Biofuels: indirect land use change and climate impact

Report
Delft, June 2010

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Publication Data

Bibliographical data:
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Biofuels: indirect land use change and climate impact
Delft, CE Delft, June 2010

Land use / Fuels / Plants / Production / Policy / Effects / Climate change / Risks

Publication code: 10.8169.49

CE publications are available from www.ce.nl

Commissioned by: BirdLife International, Transport and Environment and the European Environmental Bureau.
Further information on this study can be obtained from the contact person Harry Croezen.

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Summary

Introduction
One of the main reasons cited for introduction of the mandatory 2020 target of 10% renewable energy (mainly biofuels) in Europe's road transport sector is the reduction of greenhouse gas emissions.

Until a few years ago biofuels were considered a robust option for reducing CO_2 emissions. The thinking went as follows. Biofuels displace fossil fuels, mainly oil, in the transport sector. Although biofuels have roughly the same tailpipe carbon emissions as fossil fuels, this carbon was previously absorbed from the atmosphere when the biofuel feedstock was grown. Net carbon emissions do occur, though, because biofuels production and feedstock cultivation require inputs in terms of fertilizer application, use of diesel for agricultural machinery, energy in processing the feedstock to fuels, etc. The use and/or production of these inputs generate greenhouse gas emissions, too. Overall, though, biofuels would by and large reduce emissions compared with fossil fuels.

It was largely this thinking that was reflected in the sustainability criteria for biofuels that were put in place in the renewable energy directive (RED). Among other things, the Directive requires that the greenhouse gas emissions associated with production and use of biofuels are at least 35% and from 2017 at least 50% lower than those associated with production and use of conventional petrol and diesel. The RED requires that the whole production chain from cultivation of the feedstock up to use of the biofuels is considered, including direct conversion of land to grow biofuels feedstock.

However, over the past few years much evidence has emerged that this thinking is only part of the story and that it does not capture the full climate impact of biofuels. In particular, the RED does not take into account the potential indirect effects of biofuels production. When biofuels are grown on existing arable land, indirect land use change (ILUC) will ensue, since current demand for food and animal feed will push these production activities into new areas such as forests or grasslands. Conversion of forest or grassland to agricultural land can lead to very significant releases of carbon to the atmosphere.

Studies show that emissions resulting from ILUC are so significant that they could sway the climate effects of biofuels from positive to negative, compared with fossil fuels. As yet, however, the most recent range of studies have not been systematically compared and summarized.

Objective of this study
The objective of this study is to:
- compile the available recent literature on ILUC emissions;
- compare these emissions with the assumed gains of biofuels;
- assess how ILUC changes the carbon balance of using biofuels;
- formulate policies to avoid these extra emissions associated with ILUC.

Trends in land use, with and without biofuels
All the studies on global agricultural markets reviewed predict that new arable land will be required to meet future global demand for food and feed. Although there will be increased productivity on current arable land (intensification), food and feed demand will probably grow faster, which

means that mobilization of new land is likely to occur. Biofuels produced from crops (the current mainstream practice) will add extra demand for crops like wheat, rice, maize, rapeseed and palm oil. This will increase prices for these crops (as well as for land) and lead to two impacts: intensification of agricultural production and conversion of forests and grasslands to arable land.

Assessing indirect land use change from growing biofuels: two approaches

We identified two possible approaches to assessing the risks vis-à-vis ILUC-related GHG emissions due to biofuels.

The first approach is to use agro-economic models which simulate global agricultural markets, trade, intensification, possible crop replacements and so on. These models can predict the land use effect of using particular crops for biofuels. In this research project we compared the results of seven different modelling approaches (IIASA, LCFS, EPA, Banse, JRC AGLink, IFPRI GTAP and IFPRI FT). Although the results of the models differ (because of different assumptions) several clear general trends emerge:

- Extra intensification caused by higher commodity prices will reduce the ILUC effect of biofuels (if achieved without additional fertilizer input that leads to higher N_2O emissions), but will not nullify it.
- For all crops the models predict a minimum, a maximum and an average ILUC effect.
- ILUC effects vary, depending on the type of biofuel and crop concerned, but in general for many crops an average effect of 60 gram CO_2/MJ biofuel is indicated. This is roughly two-thirds of the total carbon footprint of petrol and diesel.

The second approach to examining ILUC is to adopt a 'one-for-one' strategy, whereby every extra hectare of land used for biofuels is assumed to lead to one hectare of grassland or forest being converted to new farmland. This approach leads to 'worst case' estimates of ILUC emissions, because gains from intensification as described above are ignored. The Dutch 'Corbey' advisory commission and the WGBU (German Advisory Council on Global Change) choose this option and arrive at a higher figure of 120 to 500 gram CO_2/MJ biofuels for ILUC emissions (a correction of 140 to 590% points in the GHG emission calculation). This is roughly two to six times the carbon footprint of petrol and diesel.

ILUC estimates

Table 1 summarizes the estimates of ILUC-related CO_2 emissions calculated with the seven selected models.

