leads to large amounts of carbon sequestration in the Amazon.

The values for IFPRI and the ILUC Factor are relatively close: 67 and 75 gCO_2eq/MJ with a 20-year time horizon for emissions respectively (values would be 45 and 50 gCO_2eq/MJ with a 30-year time horizon). As IFPRI provide very little detailed data on their modelling, their value cannot be explained further. The ILUC Factor again, as with sugarcane, heavily depends on the assumption of the ILUC risk level. We chose to use the medium level here.

The CARB result is a bit higher, when compared based on the 30-year time horizon, at 62 gCO_2eq/MJ. The amount of cropland expansion is about three times lower than in the EPA study (0.31 instead of 0.94 ha/toe), but the associated emissions per hectare are almost six times higher (253 instead of 43 tCO_2eq/ha). This latter fact is caused by the absence in the CARB study of the effect of pasture reduction in the Amazon found in the EPA study.

The end result of the E4tech study is in line with that of the CARB study at 66 gCO_2eq/MJ. However, this could be coincidental as E4tech assumes substitution of soy oil by palm oil and rapeseed oil and thus uses the values found for those two oils to calculate the value for soy oil.

2.5.4 Other pathways

The IFPRI study and the E4tech study have performed pathway-specific analysis for more crops than corn, sugarcane and soy. These are discussed here.

IFPRI

The IFPRI study has run pathway-specific model runs for more crops than corn, sugarcane and soy. No detailed intermediate results are available for these pathway-specific calculations performed by IFPRI. However, there are end results for GHG emissions associated with (I)LUC based on a 20-year project horizon. These are presented in Table 2 - 7.

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[30] Please refer to the detailed discussion of the EPA methodology in this section for more details on this effect.

Table 2 - 7 Results from pathway-specific model runs in the IFPRI study other than corn, sugarcane and soy.

Pathway	GHG emissions associated with (I)LUC (gCO_2eq/MJ fuel)
Ethanol from:	
Sugar beet	16
Wheat	37
Biodiesel from:	
Palm oil	50
Rapeseed oil	54
Sunflower oil	61

The lack of detailed intermediate results makes it difficult to discuss the found values. What is clear though is that sugarbeet (16 gCO_2eq/MJ) scores about equal to sugarcane (18 gCO_2eq/MJ). It is also clear that relatively high yielding crops – sugar beet, sugar cane, palm oil – score well within their respective fuel type category. Finally, in this study, ethanol pathways score significantly better than biodiesel pathways, although this can not be explained from the limited information provided.

E4tech

E4tech has done detailed additional pathway-specific causal-descriptive analysis for palm oil, wheat and rapeseed oil. The results are presented in Table 2 - 8 and then discussed per pathway.

Table 2 - 8 Pathway-specific results on GHG emissions from (I)LUC for biofuel from palm oil, wheat and rapeseed oil in the E4tech analysis. Please refer to the text for detailed discussion of these results.

E4tech	Unit	Palm oil	Wheat	Rapeseed oil
Effect of co-products as share of total emissions				
	%	50%	318%	67%
Additional demand from biofuels for energy crops results in				
Biofuel-induced agricultural intensification	%	0%	78%	25%
Reduced demand in other sectors	%	0%	0%	0%
Cropland expansion	%	100%	22%	75%
Extent of cropland expansion				
Cropland expansion	ha/toe	0.11	-0.32	0.32

E4tech	Unit	Palm oil	Wheat	Rapeseed oil
GHG effect of cropland expansion				
Weighted average of emissions from crop expansion[31]	tCO2eq/ha	834	107	101
Project horizon for emissions from (I)LUC	Years	30	30	30
Emissions from (I)LUC	gCO_2eq/MJ fuel	81	-36	17
Emissions from (I)LUC (assuming a standardized project horizon of 20 years; for comparison only)	gCO_2eq/MJ fuel	122	-54	26

Palm oil

[We reviewed scenario 4 of the palm oil scenarios of E4Tech, please refer to Section 2.4 for details.]

E4tech assumes that all palm oil used for biofuels will lead to additional palm oil production, as palm oil is currently the cheapest vegetable oil on the market. This expansion is assumed to take place in regions that are currently already producers of palm oil: mainly Indonesia and Malaysia. No biofuel induced agricultural intensification is foreseen based on expert opinions by stakeholders.

The palm oil is found to have a strong co-product effect, that compensates for 50% of the emissions of palm expansion. The main driver for this is that E4tech assumes that the co-product palm kernel oil will displace low yield coconut oil. Unfortunately, this is not readily supported by historic data, as we explain in Section 2.6.4.

This large co-product effect, combined with the high yield of oil palms, leads to a relatively low cropland expansion of 0.11 ha/toe. However, as this expansion takes place in Indonesia and Malaysia, including significant amounts of forested land as well as peatland, the emissions associated with this expansion are extremely high at 947 tCO_2eq/ha. This is partially caused by the fact that the scenario reviewed by us includes 33% of expansion on peatland, which has very high carbon stocks. This causes the resulting (I)LUC emissions to be high at 81 gCO_2eq/MJ.

Wheat

[We reviewed scenario 4 of the wheat scenarios of E4Tech, please refer to Section 2.4 for details.]

In most E4tech scenarios, including the one reviewed by us, 78% of the wheat needed for biofuels comes from additional yield increases, not requiring any additional land. This is the results of the use of the Lywood (2009a) method, discussed further in Section 2.6.1. Any additional fertiliser emissions needed for these yield increases are not included in the calculations. This is discussed in more detail in section 2.6.2.

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[31] The values in this row are for the actual expansion of the main crop considered and exclude any influence of the co-products. When these are taken into account, values are: 956, 144 and 69 tCO_2eq/ha respectively.

The remaining 22% of the wheat needed for biofuels is met by extra land use for wheat production in the EU. This is assumed to lead to avoided abandoning of cropland in the EU with no impacts outside the EU. We critically discuss this assumption in Section 2.6.5. The yields assumed for wheat on this otherwise abandoned cropland are assumed to be the EU average. Section 2.6.6 discusses this assumption and its effects in more detail.

Furthermore, this cropland expansion on otherwise abandoned land leads to low emissions as the avoided reversion of cropland to natural land has low associated foregone carbon sequestration. This is partially caused by an error in the underlying carbon stock data used in the study, as discussed in Section 2.6.7.

Finally, the high yielding wheat also produces significant amounts of DDGS co-product which is assumed to be used as animal feed. DDGS is assumed to replace significant amounts of soy meal, leading to avoided conversion of natural land to low yield soybean cropping in South America. This avoided soy area expansion more than compensates for any wheat area expansion in the EU, leading to a net area reduction of -0.32 ha/toe. (Note that this is party explained by the fact that only 22% of the wheat for biofuels causes additional land to be taken into wheat production, the other 78% of the wheat comes from biofuel induced yield increases.) At the same time, emission savings due to avoided conversion of natural land to soy cropland in South America are relatively high, as this concerns land with relatively high carbon stocks. This leads to a very high co-product credit of 318% for wheat ethanol. Please refer to Section 2.6.3 for more discussion on this.

The resulting total (I)LUC emissions for ethanol from wheat are thus negative: -36 gCO_2eq/MJ. In interpreting this value, it should be noted that all assumptions critically discussed in Sections 2.6.1-2.6.7 have a reducing effect on the (I)LUC emissions for ethanol from wheat as noted in the text above. In the other wheat to ethanol scenarios analysed by E4tech some of these assumptions have been varied, but in each scenario only one of the assumptions is varied. Therefore, while most of these scenarios find a higher ILUC value than scenario 4, none of them gives an indication of the ILUC value in which all issues described in section 2.6 are taken into account.

Rapeseed oil

[We reviewed scenario 1 of the rapeseed oil scenarios of E4Tech, please refer to Section 2.4 for details.]

Rapeseed oil use for biofuels is assumed to be met by extra production in the EU first. As no biofuel induced yield increases are foreseen in the EU, this is assumed to lead a chain of agricultural displacement events, ultimately leading to avoided abandoning of EU cropland compared to the baseline scenario. As with wheat, this is subject to the considerations in Section 2.6.5 and 2.6.6. However, E4tech finds an insufficient land availability in the EU to produce all needed rapeseed. Therefore EU imports of rapeseed from the Ukraine are increased.