Table 1 CO_2 emissions due to ILUC, based on the models considered (Econometrica, E4tech, LCFS II, EPA, AGLINK, IIASA, IFPRI BAU, IFPRI FT), expressed as g CO_2/MJ biofuel and percentage of carbon emissions of fuel replaced

	Highest value (1)	General value (2)	Average (3)	Highest value (1)	General value (2)	Average (3)
1st gen. ethanol	60	60	29	72%	72%	34%
Sugar beet ethanol	65	60	42	78%	72%	50%
Wheat ethanol	60	60	35	72%	72%	42%
Maize ethanol	79	60	55	94%	72%	65%
Sugar cane ethanol	69	60	38	82%	72%	45%
2nd gen. ethanol, residues	0	0	0	0%	0%	0%
2nd gen. ethanol, crops	?	?	?	?	?	?
1st gen. biodiesel	60	60	47	72%	72%	56%
Rapeseed biodiesel	60	60	36	72%	72%	43%
Soybean biodiesel	68	60	54	81%	72%	64%
Sunflower biodiesel	75	60	64	89%	72%	76%
Palm oil biodiesel	74	60	55	88%	72%	66%
Waste oil biodiesel	0	0	0	0%	0%	0%
HFO Palm	74	60	57	88%	72%	68%

Notes:
- Highest value: highest ILUC emission per MJ biofuel as calculated with the respective model.
- General value: indicative average ILUC emission factor of the ILUC emissions per MJ biofuel, averaged over all the biofuels considered.
- Average: arithmetic average of the ILUC emissions per MJ biofuel as calculated with the respective model, for a specific crop.

The ILUC effect of second generation crops is not predicted in the models considered and requires further evaluation.

ILUC policies

We conclude that at the moment the only way to prevent ILUC is to introduce a so-called 'ILUC factor', i.e. an additional CO_2/MJ figure, in the GHG rules for biofuels, with several clearly defined exemptions.

We see four possible approaches to an ILUC factor:

A: Minimum ILUC risk: Use maximum ILUC factors from models
To assure that any ILUC risk is eliminated, the maximum calculated ILUC factor from model calculations for the different individual crops can be taken as representative. This would mean an ILUC factor of between 60 and 79 gram CO_2/MJ biofuel (72 tot 94% would then have to be added to the GHG calculation).

B: Low ILUC risk: Use an average and general ILUC factor
Using one or a selected number of models, an average ILUC factor for the complete biofuel policy target is estimated. Given the results of the simulations considered in this study, an average value of 60 gram CO_2/MJ biofuel seems a good first estimate. Alternatively, an average factor for diesel substitutes and for petrol substitutes could be applied. In that case 60 gram CO_2/MJ biodiesel and 40 gram CO_2/MJ bio-ethanol (see Figure 7) could be applied as an initial estimate.

C: Medium ILUC risk: Use crop-specific average ILUC factors
If a certain level of ILUC risk is deemed acceptable in biofuel policies and model simulations are considered sufficiently accurate, one could conclude that the average crop-specific ILUC emissions calculated with model simulation(s) are a reasonable prediction of the ILUC effect. This approach will lower the ILUC risk but will not completely eliminate it, because actual ILUC may be higher if the more pessimistic models prove to be more representative for real-world effects. With this approach the ILUC factor for the crops will be between 35 and 64 gram CO_2/MJ, depending on the biofuel feedstock (42 to 76%).

D: Eliminate any ILUC risk: Do not apply model simulations but use a direct link between biofuels and land use
If the model simulations are not considered sufficiently accurate, a 'risk adder' approach as suggested by the Dutch Corbey Commission or applied in the WBGU advice to the German government could be applied. These approaches are often intended as a stop-gap until more reliable models become available. As previously indicated, in these approaches a maximum-risk scenario is applied in which the basic assumption is that each hectare of land used to produce biofuels leads to conversion of one hectare of natural forest to new farmland. In the Corbey Advice, for the associated loss of carbon sinks a globally averaged factor is applied, 105 tonnes/ha (= 120 to 500 gram CO_2/MJ biofuels).

Exceptions

All four approaches to an ILUC factor require exemptions for:

1. Use of marginal, severely degraded or abandoned land which has not been used for food production in the last 5 years; in such cases only direct land use-related GHG emissions would need to be reported.
2. Intensification of production over and above the 2% per year required for food output (over an average period of 5 years); in such cases there would be an exemption for the additional yield.
3. Use of wastes and residues, as defined in the EU's waste framework directive and in compliance with the waste hierarchy defined in there. This means materials for which there is no alternative more beneficial use such as for material purposes or as soil improver.

A combination of the described approaches could potentially result in almost or completely ILUC-free biofuels for Europe, but this will require a substantial modification of current policies.

CO_2 emissions in 2020

For 2020 the models predict a direct (i.e. excluding ILUC) GHG reduction for the EU biofuels programme of around 70 Mt CO_2 per year. With the maximum risk approach of the Corbey Commission, biofuel policies would lead to additional, ILUC-related emissions of approximately 270 Mt, hence a net extra emission of 200 Mt a year (the same as the annual emission of a country like Belgium). With the modelling approach (including extra intensification caused by higher prices) the ILUC effect is estimated as about the same as the direct gain and the net result of the policy on GHG emissions would be approximately zero.

To conclude, by properly accounting for the emissions associated with indirect land use change a real reduction of 70 Mt CO_2-eq per year seems possible.

1 Introduction, indirect land use change – the forgotten factor?

The EU biofuels policy, which was introduced in 2003 and further elaborated in 2008/2009 (see Renewable Energy Directive (RED) and Fuel Quality Directive (FQD)), has three specific aims:

- Reducing dependency on imports of crude oil and transportation fuels (security of supply).
- Maintaining agricultural productivity, incomes and employment and preserving quality of life in rural areas.
- Reducing transport-related greenhouse gas (GHG) emissions by using sustainably produced biofuels.

The present report focuses on the last of these issues: net GHG emission reduction in the transport sector.

The EU RED biofuels target for 2020 is to have 10% of fuel demand in EU road transport covered by biofuels. This translates to a potential amount of biofuels of approximately 32 Mtoe[1]. The amount actually utilized will probably be less, since various types of biofuels (2nd generation, biogas, waste-derived ethanol and biodiesel) can contribute doubly to the 10% target. Current biofuels consumption amounts to 10 Mtoe, or 3% of current EU transport fuel consumption.