The additional demand for rapeseed from Ukraine leads to significant biofuel induced yield increase in the Ukraine: 25% of the total biofuel demand for rapeseed. We discuss this in Section 2.6.1. The remaining demand is met by area expansion of rapeseed in the Ukraine on natural land.

This extra land use for rapeseed in the EU and the Ukraine are compensated by the fact that the co-product rapeseed meal is used as animal feed. As with wheat DDGS this leads to avoided conversion of natural land to low yield soybean cropping in South America. This leads to a large co-product credit of 67% for rapeseed. Please refer to Section 2.6.3 for more discussion.

Even though there is a large co-product credit, the low (biofuel) yields of rapeseed still lead to a net area expansion of 0.32 ha/toe. However, the emissions associated with this LUC are found to be low: 69 tCO_2eq/ha. As with wheat this low number is the result of an error in the underlying carbon stock data used by E4tech, see Section 2.6.7.

The resulting total (I)LUC emissions for biodiesel from rapeseed oil are 17 gCO_2eq/MJ. In interpreting this value, it should be noted that all assumptions critically discussed in Sections 2.6.1-2.6.7 have a decreasing effect on the (I)LUC emissions for biodiesel from rapeseed as noted in the text above. In the other rapeseed to biodiesel scenarios analysed by E4tech some of these assumptions have been varied, but in each scenario only one of the assumptions is varied. Therefore, while most of these scenarios find a higher ILUC value than scenario 1, none of them gives an indication of the ILUC value in which all issues described in section 2.6 are taken into account.

Comparison of IFPRI and E4tech results

Unfortunately it is not possible to compare the IFPRI and E4tech results for biofuel from palm oil, wheat and rapeseed oil in detail, as the IFPRI study does not provide the necessary detail.

2.6 Discussion on key assumptions in E4tech-study

One of the key benefits of the causal descriptive ILUC modelling performed by E4tech is its transparency. Almost all key assumptions are documented in the report, making it transparent how the various ILUC numbers were obtained. This is in sharp contrast to most agro-economic equilibrium models, in which assumptions on key parameters are often hidden in the mathematical functions of the model where they are usually invisible to people other than the modellers.

The transparency of the E4tech study allowed this review to reflect on some of the key assumptions made in that study in more detail, which we have done in this section. In general, the comments we make with respect to these assumptions should not be taken as a weakness of the study relative to the studies based on agro-economic equilibrium models as the lack of transparency in these models did not permit a fair comparison within the scope of this report.

The next sections describe the key assumptions made in the E4tech scenarios reviewed by us in more detail. In their study, E4tech analysed different scenarios with different assumptions to assess the impact of variations in assumptions on the end result. As explained in Section 2.4, we chose the E4tech scenario with the most common denominators in its assumptions for our review. Where relevant, we discuss the results of the variations in the assumptions in these scenarios in this section.

In discussing the assumptions, we have tried to, where relevant, indicate: whether the assumption on a parameter is in line with historical developments for that parameter[32]; whether the assumption is significantly different from historical developments and what reasons are given for that in the report; or whether the assumption is based on an error in the report or the underlying data.

2.6.1 Demand induced yield increases

Why it matters - *optimistic assumption.* All biofuel demand that can be met through an additional increase in yields, that results from the additional demand for biofuel feedstock, does not require additional land and therefore does not cause land use change. Therefore, the size of the demand induced yield increase is a key parameter in any ILUC study. This is also discussed in Section 2.3.

Assumption in E4tech scenario analysed in this report: for most crop-scenarios the E4-tech study based their assumptions on a paper by Lywood (2009a) which establishes a relationship between output growth and yield and area growth. This leads to a very large demand-induced yield increases for especially EU wheat, and to a lesser extent for sugarcane and Ukrainian rapeseed. For wheat, 78% of total biofuel demand is met by additional yield increases in the scenario reviewed by us.

Discussion: the wheat-yield growth numbers resulting from the assumption in E4tech (2010) for EU crops are very high compared to wheat-yield growth numbers in the EU since 1990. Scenarios 4-8 for wheat in E4tech (2010) assume an annual yield increase of 1.35% between 2008 and 2020. It is furthermore assumed that two-thirds of this is caused by the increased biofuel demand (without the biofuel demand, the yield is assumed to grow by only around 0.45% annually). For comparison, the actual annual yield growth in the EU-27 between 1990 and 2009 was 0.7%. Between 1999 and 2009 it was 1.0%. In summary, for EU wheat E4tech (2010) assumes a future annual yield growth that is significantly higher than it has been in the last 10 to 20 years and attributes the majority of it to the increased biofuel demand. This results in the

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[32] All historical numbers on yields, area and production are from FAOSTAT unless otherwise stated.

assumption that 78% of all additional wheat needed for biofuel is met by additional yield increase (and therefore has zero land use impacts). A lower demand induced yield increase would lead to more LUC and therefore a higher ILUC value. This is explored in scenario 3 of the E4tech wheat analysis. In that case, with the lower yield effect being the only difference compared to the scenario reviewed by us, the resulting GHG emissions are 31 $gCO2_{eq}$/MJ fuel higher.

It is worth noting that the high yield growth prediction in E4tech (2010) compared to historic numbers cannot be explained by a stronger growth in production in 2008-2020 compared to historic growth in production. Annual growth in EU-27 wheat production in scenarios 4-8 in E4tech (2010) amounts to 1.1%, the same as the actual average annual production growth in EU-27 wheat production realized between 1990 and 2009.

The assumed yield growth for Ukrainian rapeseed and Brazilian sugarcane are in line with historical yield growth numbers but what stands out is that the vast majority of the yield increase is assumed to be driven by the additional biofuel demand. For Brazilian sugarcane, 67% of total yield growth between 2008 and 2020 is assumed to be the result of additional biofuel demand. In other words, without this additional biofuel demand yields would grow only a third of what they do in the biofuel scenario. The same number for rapeseed from Ukraine is even higher, at 93%. What is remarkable about the rapeseed number is that in de baseline production is increasing by 3.2% annually and yields only grow 0.2% annually, a ratio of 0.2:3.2 = 0.08. In the biofuel scenario the yield suddenly grows 12 times faster, at 2.9% annually. While the growth in production is also stronger in the biofuel scenario, 8.6% annually, the ratio of growth in yield to growth in production now is 2.9:8.6 = 0.34. In other words, in the biofuel scenario yields respond more than four times as strong to growth in production than in the baseline scenario.

2.6.2 Emissions from additional fertilizer

Why it matters – *optimistic assumption***.** In E4tech (2010) the additional feedstock for biofuels partly comes from additional yield increases. Especially for wheat this fraction is very high: 78% of the wheat for ethanol stems from additional yield increases. Some parties have argued that such yield increases will, at least in part, stem from additional nitrogen fertilizer application and that this will therefore increase GHG emissions from fertilizer production and application.

Assumption in E4tech-study: E4tech (2010) does not take into account GHG-emission from additional fertilizer. (Note that most of the reviewed studies do not take this into account). The argumentation given for this is that a) not all yield increases will stem from increased fertilizer usage and b) emissions from additional fertilizer are not expected to change the order of magnitude of ILUC emissions. The latter is illustrated with a simple calculation of the rough size of such emission for wheat ethanol, which they estimate to be 8.9 gCO_2/MJ ethanol.

Discussion: with respect to a) it seems plausible that certainly not all yield increases will stem from additional fertilizer application. However, with respect to b) E4tech base their conclusion on the size of emissions from additional fertilizer on a calculation based on rough assumptions on the effect of additional fertilizer on yields. Based on these assumptions E4tech (2010) finds a maximum value of 8.9 gCO_2/MJ ethanol. Using the same assumptions we find a maximum value of 12.9 gCO_2/MJ ethanol. As further explained in Appendix A, the difference is due to the fact that E4Tech (2010) allocates the additional N-fertilizer emissions to *all* EU-wheat ethanol instead of to the *additional* wheat ethanol resulting from demand-induced yield increase.

The underlying assumption used in E4tech's calculation is that a 10% increase in N-fertilizer in the UK would increase wheat yields by 0.5 t/ha. No reference is provided for this. A report by the UK HGCA (HGCA, 2007) shows a much higher increase in fertilizer needed to increase UK wheat yields by 0.5 t/ha, around 35%. Applying these numbers leads to 106 gCO_2/MJ ethanol resulting from additional fertilizer to achieve the higher yields: a number 12 times larger than the number given by E4tech. Therefore, the number of 8.9 gCO_2/MJ ethanol appears to be the result of a combination of 1) an optimistic assumption on wheat yield responses to higher N-fertiliser inputs and 2) an optimistic assumption on the allocation of the emission to the additional wheat-ethanol produced. This is discussed in more detail in Appendix A. The higher number of 106 gCO_2/MJ ethanol mentioned above surely is an overestimate of the actual emissions from the additional yield increase, as not all yield increase will come from increased N-fertilizer application, but it shows these emissions could be significantly larger than 8.9 g CO_2/MJ ethanol.

2.6.3 The role of co-products – DDGS and rapeseed meal

Why it matters – *optimistic assumption.* Additional availability of co-products from biofuel production reduces the demand for the products that are replaced by these co-products. The reduction in land needed to grow these replaced products depends on what product is replaced and at what yields.

Assumptions in E4tech scenario analysed in this report: the E4-tech study based their assumptions on a paper by Lywood (2009b). What stands out compared to other ILUC studies is the high proportion of soy meal replaced by especially rapeseed meal and wheat DDGS: every ton of DDGS or rapeseed meal replaces 0.6 ton of soy meal[33]. Because of the low yields of soy and the deforestation in South America connected to it, replacing soy meal results in a very large carbon credit. A lower soy meal replacement rate is explored in scenario 5 of the E4tech rapeseed oil analysis. In that case, with the lower replacement rates being the only difference compared to the

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[33] For both wheat and rapeseed, one scenario is included in which only 50% of the DDGS or rapeseed meal is used to replace other products. This significantly increases the iluc numbers for wheat-ethanol and rapeseed-biodiesel.

scenario reviewed by us, the resulting GHG emissions are 11 $gCO2_{eq}$/MJ fuel higher. In the wheat analysis, no variation of soy meal replacement rates was analysed.

Because less soy is produced, less soy oil is produced as well. E4tech (2010) assumes this is compensated by an increase in palm oil production. The GHG effect associated with this increase is calculated from one of the palm oil scenarios calculated by E4tech. It is worth noting that the outcome of the chosen palm oil scenario is in the low end of the range found for indirect palm oil emissions, as this scenario considers only 5% expansion on peatland.

Discussion on soy meal replacement: the replacement ratio of 0.6 ton of soy meal per ton of DDGS or rapeseed meal is high compared to some other ILUC studies. E.g. CARB assumes that DDGS from corn only replaces corn, not soy meal. However, there are significant differences between the US feed market and the EU feed market that can explain different values for the two markets. Also, the values used in E4tech (2010) are within the range given by Croezen et al. (2008).

Discussion on soy oil compensation by palm oil

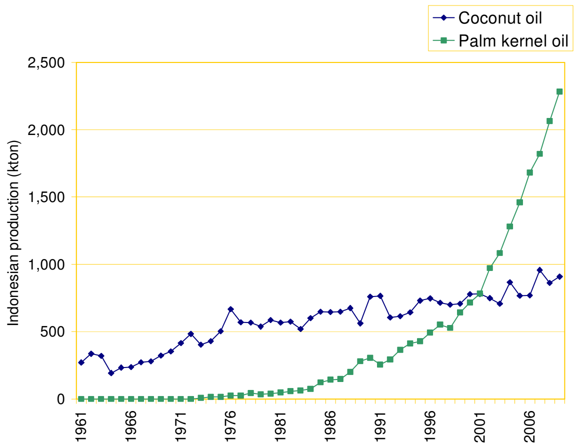
The chosen scenario for substitution by palm oil assumes that only 5% of the palm oil produced to compensate for the reduction in soy oil production comes from peatland. This 5% is low compared to numbers cited by peatland experts after the E4tech study was completed. The University of Leicester (2010) estimates that current palm plantations on peatland already make up 30% of total planted area and that this number will be higher for new plantations. These observations are also in line with recent satellite findings by Sarvision (2011). As illustrated by palm oil scenarios 3 and 4 in the E4tech study, increasing the percentage of palm on peat from 5% to 33% increases palm oil iluc emissions by around 130%.

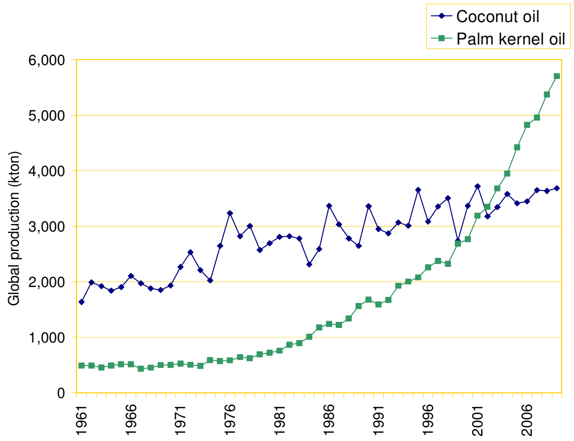
2.6.4 The role of co-products – Palm kernel oil

Assumption in E4tech-study – *optimistic assumption.* E4tech (2010) assumes that the co-product from palm oil production, palm kernel oil (PKO), will replace coconut oil. This assumption clearly impacts the ILUC number for biodiesel from palm oil, but it also impacts biodiesel from rapeseed and soy, and ethanol from wheat (because the co-products of these biofuels replace soy, leading to less soy oil production, which is then compensated by an increase in palm oil production.)

Discussion: the assumption that PKO replaces coconut oil has a very significant positive effect. This is caused by the low yield of coconut oil. This can be seen in figure 9 of E4tech (2010) (p. 47) where the credit for avoided coconut oil production makes up for half the total carbon footprint of palm oil production. This is remarkable as for every ton of palm oil, only around 0.12 ton of PKO are produced. Furthermore, the assumption that increased PKO production in Indonesia would lead to a reduced growth in Indonesian coconut oil production is not supported by historic figures.

As can be seen from the figure below, growth in Indonesian coconut oil has been relatively stable since the 70s. Indonesian PKO production was all but non-existent until the mid 80s when it took off to become more than three times as large as coconut oil production today. Global numbers show a similar development. These numbers illustrate that it is unlikely that PKO replaces large amounts of coconut oil. If they would, the very strong historic growth in PKO production would have had a more pronounced effect on historic coconut oil production. A smaller land credit for PKO would lead to higher ILUC for palm oil, and therefore higher ILUC for biodiesel from palm oil, but also for biodiesel from rapeseed and soy as well as ethanol from wheat as explained above.





2.6.5 Area expansion in EU takes place on abandoned cropland

Why it matters - *optimistic assumption.* The type and the location of land on which expansion for biofuel crops take place has an effect on the carbon emissions this causes. E.g. an expansion on abandoned cropland in the EU will cause lower LUC emissions than an expansion on forested area in tropical regions. This is caused by two elements. First, the carbon stock per hectare differs for different land types. Second, yield will differ per location and this determines the amount of hectares needed to grow the required quantities of crop.

Assumptions in E4tech scenario analysed in this report:

- E4tech (2010) assumes that the additional EU-wheat area and the additional EU-rapeseed area[34] needed for biofuels would not lead to new land being converted to cropland, but to less land being abandoned in the EU compared to the baseline scenario[35]. This is primarily explained by the assumption that in the baseline the

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[34] Note that part of the additional rapeseed is assumed to be imported from Ukraine, where it does lead to a cropland expansion.

[35] Note that in wheat scenario 3 a small variation to this assumption is studied by E4tech. In this scenario, 85% of additional EU wheat area is still realised on otherwise abandonned cropland, but in this scenario 15% of the total increase in EU wheat area compared to the baseline takes place "new" cropland. While scenario 3 finds a significantly higher ILUC number than most other wheat scnearios, this should largely be

total area used for wheat cultivation is decreasing by 2.2 Mha between 2008 and 2020.