It is held that the 10% share of biofuels in 2020 will reduce road transport GHG emissions by at least 50 Mt CO_2/year, excluding emissions related to refining and crude oil extraction, and by at least 55 Mt CO_2/year if these steps in the supply chain are included.

Reductions related to biofuels utilization should be determined using a so-called chain analysis or LCA approach that considers the GHG emissions associated with the various production phases (or chain links) in the biofuel production chain. These aggregate emissions should then be compared with the emissions associated with fossil fuel-based transport fuels and should (from 2017 on) be at least 50% lower. Expressed as a mathematical relation:

$$E = eec + el + ep + etd + eu < 41.9 \text{ g } CO_2\text{-eq/MJ biofuel}$$

Where:

E	**= total emissions from use of the fuel**
eec	= emissions from the extraction or cultivation of raw materials
el	= annualised emissions from carbon stock changes caused by direct land-use change[2]
ep	= emissions from processing
etd	= emissions from transport and distribution of biofuels

[1] Mtoe = megatonnes of oil equivalent, 41.85 GJ of lower heating value.

[2] This refers to removal of natural vegetation to generate arable land and reduction of soil organic matter (humus) as a result of vegetation removal and land management.

However, several recent scientific articles by, among others, Searchinger and Fargione (2008) indicate that certain emissions may be being overlooked, in particular the emissions due to indirect land use changes initiated by biofuels policies around the world. The articles concerned indicate that these emissions may be of such a magnitude that the reductions envisaged under the RED are actually being more than nullified, with global greenhouse gas emissions in fact increasing.

In this report we consider the issue of indirect land use change initiated by EU biofuels policy and seek to answer the following questions:
- What is the probability of biofuels policies initiating land use changes?
- What greenhouse gas emissions may result from indirect land use change, expressed as a factor in the mathematical relation given above?
- What technical measures can be applied and what policy measures adopted to limit or entirely mitigate indirect land use change and the associated greenhouse gas emissions?

We first (Chapter 2) broadly discuss the mechanism of indirect land use change. We next discuss why there is a perception among stakeholders that there is a serious risk that EU biofuels policy will initiate indirect land use change (Chapter 3) and consider the figures cited by other studies as an indication of the magnitude the associated greenhouse gas emissions (Chapter 4). We then broadly consider the technical possibilities for mitigation (Chapter 5) and, finally, present recommendations for additional policies for mitigating indirect land use change.

2 Biofuels, CO_2 emissions avoidance and land use change-related CO_2 emissions

2.1 Biofuels and greenhouse gas emission savings: the theory

By displacing fossil fuels in the transport sector, biofuels are designed to be part of the solution to climate change. Although their tailpipe emissions are the same as those of fossil fuels, they are taken to be carbon-neutral, as the carbon emitted when they are burned was previously absorbed from the atmosphere when the biofuels feedstock was grown. Since burning the biofuel immediately generates CO_2 that is only subsequently reassimilated by vegetation, however, the emissions avoidance realized by substituting fossil fuels is decelerated in time. In practice, moreover, the avoidance is not 100% because biofuels production and feedstock cultivation themselves involve consumption of fossil fuels (e.g. fertilizer, diesel for machinery, heat). Thirdly, the carbon in the biofuels does not contribute to increased atmospheric greenhouse gas concentrations only if produced from agricultural crops. The carbon in these crops is only temporarily assimilated in the crops and is released again to the atmosphere when the crops are harvested, processed and consumed.

Natural vegetation and organic matter in soils, on the other hand, are effectively stocks of stored carbon, for as long as they remain undisturbed these pools will not change in size over time, or only marginally so. A forest remains a forest with a constant standing stock of biomass, i.e. trees and undergrowth. Thus any reduction in the size of these stocks effectively boils down to creating net greenhouse gas emissions.

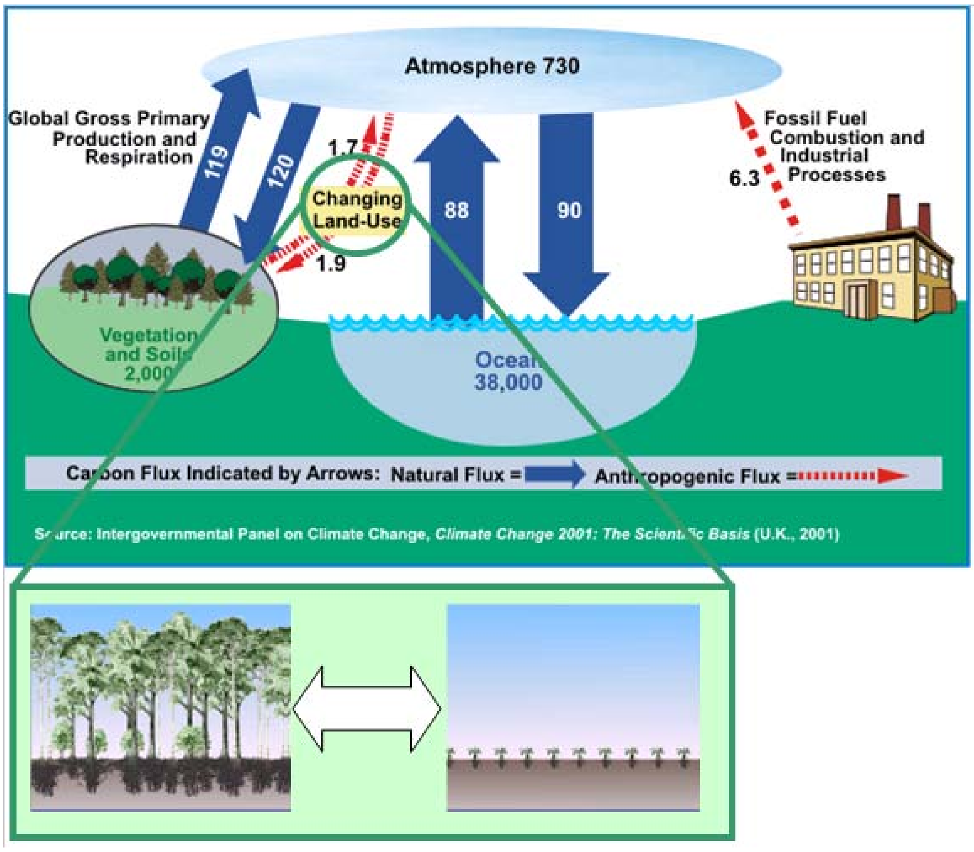
The changes in natural vegetation and soil organic matter are referred to as land use change (LUC). They can take the form of deforestation, whereby the forest is converted to grassland or arable land, or may involve conversion of grassland to arable land. The changes may be caused directly – through creation of arable land for biofuels feedstock cultivation, for example – but also indirectly. In the latter case the term indirect land use change (ILUC) is used.

This report is about ILUC-related GHG emissions caused by biofuels production.

2.2 Indirect land use change-related greenhouse gas emissions

GHG emissions due to ILUC occur when crops or land that would have otherwise been used for producing food or animal feed are used for growing biofuels, and existing agricultural production geographically shifts to new land areas created by conversion of natural areas (see Figure 2).

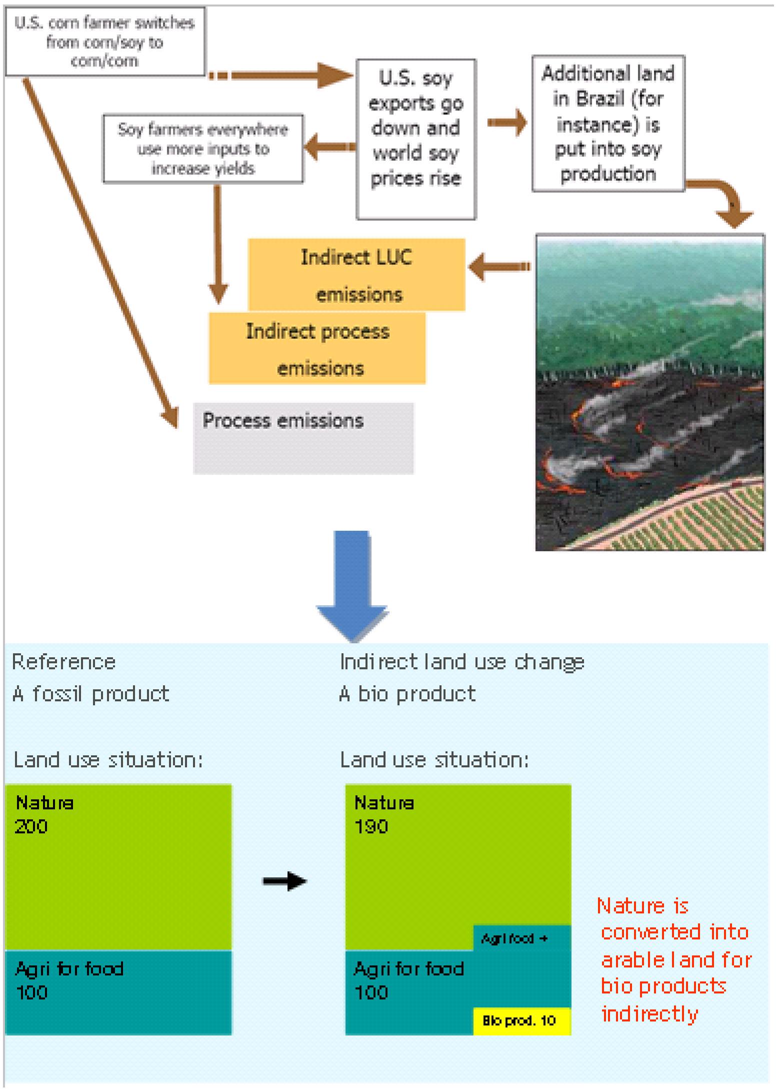
Figure 1 **Global carbon cycle**



ILUC often also works through the pricing mechanism, as the increased demand for biofuels drives up prices of agricultural commodities, which then increases the pressure on land and global ecosystems. The land use changes are 'indirect', as they do not take place at the biofuel production site itself but elsewhere in the world, though triggered by events at the production site. Thus, the natural forests and grasslands in region A may be converted to arable land for food and feed crops as a result of biofuel production being initiated in region B, where the crops of region A were previously grown.

Given that the intended aim of biofuels introduction is to reduce GHG emissions, ILUC resulting in deforestation and conversion of grassland is highly undesirable. Besides counteracting the direct reduction of GHG emissions, it can also cause loss of biodiversity associated with conversion of natural habitats. This holds especially for forests and grasslands on peat soils, cultivation on which will induce ongoing GHG emissions of 10–40 t CO_2/ha/year (Joosten, 2009) because of drainage and peat oxidation.

Figure 2 The mechanism of ILUC



Source: O'Hare, 2008.

3 Risk of biofuels policy-induced greenhouse gas-increasing land use change

Key message
There is major risk of direct and indirect land use change being induced by the EU biofuels policy. Significant volumes of biofuels require significant areas of arable land, but there already appears to be little chance of the world's current arable acreage being sufficient to produce enough food and feed to meet rising future demand. Additional crop demand for biofuels is therefore likely to require extra arable land that must be created by land use change.