- In addition, it is acknowledged that the area no longer used for wheat cultivation in the baseline would not actually be abandoned but would be used for other crops as wheat is typically grown on good agricultural land. It is then assumed that this land would have been used by other crops in the baseline, but by wheat and/or rapeseed in the biofuel scenarios. It is finally assumed that the additional wheat and/or rapeseed in the biofuel scenario will displace these other crops to other areas within the EU and that the area that they are displaced to is of a similar size as the area they are displaced from (now used for wheat and/or rapeseed).

Discussion:

- The fact that the EU wheat area declines by 2.2 Mha between 2008 and 2020 in the baseline in E4tech (2010) is the result of an explicit assumption on the baseline. The baseline in E4tech (2010) is based on predictions by FAPRI (2009) but all feedstock produced for biofuels beyond the 2008 levels are taken out in the baseline. This includes EU 1.4 Mha of wheat for biofuels in the EU.[36] Thereby, E4tech (2010) implicitly assumes that the decline in the EU wheat area in the baseline, which is the result of a modification to the actual IFPRI scenario, automatically translates into a similarly sized decline in EU-cropland. However, it is also possible that (part of) the area no longer used for wheat would have been used for an increase in the area used for another crop. (Note in this respect that E4tech (2010) also assumes a 1.2 Mha increase in EU rapeseed between 2008 and 2020.) In that case, (part of) the land would not have been abandoned and (part of) the additional wheat/rapeseed area for biofuels would either have to come from an expansion in cropland in the EU or will displace other crops that will then have to be produced outside the EU (where yields may be lower, leading to more LUC, and where carbon stocks may also be higher, leading to higher emissions per hectare). This would likely to lead to higher ILUC emissions for ethanol from wheat and biodiesel from rapeseed.
- E4tech (2010) argues that, in the baseline, the land that is taken out of wheat production is not expected to be abandoned but used for other crops because wheat is typically grown on high quality agricultural land. However, this seems to contradict with the assumption in E4tech 2010 stated above: that if a certain size area is *not* taken out of wheat production in the biofuel scenario, this would lead to a similar size of land not being abandoned somewhere else in the EU (because the crops that would have taken the place of wheat in the baseline scenario, because of which land would have been abandoned elsewhere in the EU, now still

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attributed to the lower yield increase assumption compared to other scenarios. The effect of having 15% of wheat expansion for biofuels on "new" cropland in stead of otherwise abandonned cropland, keeping everying else constant, has not been quantified. No scenarios are included in E4tech in which (part of) the wheat expansion displaces EU exports, possibly leading to cropland expansion outside the EU.

[36] FAPRI predicted only a reduction of around 0.8 Mha in EU wheat by 2020 compared to 2.2 in the E4tech (2010) baseline.

need to be produced elsewhere in the EU). This latter assumption assumes that the yields of these other crops would have been the same on the high quality land used for wheat as on the land on which they would have otherwise been grown. This contradicts with the statement that taking an area out of wheat production does not cause that land to be abandoned because the quality of the land is so good that other crops will move onto that good land. If yields of such other crops are indeed lower on the areas they are displaced to if the good land is used for wheat for biofuels, the total amount of cropland not being abandoned in the EU in the biofuels scenario is larger than the area used for wheat or rapeseed production for biofuels. This would increase the total LUC for biofuels from EU wheat and EU rapeseed as well as the associated emissions from LUC.

2.6.6 Yield on abandoned agricultural land

Why it matters – *optimistic assumption.* If new land is taken into production for biofuel feedstock production, the amount of land needed for this depends on the yields on that land. There has been debate on weather yields on land that are taken into production in the future will be lower than the average yield. Some parties have argued that this would be likely as the best land is already in use. As E4tech (2010) discusses, other parties have argued that this depends very much on the region and crop considered.

Assumption in E4tech-study: E4tech (2010) assume average yields on lands taken into production in the future and they state various reasons for this. Our focus here is on the assumption that yields on *abandoned* agricultural land are also equal to the average yields. This is relevant primarily for the EU crops wheat and rapeseed which E4tech (2010) assumes to be grown on abandoned agricultural land in the EU (or land that would have stopped growing the wheat in the absence of biofuel demand) and for which they assume the yields to be equal to the average yields.

Discussion: the assumption that for a certain crop the yields on abandoned agricultural land in the EU-27 are equal to the average yields of that crop in the EU-27 seems to be contradicted by the following observations:

- Between 1999 and 2008 11 countries in the EU-27 saw their wheat area decline by a total of 1.6 Mha (other countries showed an increase in wheat area.) The average 2007-2009 yields of wheat in these countries, weighted by the size of the abandoned wheat area in each country, amounts to 4.2 t/ha. The EU-27 average wheat yield in 2007-2009 was 5.3 t/ha. This implies that, even if the yields on the abandoned areas where the same as the *national* average, the average yield on the land that was taken out of wheat production between 1998 and 2008 was 22% lower than the EU-27 average EU wheat yield.
- Yields within a country show a certain range due to varying qualities of land within a country. Since yields are a key determinant of profitability of wheat production it is expected that "land in low yielding regions is likely to go out of production sooner than in higher yielding regions." (University of Cambridge, 2006). This

would mean that the difference between the average EU-27 wheat yields and the yields on abandoned land is even larger than the above mentioned 22%.

- Finally, there are also yield differences between the various fields within a single farm. A farm survey in the UK showed the wheat yields on the worst fields of a farm, where 37% lower than the average wheat yields on that farm. (Defra xx).

Combined, the three effects discussed above imply that the yields on abandoned cropland in the EU could be significantly lower than the average yields in the EU. in that case the amount of (I)LUC and the associated emissions would increase for both biodiesel from rapeseed and ethanol from wheat.

2.6.7 Forest reversion and carbon sequestration in the EU

Why it matters – *error in underlying data.* In E4tech (2010) most of the cropland expansion for additional wheat and rapeseed for biofuels is assumed to come from EU cropland. It is assumed that this leads to a reduction in the amount of cropland abandoned in the EU by 2020. To determine the GHG-effects of this, the relevant question is what the carbon stock on this land would have been if the land would indeed have been taken out of cropland use.

Assumption in E4tech-study: E4tech (2010) uses the Winrock data prepared for the EPA for RFS-2 on land conversion (for cropland expansion) and land reversion (for abandoned cropland) as well as Winrock data on the carbon stocks on the various land types that abandoned cropland in the EU would revert to. The same numbers are used by several of the other studies reviewed in this report, namely RFS-2 and IFPRI.

Discussion: the Winrock numbers used in E4tech (2010) for carbon sequestered in abandoned cropland that reverts back to forest contain an error. The number for carbon stored in biomass on land reverting back to forest was accidentally set to zero for the first 20 years. The carbon sequestration in biomass for land reverting to forest in the US is 9 t CO2/ha/y. Using the same number for the EU, the average carbon sequestration on abandoned cropland that would revert back to forest increases from 29 t C/ha to 78 t C/ha. Because only 34% of abandoned cropland is assumed to revert back to forest, the average carbon sequestration on abandoned cropland increases somewhat less, from 29 t C/ha to 51 t C/ha. Nonetheless, this still means that the total emissions from land use change inside the EU increase by 75%[37]. This increases the ILUC number for rapeseed-biodiesel by 25 gCO_2/MJ and the ILUC number for wheat-ethanol by 13 gCO2/MJ in the scenarios analysed in this report. The smaller increase for wheat is explained by the fact that 78% of the wheat for biofuel is assumed to come from additional yield increases, and the higher carbon stock numbers therefore only affect 22% of the wheat for ethanol.

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[37] Note that the total ILUC number for rapeseed-biodiesel and wheat-ethanol is determined by more factors than emissions from LUC in the EU alone.