3.1 Competition for agricultural commodities and expected impact of biofuels policies on commodity prices

There is widespread consensus that increased use of biofuels will result in increased competition for biomass and consequently land. Food/feed production will have to compete with utilization of biomass as a feedstock for materials on the one hand and with biofuels on the other[3]. At the same time, we will still need to preserve land for ecosystems, biodiversity and the services these provide, including carbon storage.

In fact, current utilization of biofuels is already having a marked influence on food and feed supply, as illustrated by estimates of the contribution of biofuels to the surge in food prices that occurred in 2007 (see Table 2). With increasingly higher biofuels policy targets, this influence and competition between the two applications is expected to grow, especially in the short term (see FAO, 2008).

[3] See Table 2.

Table 2 **Estimated contribution of biofuels demand to food price rises**

Source	Estimated contribution	Commodity	Time period
World Bank (April 2008)	75%	Global food index	January 2002–February 2008
IFPRI (May 2008)	39%	Corn, rice	2000–2007
	21-22%	Wheat	
CEA	35%	Corn	March 2007–March 2008
	3%	Global food index	
OECD-FAO (May 2008)	42%	Coarse grains	2008–2017
	34%	Vegetable oils	
	24%	Wheat	
Collins (June 2008)	25-60%	Corn	2006–2008
	19-26%	US retail food	
Glauber (June 2008)	23-31%	Commodities	April 2007–April 2008
	10%	Global food index	
	4-5%	US retail food	

Source: FAO (2008)

Indications of price rises specifically related to EU biofuels policy are given in Chapter 4.

3.2 Comparing food/feed forecasts and arable land availability and productivity

Among scientists there is now consensus on the counterproductive effects of increased global policy targets for biofuels. They foresee that the associated increases in demand for crops will result in direct or indirect conversion of natural forests and grasslands to arable land, thereby leading to additional GHG emissions. There is a risk of biofuels policy-induced conversion of natural habitats, it is held, as currently available global arable land and pasture are probably unable to meet future global food and feed requirements, let alone crop demands including additional amounts of crops used as biofuels feedstocks.

As a consequence, extra arable land would have to be created, probably at the expense of natural areas; forests, savannahs and grasslands. Increased demand for biofuel crops would increase the amount of natural area converted. This process may occur directly – when natural land is converted directly to arable land for biofuels feedstock cultivation – but may also occur indirectly, as a result of crops grown on existing arable land being diverted from food and feed to biofuels.

As illustrated in Table 3 and Figure 3, several studies by authoritative international organizations predict an increase in agricultural land use as a result of increased demand for food crops and livestock products. The projected increase in demand for both food and feed crops is due to global population growth as well as increased prosperity, resulting in greater consumption of land-intensive dairy products and meat.

A comparison of the anticipated rise in crop demand and assumed increases in crop yields cited in several authoritative studies also indicates that in the future additional arable land is probably required to meet food and feed demand:
- globally, crop yields are expected to increase by 1.0%-1.5% annually on average (see e.g. MNP, 2008; WAB, 2009);

– demand for cereals and oil seeds may increase by respectively 1.6% and 4.1% annually (WAB, 2009).

In other words. according to these studies there is a risk or even near-certainty that demand for cereals and oilseeds will rise faster than yields. If demand is to be met, this will mean a need for additional cropland.

The likelihood of land use change is further increased by the constant loss of cropland due to erosion and chemical and physical degradation. To maintain agricultural output at the required level, the global loss of 2–5 Mha of arable land annually due to soil erosion (see e.g. UNEP, 2007) must be compensated by cropland and pasture expansion or yield improvement, or both. Given that anticipated yield improvements can scarcely keep abreast of projected growth in demand, if at all, the only likely way in which the loss of arable land can be compensated is through arable land expansion.

The impact of future climate changes on crop yields and associated land requirements is uncertain. Several scenario studies estimating the impacts of global climate change indicate that such change will probably put additional pressure on food and feed production because of climate change-induced decreases in crop yields and water resources (see e.g. WAB, 2009; MNP, 2008). With proper adaptation and mitigation policies in temperate climate zones and perhaps also in tropical climate zones, the IPCC states that there may in fact be scope for increasing yields, however (see PBL, 2009). In general, though, the report in question (see PBL, 2009) also mentions a tension between crop productivity and food and feed demand (see Figure 3, derived from PBL, 2009).