In addition to the above error some parties have commented that care must be taken in interpreting the Winrock numbers when determining the fraction of abandoned land that will revert to forest, or the number may be underestimated. The reason for this is that the analysis of Winrock is based on satellite images from 2001 and 2007 and that land that was cropland in 2001 and abandoned after 2001 will often not show up as forest yet on the satellite image of 2007 but rather as one of the 'intermediary' land types such as "grassland", "mixed", "savannah" or "shrub land". It has been argued that some of the abandoned cropland that reverted to one of these intermediary land types by 2007 would still revert to forest but would simply need more time for this, especially if the cropland was abandoned close to 2007. If this is correct, the actual foregone carbon sequestration, as a result of additional demand for rapeseed or wheat, would be higher.

2.6.8 Carbon stocks losses from conversion to pasture in Brazil

Assumption in E4tech-study - *error in Brazilian sugarcane scenarios.* E4tech (2010) studied various scenarios for Brazilian sugarcane in which different assumptions are made on the knock-on effect of sugarcane displacing cattle. In the scenario reviewed in this report (scenario 7), 1.0 ha of pasture displaced by sugarcane leads to 0.84 ha of pasture expansion elsewhere in Brazil. Because most of the pasture expansion takes place in the north of Brazil, E4tech intended to use carbon stock numbers for the north of Brazil as described on page 130 of E4tech (2010). However, accidentally the wrong carbon stock numbers were used – those for the average of entire Brazil, not specifically for the north of Brazil.

Discussion: the error in the sugarcane scenarios means that the average carbon stock loss for lands converted to pasture, as a result of sugarcane expansion on pasture lands, should be 91 t C/ ha in stead of 56 t C / ha, a 62% increase. Correcting for this error results in a 50% increase in the ILUC emissions from Brazilian sugarcane. Because not all sugarcane ethanol comes from Brazil in the E4tech scenarios, the effect on the average ILUC emissions from sugarcane ethanol are smaller: between 3 and 10 gCO_2/MJ depending on the scenario according to the authors.

2.6.9 Conclusion - impacts of assumptions in E4tech study on various crops

The points raised above with respect to some of the key assumptions in the E4tech study have different impacts on different biofuel pathways, as illustrated in the table below. In many cases these impacts are associated with the main crop considered, but in some cases the effect takes place through the calculated co-product credit. The biofuel pathways that are most affected are wheat ethanol and rapeseed biodiesel as all the above raised points, except the last one, have an effect on these pathways.

It should be noted again that the E4tech study analysed several scenarios for each crop and that some of the assumptions critically discussed here have been varied in other scenarios. However, in doing so only one of the assumptions is varied each time, and some of the above discussed assumptions or errors have not been varied in other scenarios. Therefore, these alternative scenarios do not give an indication of what the ILUC value would be if all the above issues are taken into account.

Table 2 - 9 Overview of the issues identified in the reviewed E4tech scenarios and the crops for which they impact on the ILUC value.

Assumption	Biodiesel			Ethanol	
	PO	SO	RO	Wheat	SC
Demand induced yield increase		X	X	X	X
Emissions from additional fertilizer		X	X	X	X
Co-products: role of DDGS and rapeseed meal			X	X	
Co-products: PKO replaces coconut oil	X	X	X	X	
EU area expansion on abandoned cropland			X	X	
Yields on abandoned cropland			X	X	
C-sequestering on abandoned EU cropland			X	X	
C-stock losses from conversion to pasture					X

2.7 Conclusion

We reviewed the quantification of pathway-specific indirect effects of biofuel production for biofuel from corn, sugarcane, soy and other feedstocks using seven studies.

Within each pathway, there is no clear consensus on the size of total emissions from direct and indirect land-use change. A slight trend can be seen where sugarcane generally has the lowest emissions from land-use change (4-46 gCO_2eq/MJ), followed by corn (27-103 gCO_2eq/MJ, with the second highest value being 54 gCO_2eq/MJ), followed by soy (32-75 gCO_2eq/MJ). In the other pathways, a similar trend is visible: ethanol pathways score better than biodiesel pathways. However, due to the large ranges in the results it would be premature to draw firm conclusions, based on the studies reviewed in this report, on the (I)LUC from ethanol versus biodiesel.

While the results vary per study, most studies find the emissions for most pathways to be significant when compared to e.g. a fossil reference value of 80-90 gCO_2eq/MJ fuel. An exception to this rule is the ethanol from wheat scenario in the E4tech study, that finds negative (I)LUC emissions. However, the assumptions and error made in that scenario (see Section 2.5.4 for details) were critically discussed in Section 2.6 of this review.

But even when studies find comparable numbers this does not always imply they share a common understanding of ILUC: there may simply be various differences in the intermediate outcomes that cancel each other out. For example, EPA and CARB find comparable numbers for ethanol from US corn while they differ markedly in their findings on the amount of (I)LUC and the GHG emissions per unit of (I)LUC. This illustrates the importance of looking at the underlying numbers in addition to the end results.

The differences between specific studies within a certain pathway can be made reasonably clear by our framework for quantitative comparison of the intermediate results. In many instances the data to derive these intermediate results are not available and, more importantly, a clear explanation of the causes of the found differences is not given by the authors. Sometimes these data are in principle available, but are not reported in the studies presented by the quantification initiatives. In other instances, the data cannot be extracted from the quantification at all, mostly due to the complex setup of the models and methodologies used. An exception to this rule was the E4tech study which contained a very transparent and well documented causal-descriptive approach. However, in general, a more comprehensive documentation of assumptions and intermediary results would allow for a more detailed comparison between models, their similarities and differences.

Box 2: ILUC impacts on biodiversity

All studies reviewed in this report focus on the GHG emissions from (I)LUC resulting from an additional demand for biofuels. None of the studies includes a detailed analysis of the impacts of (I)LUC on biodiversity. However, as explained in Section 2.2.1 indications on the impacts on biodiversity are available from the existing studies. After all, all of the reviewed studies, except the ILUC-factor from the Öko -Institute, provide the following information:

- The amount of (I)LUC that takes place, usually on a country/region level (step 2 in the 4-step process described in Section 2.2.1). This information is summarised for each crop in each study in the tables of Section 2.5 in ha/toe.
- The type of land converted as a result of (I)LUC (step 3 in the 4-step process described in Section 2.2.1. Combined with the information on the country/region where the (I)LUC takes place, this provides information on the type of biome or ecosystem that is converted.

Therefore, even though the reviewed studies did not explicitly analyse the impacts on biodiversity, they contain valuable information on the potential biodiversity impacts of additional biofuel demand.

Another indication of the impacts on biodiversity of additional biofuel demand is given by the recent "Rethinking Global Biodiversity Strategies" (PBL 2010). While this study is not specifically focussed on the impacts of biofuels or bioenergy it does find in its results that increasing the amount of bioenergy, without additional measures to minimise impacts on biodiversity, has a negative impact on global biodiversity by 2050 even if it reduces global warming. Interestingly the study also finds that if additional measures are taken alongside bioenergy, such as additional yield increases, the total impacts on biodiversity are positive.

To increase the understanding of the impacts of biofuels on biodiversity, it is recommended that future biofuel/bioenergy (I)LUC studies attempt to quantify these biodiversity impacts next to the impacts on GHG emissions.

3 Mitigation of unwanted indirect effects

The previous chapters focused on the quantification of indirect effects of bioenergy production. This chapter focuses on how unwanted indirect effects can be prevented. It will be argued that different but complimentary solutions are needed for the short and long term respectively. Surprisingly, most work on ILUC continues to focus on a quantification of the effects, with still relatively little attention to concrete mitigation options. The few mitigation options that have been developed, or are under development, are discussed.