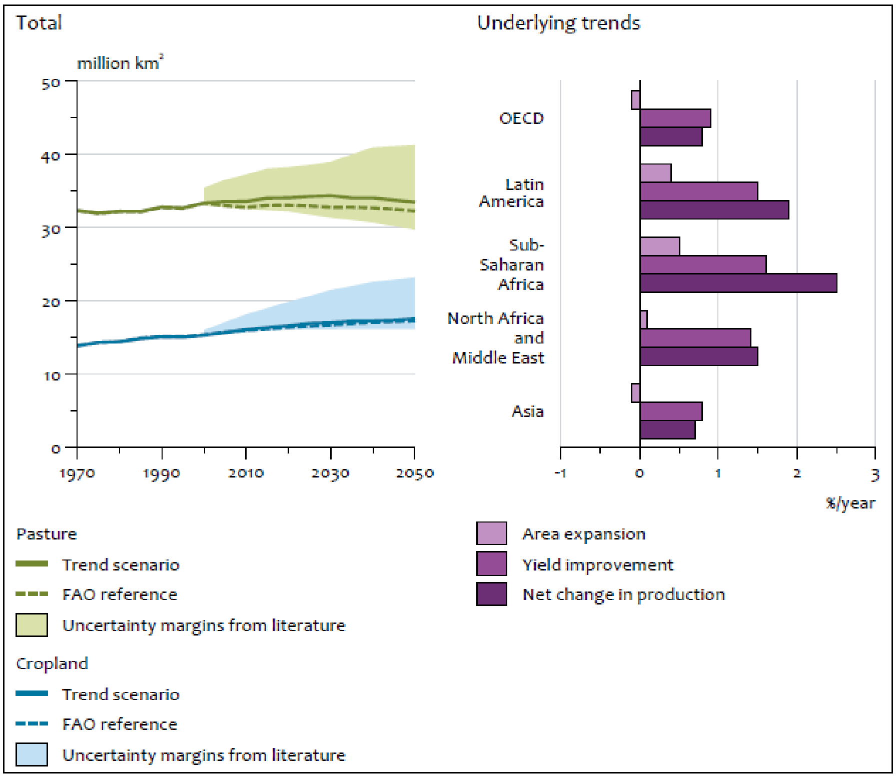
How much extra arable land is required is uncertain, as also illustrated in Figure 3. Most authoritative studies sketch a picture in which arable land expansion follows the higher end of the uncertainty margin given in Figure 3, although there are also alternative indications that future developments could result in a more limited requirement for extra arable land. As mentioned in Morris (2009), models developed by the International Food Policy Research Institute (IFPRI) indicate that global food demand will increase less rapidly in the future than in past decades. This relative decrease is caused by a slowing of global population growth and because per capita food consumption is already fairly high in some of the most populous developing countries. For cereals, for example, 0.9% rather than 1.9% consumption growth per annum is anticipated.

Table 3 **Estimated global agricultural land use in 2020 due to increasing demand according to different assessments (in billion km^2)**

	2000	OECD Environmental Outlook	Agricultural Assessment (IAASTD)	FAO Agriculture Towards 2030
Arable land	15	18	18	17
Pasture land	33	36	37	33
Total agricultural land	49	55	56	51

Source: Kok et al., 2008; WAB, 2009.

Figure 3 **Land use for food and feed production as cited in PBL, 2009**



'Trend scenario' refers to a scenario considered in IAASTD (2008), 'FAO scenario' to the reference scenario considered in FAO (2006).

All the studies considered, however, indicate that it is almost certain that extra arable land will be needed to meet future demand for food and feed.

3.3 The impact of biofuels policies

Biofuels policies stimulate or even prescribe the use of biofuel, leading to growing demand for agricultural commodities. This rise in demand will further increase demand for crops and the associated need for cropland expansion and hence drive up food prices.

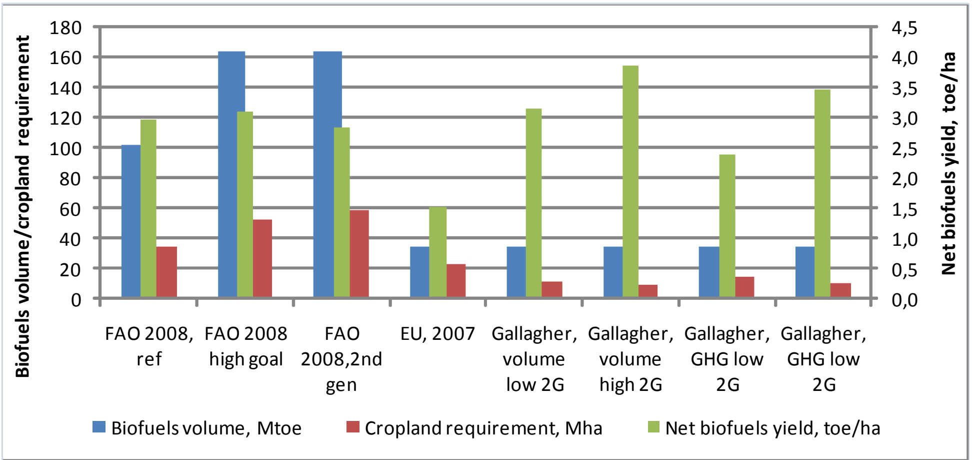
The examples of land requirements for biofuels feedstock cultivation cited in the literature studied provide an indication of such requirements as a function of intended biofuels volume. As an illustration, the hypothetical potential for producing the biofuel ethanol is shown in Table 2, which shows how much ethanol can be derived from current global production of cereal and sugar crops. It illustrates well that a significant substitution of conventional transport fuels by ethanol on a global scale would require significant extra amounts of crops and thus also a significant additional area of arable land.

Table 4 **Hypothetical potential for ethanol from entire current global principal cereal and sugar crops production**

	Global area	Global production	Biofuel yield	Maximum ethanol	Petrol equivalent	As share of 2003 global petrol use
	(Mha)	(Mt)	(Litres/ha)	(10^9 litres)	(10^9 litres)	(Percentage)
Wheat	215	602	952	205	137	12
Rice	150	630	1806	271	182	16
Maize	145	711	1960	284	190	17
Sorghum	45	59	494	22	15	1
Sugar cane	20	1300	4550	91	61	6
Cassava	19	219	2070	39	26	2
Sugar beet	5.4	248	5060	27	18	2
Total	599	...	...	940	630	57

Source: FAO, 2008.

Figure 4 **Indicative land area requirements for various biofuels scenario studies**



- Gallagher, volume = 10% EU target with cheapest biofuels of which 0% (low G2) or 30% (high G2) 2nd generation biofuels.
- Gallagher, GHG = 10% EU target with biofuels with highest GHG emission reduction percentage of which 0% (low G2) or 30% (high G2) 2nd generation biofuels.
- EU, 2007 = official EU biofuels policy impact analysis for the 2020 biofuels target.