3.1 Possible ways to mitigate unwanted indirect effects from bioenergy

3.1.1 The bigger picture: Global versus project-level mitigation measures

In theory, three types of mitigation measures are available to prevent or minimise unwanted indirect effects from bioenergy. The first two concern global mitigation measures, while the third describes project-level mitigation measures:

1. *Prevent unwanted direct LUC, globally and for all sectors.* Unwanted ILUC from bioenergy manifests itself through unwanted direct LUC for the production of agricultural products for other sectors such as the food and feed sectors. Preventing unwanted direct LUC, for example through better land-use planning and corresponding enforcement, would thus eliminate unwanted ILUC altogether. Note that because of the international characteristics of ILUC and the competition for land between different sectors, this mitigation measure requires global implementation for all land-based sectors to be effective. While a worthy mitigation measure for the longer term, this mitigation measure is unlikely to materialise fully in the short to medium term and is largely outside of the influence of the bioenergy sector.
2. *Reduce pressure on land from the agricultural sector as a whole* by increasing yields, supply chain efficiencies and/or a reduction in consumption, for example through increased R&D. This could reduce the need for expanding the area used for agricultural production. However, a globally constant or shrinking agricultural area alone does not necessarily prevent unwanted LUC. Shifts in land used for agricultural production (without a net increase in the total area) can still cause unwanted LUC. Also, this mitigation measure is unlikely to materialise sufficiently in the near future, with projections from leading agricultural institutions indicating an expanding agricultural area during the next decades. Also this option lies largely outside of the influence of the bioenergy sector.
3. *Practical production models that prevent indirect impacts at a project level.* While the other two mitigation measures take a more macro approach (in which governments will be key actors) this approach focuses on the role individual producers – acting alone or in cooperation with others inside or outside of the bioenergy sector – can play (in the absence of the above two mitigation

measures). This includes mitigation measures such as the much debated production on "unused land". Such mitigation measures are able to lend themselves to a certification approach as they focus on individual producers.

3.1.2 What individual producers can do to prevent unwanted indirect effects

Four main solutions have been put forward for producers to expand biomass usage for energy purposes without causing unwanted indirect effects (Ecofys 2007a, Ecofys 2008, Ecofys, 2009, RFA 2008):

1. Biomass production on "*unused land*" – land that does not provide provisioning services[38,39]. Because this does not displace other human uses of the land, it does not cause any indirect effects. Clearly, expanding production on unused land does lead to a direct LUC. The big advantage is that direct LUC is controllable (e.g. through certification) and can be limited to those areas where effects are acceptable, while the effects of indirect LUC are largely uncontrollable[40].
2. Introducing energy crop cultivation without displacing the original land use through *increased land productivity or integration models*. Especially in developing countries there is a significant potential for yield improvements. Potential negative environmental or social impacts from intensification models have to be taken into consideration for this type of solution. Note that integration models can stretch beyond the scale of individual farms, for example when bagasse from sugarcane is used to feed cattle of surrounding cattle farmers.
3. Bioenergy production from *residues*. Current functions and uses of these residues must be well understood, otherwise displacement, and the associated indirect effects, may still occur.
4. Bioenergy production from *aquatic biomass* such as algae currently not used for other purposes. Specific sustainability aspects for such production would need to be taken into account.

3.2 Summary of existing mitigation initiatives

This section gives a summary of the existing mitigation initiatives for unwanted indirect effects of bioenergy production. First, the two main characteristics on which each initiative is analysed are presented. Then, a table gives a summary of the various initiatives and provides an initial analysis on the two main characteristics. In sections 3.3 through 3.6 the individual initiatives are analyzed in detail on a number of important characteristics.

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[38] The Millennium Ecosystem Assessment distinguishes four categories of ecosystem services: Provisioning services, regulation services, cultural services and supporting services. Provisioning services are defined as harvestable goods such as fish, timber, bush meat, genetic material, etc.

[39] Also referred to as "degraded land", "marginal land", "waste land" or "abandoned land".

[40] Often an area is not completely "unused" and a sliding scale exists between this "unused land" concept with the "intensification" concept, see next bullet.

3.2.1 Main characteristics used in analysis of mitigation initiatives

- Scope: Is the measure focused on GHG effects only or also on other measures such as biodiversity and food consumption?
- Behavioural change: Does the measure provide concrete incentives for behavioural change by the actors involved in biofuel production and consumption? This can be relevant on two levels. First: are actors driven to choose a certain feedstock with a lower risk of indirect effects? Second: are actors that are committed to a certain feedstock driven to make choices in their production process that eliminate or minimise risks on indirect effects?

3.2.2 Summary of the various mitigation initiatives and their characteristics

Table 3 - 10 shows a summary of the various initiatives that have proposed or are developing proposals for measures to mitigate indirect effects of biofuels. Detailed analysis is provided in sections 3.3 through 3.6.

	Measure	**Scope**	**Drives behavioural change**	
			Feedstock choice	**For a given feedstock**
RFS – US Renewable Fuels Standard	GHG-factor	GHG	+	-
LCFS – Californian Low Carbon Fuel Standard	GHG-factor	GHG	+	-
LIIB – Low Indirect Impact Biofuels (Ecofys et al.)[41]	Preventing displacement by expanding on land without provisioning services	GHG Biodiversity Land rights Food consumption	+	+
LIIB – Low Indirect Impact Biofuels (Ecofys et al.)	Preventing displacement through agricultural intensification	GHG Biodiversity Land rights Food consumption	+	+
LIIB – Low Indirect Impact Biofuels (Ecofys et al.)	Preventing displacement through using wastes or residues	GHG Biodiversity Land rights Food consumption	+	+
EU RED – EU Renewable Energy Directive	Various policy options are being considered			

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[41] Formerly known as Responsible Cultivation Areas (RCA, Ecofys et al. 2010).

Table 3 - 10 Summary of the various initiatives that have proposed or are developing proposals for measures to mitigate indirect impacts from biofuels. For each initiative the main measure and its scope are given. Also, it is indicated with a +/- score whether the initiative is likely to drive behavioural change of actors as described in section 3.2.1. Detailed analysis is provided in sections 3.3 through 3.6.

3.3 Detailed analysis of mitigation initiative: RFS

3.3.1 RFS and indirect effects

The Renewable Fuels Standard is a federal biofuel obligation in the United States that consists of various components for different "types" of biofuels. In the RFS different pre-defined biofuel chains (e.g. corn ethanol) are categorised based on their feedstock and GHG performance. The GHG performance is calculated with a life cycle analysis that includes a pre-determined amount of emissions from ILUC thus including ILUC in the characterisation of a particular pathway for a biofuel.

3.3.2 Scope

The RFS focuses on GHG savings and for ILUC the policy includes only the GHG effects. While this may have close links with effects on biodiversity and food consumption, measures to mitigate unwanted effects on these aspects are not explicitly included in the RFS.

3.3.3 Incentives for behavioural change

The emissions from ILUC have a significant impact on the GHG emissions of a biofuel pathway in the RFS, and thereby on the type of biofuel the pathway is categorised into. As the RFS requires that a certain part of the total target is met though biofuels with a high GHG saving, it provides a concrete incentive for biofuel types with little or no emissions from ILUC, such as biofuels from residues. In other words, the RFS contains an incentive for producers to choose a feedstock with little or no emissions from ILUC.

However, for a given feedstock, producers cannot prevent or lessen the GHG effect from ILUC by taking additional measures to prevent or reduce the risk of ILUC, because it is a standard, pre-determined amount coming from the life cycle calculations done within the RFS. Thereby, for a given feedstock the RFS does not provide any incentives for producers to change their behaviour such as to minimise the risk of ILUC.

3.4 Detailed analysis of mitigation initiative: LCFS

3.4.1 LCFS and indirect effects

California's Low Carbon Fuel Standard (LCFS) adopted by the Air Resources Board on 23 April 2009 requires a 10% reduction in the average greenhouse gas emission intensity of the State’s transportation fuels by 2020. Biofuels are expected to play a major role in achieving these targets.

The GHG savings of biofuels compared to the fossil reference fuels are determined through an LCA of pre-defined biofuel chains. Emissions from ILUC are included in this LCA. Thereby the scheme provides incentives for biofuels that cause no or less ILUC. Currently, calculations have been done for a few different pre-defined biofuel chains fed by energy crops.

3.4.2 Scope

The focus of the LCFS is on GHG emissions and therefore only GHG effects from ILUC are currently within the scope of the LCFS. Discussions are ongoing on including wider social and environmental sustainability aspects.

3.4.3 Incentives for behavioural change

As for the RFS, the LCFS provides an incentive for biofuel producers to use feedstocks that have little or no emissions from ILUC. Currently, like the RFS, the LCFS does not give clear guidelines that a biofuel producer can follow at the project level, after a feedstock has been chosen, to prevent or mitigate unwanted indirect effects. As a result, no incentive for implementing effective ways to mitigate indirect effects exists other than feedstock choice.