Biofuels yields seem high, illustrating the effects of by-products utilization and residues application as a biofuels feedstock. For comparison: total global cropland amounts to 1,500 Mha.

The exact impact of biofuels policy in general and of EU biofuels policy in particular will, however, depend very much on such factors as:
- The applied blend of biofuels – based on conventional food and feed crops (1st generation) or based on residues or other non-land-based feedstocks.
- The level of the biofuel target and of possible targets for individual types of biofuel; see e.g. the specific targets for 1st and 2nd generation ethanol in the US Low Carbon Fuel Standards (LCFS).
- Flanking policies such as:
  - sustainability criteria, as included in the EU Renewable Energy Directive (RED);
  - how different types of biofuels are valued and contribute to the targets formulated; cf. the double counting of biofuels from residues, for example;
  - trade policies and agricultural policies on cultivation, e.g.:

- o preferred supplier agreements between EU and extra-EU states
  - o subsidies for cultivation of non-food and feed crops on fallow land
  - o stimulating cultivation of biofuels feedstocks on marginal and degraded lands
- stimulating improvement of yields of specific food and feed crops, potentially freeing up areas for biofuels feedstock cultivation.

These aspects are discussed in the next chapter.

4 LUC- and ILUC-induced GHG emissions cited in the literature

Key message

Model simulations of EU biofuels policy and global biofuels implementation indicate that the greenhouse gas emissions associated with indirect land use are very significant and generally amount to 20–60 g CO_2-eq/MJ biofuel, equivalent to 25-75% of the carbon emissions per MJ of the petrol and diesel being substituted.

There are four options for using these calculated ILUC effects as an ILUC factor in policy-making:
- Use crop-specific maximum GHG emissions per MJ biofuel calculated with model simulations as an ILUC factor.
- Use an averaged, general ILUC factor for all biofuels or for a category of biofuels (biodiesel and bio-ethanol for example).
- Use crop-specific average model simulation results as an ILUC factor.
- Place no faith in model simulations and opt for a direct relation between biofuels and land use (as in the Corbey report).

With the ILUC factors found in the literature, no food crop-based biofuel unambiguously meets the RED GHG emission reduction standard of 50%. For all the biofuels considered, assumptions and scenarios can be defined whereby (I)LUC-related emissions cause total GHG emissions to exceed the RED emission limit.

The simulations and the chain analyses indicate, on the other hand, the factors that can reduce the risk of ILUC-related GHG emissions. ILUC emission factors will generally be limited if:
1. Imports are not from regions where the agricultural frontier is moving into naturally carbon-rich ecosystems.
2. Feedstock production is concentrated on arable land that would otherwise be abandoned.
3. Yield increases are maximized in a sustainable manner which avoids increased emissions from fertilizer use.

Following on from the broad discussion of the probability of biofuels-induced land use change in Chapter 3, this chapter focuses on the associated GHG emissions: the so-called ILUC factor.

First of all the possible approaches to defining ILUC factors are briefly introduced. We then present the estimates of EU biofuels policy-associated GHG emissions from (I)LUC cited in other studies using their different approaches. In the following sections, these estimated ILUC-related emissions are discussed and suggestions made for including an ILUC factor in biofuels policy. Next, the impact of working assumptions on the magnitude of the calculated (I)LUC factor is illustrated. Finally, the chapter is summarized and conclusions drawn with respect to: 1) the likely magnitude of EU 2020 policy goal-induced land use change, and 2) the possibilities for mitigating this land use change and associated GHG emissions by including additional sustainability criteria in the EU renewable energy directive.

4.1 Approaches to accounting for the risk of biofuels-induced (I)LUC

Because ILUC impacts are beyond the control of biofuels producers, they need to be estimated using global agricultural models.

In general, three kinds of approaches seem to be applied (with the names in brackets being the examples considered in this report):
- risk adder approach (WBGU/Öko, Corbey advice, in some aspects Ecometrica);
- chain analysis, comparable with chain analysis in the RED (Ensus, E4Tech, in some aspects Ecometrica);
- agro-economic modeling (IIASA, JRC AGLINK study, IFPRI study, FAO-OECD 2009–2018 Outlook).

In the risk adder approach, a standardized emission factor is assumed for the land used for biofuels feedstock production, generally a globally averaged GHG emission factor for conversion of forest to arable land. Under the RED legislation this emission should be divided by a period of 20 years to calculate the GHG emissions per unit of biofuels. An ILUC factor for a specific biofuel is then estimated by dividing the resulting annual GHG emission by the biofuels yield per hectare. This approach ignores any effects of by-products and agro-economic interactions between prices, demand, (increases in) specific crop yields and trade, or does not render them explicit.

In the chain analyses, an LCA-like approach is applied. The (I)LUC-related GHG emissions are estimated by comparing land use in a business-as-usual scenario with a situation in which a certain amount of (extra) biofuels is produced, with the modellers estimating where (in which region) the extra feedstock is grown. Based on anticipated market developments, as described in other studies, they estimate how much and what kind of land use change occurs. In this calculation projected crop yield increases are taken into account, as are the effects of substitution of primary crops by biofuels by-products (e.g. substitution of coarse grains by distiller grains). The E4Tech study even takes into account carbon assimilation in the reference situation by spontaneous re-growth of vegetation on abandoned arable land. Although by adopting such procedures this approach seeks greater precision in estimating how much and what kind of land use change can be expected, economic interactions and their effects on the outcome are largely ignored.