3.5 Detailed analysis of mitigation initiative: EU Renewable Energy Directive

The EU Renewable Energy Directive (RED) contains a 10% target for renewable energy in transport, in which biofuels are expected to play an important role. Only biofuels that meet certain sustainability criteria count towards this target. These sustainability criteria primarily cover GHG emissions from the entire fuel chain, and carbon stocks and biodiversity effects from direct LUC. The RED currently does not contain explicit measures aimed at reducing unwanted indirect impacts. However, the European Commission (EC) published a report in December 2010 in which it indicated that it would, by July 2011, publish an Impact Assessment that would look into four possible policy options to address indirect impacts of biofuels:

1. take no action for the moment while continuing to monitor;
2. increase the minimum greenhouse gas saving threshold for biofuels,
3. introduce additional sustainability requirements on certain categories of biofuels,
4. attribute a quantity of greenhouse gas emissions to biofuels reflecting the estimated indirect land-use impact.

The EC might, in its Impact Assessment, indicate which policy option it believes is most appropriate and might publish a policy proposal accompanying the Impact Assessment to amend the RED and FQD accordingly.

3.6 Detailed analysis of mitigation initiative: Low Indirect Impacts Biofuels

3.6.1 Low Indirect Impacts Biofuels

The Low Indirect Impacts Biofuels (LIIB) initiative started in 2008 as a private sector initiative coordinated by Ecofys in collaboration with NGOs such as WWF and Conservation International and industrial parties such as Shell, BP and Neste Oil with the overarching goal to:

> *Identify areas and/or production models that can be used for environmentally and socially responsible energy crop cultivation, without causing unwanted displacement effects. (Ecofys 2010)*

What is now called LIIB was originally called Responsible Cultivation Areas (RCA). Currently, the initial RCA initiative is being developed into a Certification Module for Low Indirect Impact Biofuels – in a consortium including WWF, Roundtable on Sustainable Biofuels, Ecofys, DNV and several pilot organisations, funded by the Global Sustainable Biomass programme of NL Agency. The aim of this Certification Module is allow policy makers, voluntary certification schemes, producers and other stakeholders to credibly distinguish biofuels that were produced in a way that minimizes the risk of unwanted indirect effects.

The central principle under the LIIB initiative is that of the need for additional production. Indirect effects of additional energy crop production are the result of a displacement of other productive functions of the land. For example, existing palm oil production that was previously used for the food sector is now used for biodiesel production. Displacement of existing production is therefore at the heart of the concept of indirect effects. Preventing displacement, by realising additional production instead of displacing existing production, is therefore at the heart of the solution to minimise the risk of indirect effects.

The current project that develops a Certification Module for Low Indirect Impact Biofuels focuses on providing project-level solutions for producers that want to minimise the risk of ILUC. Thereby, the focus is on three of the options introduced in section 3.1.2:

1. Realising additional production without displacement by expanding production on land without provisioning services;
2. Realising additional production without displacement by increasing land productivity. Two sub-options are distinguished here:
    a. Yield increases on existing biofuel feedstock farms/plantations such as palm oil or rapeseed.
    b. Integration models in which food and fuel production are combined in such a way that biofuel feedstock is produced without displacing food production.
3. Realising additional biofuel production through the use of previously unused residues.

It is acknowledged that this list of solution types is not necessarily complete and that other solution types could be added at a later stage.

Two concrete examples are included in the textboxes on the following pages. More elaborate information on the potential for the LIIB production models and their main barriers can be found in "Mitigating indirect impacts of biofuel production - Case studies and Methodology" (Ecofys 2009a) and the three reports of the three RCA pilot studies in Indonesia and Brazil (Conservation International 2010a, Conservation International 2010b, WWF 2010). Other studies that show the potential and the environmental and social benefits of the sustainable production models that fall under LIIB include "Bioenergy and food production for local development in Brazil: inputs for policy-making (Sparovek et al, 2010), and Smallholder Oil Palm Production Systems in Indonesia: Lessons from the NESP Ophir Project (Jelsma et al, 2009).

The Certification Module for Low Indirect Impact Biofuels is currently being tested in four pilot locations (Brazil, Indonesia, Mozambique and South Africa) and opportunities for further piloting, with increased focus on EU countries, are being investigated.

3.6.2 Scope

The central concept of the LIIB initiative is to expand agricultural production for biofuels without displacing other provisioning services of the land.[42] This would prevent all the potential consequences, such as effects on biodiversity or carbon stocks, of such displacement. Unwanted effects on food consumption will also largely be prevented as no food or feed production is displaced, thereby preventing shortages in the food/feed sector. Provisions are also included that prevent the use of agricultural land for biofuels in areas where such agricultural land is scarce.

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[42] Within the development of the RCA, but also in other developments, a debate has been raised on the effectiveness of expanding on land without provisioning services or 'idle land'. A more elaborate discussion of this debate and its links to the RCA initiative are presented in Appendix B.

3.6.3 Incentives for behavioural change

The LIIB concept includes concrete incentives for producers to change their behaviour. Producers are requested to cultivate their feedstock either on lands without provisioning services (while also meeting biodiversity, carbon stocks and land right criteria) or to increase the productivity of the land, e.g. by integrating food and fuel production (see concrete examples in Boxes below).

The LIIB concept is feedstock neutral. This means that, in principle, all feedstocks could meet the LIIB criteria.

3.7 Conclusion on current mitigation measures

Three main conclusions can be drawn on current mitigation measures for indirect effects of biofuel production:

- The amount of mitigation measures that currently exists is small. In addition, of this small amount of measures most are not yet fully operational.
- Most of the mitigation measures focus only on GHG effects of biofuels by incorporating an ILUC factor in the general life cycle analysis of feedstock-based biofuel pathways. This has the inherent limitation that there is no incentive for options to mitigate indirect effects at the project level, given a certain feedstock.
- The LIIB initiative is the only initiative to the authors’ knowledge to work on pragmatic solutions for biofuel feedstock production that has a minimised risk of indirect effects by preventing displacement effects from occurring at the project level. The concept is currently being developed into an operational Certification Module for Low Indirect Impact Biofuels, which policy makers and other stakeholders could use to distinguish biofuel produced in a way that minimises the risk of unwanted indirect effects.

Box 3: Options for energy crop production without displacement from the LIIB initiative (I/II)

Expanding oil palm production on "unused land"

- *Expanding production without ILUC:* Casson (2007) describes how carbon emissions from the oil palm sector can be reduced by redirecting oil palm expansion away from forested areas and peat lands to degraded lands. Planting oil palm on Imperata Grassland could lead to an increase in carbon stocks as well.
- *Potential:* Casson (2007) cites numbers on degraded land from the Indonesian Ministry of Forestry, which has classified over 23 million hectare as degraded land. Garrity et al. (1997) estimated the total area of Imperata Grassland in Asia at 35 million hectare (8.5 million hectare in Indonesia). This compares to roughly 10 million hectare of globally harvested oil palm plantations today.
- *Risks:* Not all degraded land will be available. Some of it will not be suitable for oil palm production. Furthermore, degradation is often caused by the presence of people and degraded areas are therefore often populated and the local population may be occupying some of the lands. In addition, degraded land can still contain high conservation values.
- *Economic viability:* Generally feasible. Some additional costs in the case of Imperata Grassland for herbicides treatment in the early years of establishment. Fairhurst et. al. (2009) find that Oil Palm plantations on grasslands are more profitable than plantations on secondary forest.
- *Added value from carbon benefits:* Ecofys (2007b) finds that the GHG-performance of biofuel from oil palm can be significantly improved if plantations are established on Imperata Grassland. This could lead to a higher economic value as mechanisms such as the EU Renewable Energy Directive and EU Fuel Quality Directive reward higher GHG savings.

Box 4: Options for energy crop production without displacement from the LIIB initiative (II/II)

Integration of sugarcane and cattle

- *Expanding production without ILUC:* Sparovek et al. (2007 and 2010) present an integrated sugarcane and cattle production model in which hydrolysed bagasse is used as animal feed. The additional feed would allow for more cows per hectare, freeing up part of the pasture land for sugarcane. As a result the same land that used to support a certain number of cattle, now supports the same amount of cattle while also producing ethanol from sugarcane. In other words, sugarcane production is expanded on pasture areas without displacing the original cattle production. This could reduce the migration of ranchers to remote areas in the Cerrado and the Amazon region.
- *Potential:* The authors do not give estimates for the total potential. Not all pasture land will be suitable for sugarcane. Total permanent meadow and pastures, both natural and cultivated, in South America amount to over 450 million hectare, with 200 million hectare in Brazil (FAO 2009). Total sugarcane area equals 8 million hectare (6.7 in Brazil), suggesting a significant potential for the integration model. Also the RCA pilot study on sugarcane-cattle integration in Brazil finds a significant potential (CI 2010b).
- *Risks:* The integration model requires close interaction between two very different sectors. Diverting part of the bagasse from electricity generation to animal feed has only a minimal impact on the direct emissions of the sugarcane to ethanol chain (<1% reduction in the GHG-savings compared to fossil fuels.)
- *Economic viability:* The authors state that the model is feasible at current market conditions.
- *Added value from carbon benefits:* Policies to promote GHG-savings through biofuels in the EU and US are expected to include emissions from ILUC in the near to medium future. Projects that can demonstrate to prevent ILUC, such as the integration model, would then be recognised to achieve higher GHG-savings and may therefore obtain a higher value.

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Appendix A Emissions from additional fertilizer

E4tech (2010) states that the increased emissions from applying additional N-fertilizer to wheat, in order to increase the wheat yields and thereby expand production without expanding the land, amount to 8.9 gCO_2/MJ ethanol. Using the same assumptions we find a value of 12.9 gCO_2/MJ ethanol. Using yield response numbers from a previous report from the same organization that E4tech uses for the yield response figure given in their report, The UK HGCA, we even find a number of 106gCO_2/MJ. The number of 8.9 gCO_2/MJ ethanol therefore appears to be the result of a combination of 1) an optimistic assumption on wheat yield responses to higher N-fertiliser inputs and 2) an optimistic assumption in the allocation of the emission to the additional wheat-ethanol produced.

- E4tech (2010) states on p28 that it assumes UK N-fertiliser application rates are 183 kg N / ha with corresponding wheat yields of 7.76 ton / ha. This translates into an average N application of 23 kg N / ton wheat. It is furthermore assumed that “a 10% increase in fertilizer input would lead to an increase in yield of 0.5 t wheat / ha.” This amounts to 36 kg N per ton of additional wheat, an increase of 13 kg N per ton of wheat compared to the current average number. This number was used for illustrative purposes only but it is unclear where this number is based on. The same section shows a graph from HGCA (2009) on the relationship between N supply and grain yield but numbers on the response of grain yields to additional N fertilizer cannot be directly derived from that figure as it only gives N-numbers relative to the optimal N supply, not relative to the absolute N supply. Based on a figure in a report by the same organization (HGCA, 2007) a rough number can be estimated, at around 130 kg N per ton of additional wheat. This is an increase of 107 kg N per ton of additional wheat compared to the current average number 0f 23 kg N per ton of wheat: a difference of a factor 8 with the E4tech (2010) assumption.
- E4tech (2010) states on p 29 that the additional N-fertilizer, of 36 kg N per ton of additional wheat, causes a total increase in fertilizer related emissions of 8.9 gCO_2/MJ ethanol. We calculate the number to be 12.9 gCO_2/MJ ethanol, see table below. The difference is caused by the fact that E4tech allocates the additional emissions from additional N-fertiliser to all EU wheat-ethanol production, and we allocate it purely to the wheat-ethanol resulting from demand-induced yield increases – after all, the wheat produced on additional wheat land will have its own emissions from fertilizer application. This effect is partly compensated by the fact that E4tech does not allocate any of the emissions to DDGS, while we allocate 40% of the emissions to the *additional* DDGS produced as a result of the yield increase (allocation based on energy content).

We therefore find that if the UK would increase its yield purely through the use of additional N-fertilizer, the emission from additional N-fertilizer application would amount to 106 gCO_2/MJ ethanol, not 8.9 gCO2/MJ ethanol[43]. While this number surely is an overestimate of the actual emissions from the additional UK wheat yield increase, as not all yield increase will come from increased N-fertilizer application, it shows these emissions are more important than suggested by the number of 8.9 g CO_2/MJ ethanol in E4tech (2010).

Table A - 1 Emissions from additional fertilizer input. Recalculation of the numbers cited by E4tech (2010). Note that the last row shows the maximum additional emissions associated with additional fertilizer to produce the additional wheat for biofuels. This is a maximum figure as it assumes that all yield increase stems from additional N-fertilizer application. Also note that this number does not include the business as usual average fertilizer application per ton of wheat as such emissions are already included in the LCA of the direct emissions of biofuel pathways. Therefore the values in the last row are the result of penultimate row minus average value of 23 kg N per ton of wheat.

The calculations are based on the same emission factors as used in E4tech (2010) and used default conversion efficiencies and allocation to co-products from Biograce.

	Current practice as assumed in E4tech (2010)	+10% N E4tech (2010) numbers on yield response	+10% N HGCA (2007) numbers on yield response
N-application (kg N/ha)	183	201.3	248
Yield (t wheat/ha)	7.76	8.26	8.26
kg N / t wheat - average	23.6	24.4	30.0
kg N / t wheat - marginal		36.6	130.0
additional kg N / t wheat for marginal wheat compared to average wheat		13.0	106.4
kg CO2 emissions / kg N (fertilizer production and soil emissions)	12.9	12.9	12.9
g CO2 from N / kg wheat - average	304	314	387
g CO2 from N / kg wheat - marginal		472	1677
MJ of ethanol / kg wheat (from Biograce)	7.8	7.8	7.8
allocation to DDGS (from Biograce)	40%	40%	40%
allocation to ethanol (from Biograce)	60%	60%	60%
g CO2 from N / MJ ethanol - average	23	24	30
g CO2 from N / MJ ethanol - marginal		36	129
g CO2 from N / MJ ethanol - marginal less average		12.9	106

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[43] Note that the correct number here is the additional fertilizer needed to produce one additional ton of wheat in which all the additional fertilizer is allocated to the increase in wheat yield, see table A-1 for calculations.

Appendix B The debate on the effectiveness of expanding on 'idle land' and its links to the RCA initiative

This appendix serves as an extension to the information presented on expanding on land without provisioning services in section 3.6.

Discussions with experts and stakeholders have primarily raised concerns on the effectiveness of using land without other provisioning services. Some parties claim that agricultural land is scarce and will become more scarce in the future and therefore should not be used for biofuels at all. In other words, while expanding production in these areas may not cause displacement effects today, there may be displacement effects in the future – as the land would otherwise have been taken into production for food in the future.

The validity of this argument depends strongly on the future land requirements for food, feed and fibre production on the one hand and the availability of agricultural land on the other hand. Both are subject to large uncertainties. On the positive side, the doubling in world food production in the past decades was met almost entirely by agricultural intensification, with only 10-15% of the increase in production coming from an expansion in cropland. With a slowdown in population growth, future growth rates in food demand are expected to decline. In terms of land availability, a recent study by IIASA shows that several hundreds of millions of hectare of land suitable for rain-fed biofuel crop production exist that are not used for cropland today and are not under forest cover or in protected areas. On the negative side, yields may not grow as strong as they did in the past and climate change may have negative impacts. On the large potential land availability found by studies such as (IIASA 2009), large uncertainties exist on what these lands are actually used for today and to what extent these areas can be taken into agricultural production. Further analysis of this topic is beyond the scope of this study.

The coordinators of the initiative state that the solution is primarily meant as an intermediate solution, initially aimed at the period up to 2020/2022 – the period for which the EU and the US have set biofuel mandates, until global efforts to control unwanted direct LUC are effectively implemented, thereby eliminating unwanted indirect LUC, and that the risk of structural land shortages in the medium term is small. In addition, the coordinators state that today's biofuel energy crop feedstocks can switch easily between food and fuel markets and therefore using areas without current provisioning services for biofuels does not pose irreversible risks – the crops and the areas on which they are cultivated could be reverted to food market relatively easily.