In agro-economic models, all the parameters are interconnected. In this way feedback loops can be taken into account, such as reduction of cereals demand for food and feed – and associated land requirements - as a result of biofuels policies-induced market price increases of cereals. The fact that feedback loops such as reduced cereals demand – very likely in the shape of poor people eating even less than now - may be socially highly undesirable is not further discussed here. These models may also cover indirect effects that are difficult to take on board in other approaches, such as the net impact of arable land moving onto pastures (will this lead to pastures shifting to forests or to an intensification of livestock breeding?). By using models, such mechanisms can be simulated.

For estimating EU biofuels policy-induced (I)LUC GHG emissions covering all relevant biofuels, feedstocks and interactions, models are probably the most relevant tool. Although model simulations are not yet accurate enough, because of insufficient availability of data, the simplified representation of real-life processes and incomplete coverage of relevant processes, this is still the best way of approximating the magnitude of ILUC-induced greenhouse gas emissions.

The risk adder approach is more of a political approach based on the opinion that all relevant and possible emissions in the biofuels chain should be taken into account. Ignoring indirect land use change would lead to a situation in which biofuels seem more beneficial than they actually are, as discussed in Chapter 3. In view of the current status of models, the risk adder approach functions as a stop gap until better modelling results become available.

4.2 Estimates of EU biofuels policy-induced (I)LUC GHG emissions

There are a very limited number of model simulations designed to estimate EU biofuels policy-induced land use change and associated GHG emissions and ILUC factors specifically for EU biofuels policy.

To date, the only simulation in which ILUC factors have been calculated for EU biofuels policy is the IFPRI analysis conducted for the EU, which was finalized in March 2010. In this simulation two policy scenarios are distinguished for the EU agricultural market. The Business As Usual scenario (BAU) represents current EU agro market policies, the Free Trade (FT) scenario a further liberalization of the EU agro market. Both scenarios evaluate the impacts of an increase from the current 10 Mtoe of biofuels from food crops to 18 Mtoe (5.6% of EU automotive transport fuel consumption by 2020. Further liberalization means more imports of biofuels or feedstocks from outside the EU. The model assumes that most of the increase would pertain to ethanol rather than biodiesel.

The AGLINK simulations conducted by JRC for the EU at the end of 2009 do not themselves yield figures for (I)LUC-related GHG emissions. We therefore converted the land use changes calculated in this simulation to GHG emissions and ILUC factors using estimates of the types of land converted and the associated changes in carbon stocks (see Appendix A). For comparison, the land use changes estimated by Banse et al. are given, but these are too aggregated to allow estimation of associated GHG emissions and ILUC factors.

ILUC factors for sugar cane ethanol calculated under the US Renewable Fuel Standard (RFS II) and California's Low Carbon Fuel Standard (LCFS II) are also added for comparison in view of the potential importance of Brazilian sugar cane ethanol imports to the EU. Both values have a legal status and have been estimated using similar models, but differ significantly as a result of different assumptions concerning future developments in animal husbandry in Brazil.

The IIASA simulation is a global simulation and predicts a linear relation between the amount of first-generation biofuels used and the area of grassland and forest converted to arable land. It is considered here as a reference for the ILUC factors derived in the IFPRI study and from the JRC AGLINK simulation.

Table 5 General aspects of the approaches and studies considered, first table

	Corbey and WGBU	E4Tech	ENSUS	IIASA[4]	Sugar cane ethanol Brazil[4]	
Adopted approach	Risk adder approach	Chain analyses	Chain analyses	Partial equilibrium model	Partial equilibrium models	
Refers to	No specific target	EU biodiesel target	See below	Global biofuels scenario, including Brazil, USA, EU, ROW	RFS II	LCFS II
Biofuels blends and volumes considered	Not included	6.5 Mtoe RME, 16.5 Mtoe palm oil biodiesel	Not specified	100 Mtoe EtOH, 25 Mtoe biodiesel	3.5 Mtoe EtOH	3.0 Mtoe EtOH
Feedstocks considered	All	1^{st} generation	1^{st} generation	1^{st} generation and 2^{nd} generation	1^{st} generation	1^{st} generation
Treatment of co-products		Displace primary agri commodities	Displace soy meal and cereal	Displace primary agri commodities, exact effect unclear	Electricity, allocated to	Electricity, allocated to
Trend in yields	Not included	Included in the model	Yield follows demand, below 1,8% annual demand growth no area expansion	Included in the model, how is unclear	Included	Included
Food/feed demand	Not included	Not included	Not considered	Changes in food demand as result of biofuels demand	Included	Included
Relation between price and food/feed demand	Not included	Not included	Not considered	Included – price 30% higher compared with reference	Included	Included
Relation between price and intensification	Not included	Not included	Not considered	Included in the model	Included	Included
Arable land increase, Mha	Not considered	Rapeseed: net 2.5, Palm oil: net 3.9	Assumed	22		
ILUC factor, kg/GJ (20 years depreciation)		Palm oil biodiesel = 74 Rapeseed biodiesel = 4	Feed wheat: -136 Maize -96, Rapeseed -157 Sugar beet 0, Sugar cane 55 Soy bean 166, Oil palm 153	45 average, ± 60 for 1^{st} generation (mostly ethanol), 0 for 2^{nd} generation	6	69
Remarks	Corbey assumes 105 tonne C/ha	Draft results	Assumes maximum avoidance of deforestation in tropics. By-products of EU crops as soy replacement		Increased live-stock density	No increased livestock density

For comparison: estimated 2020 EU automotive transport fuel consumption will amount to 316 Mtoe. A 10% target would obviously require 32 Mtoe biofuels.

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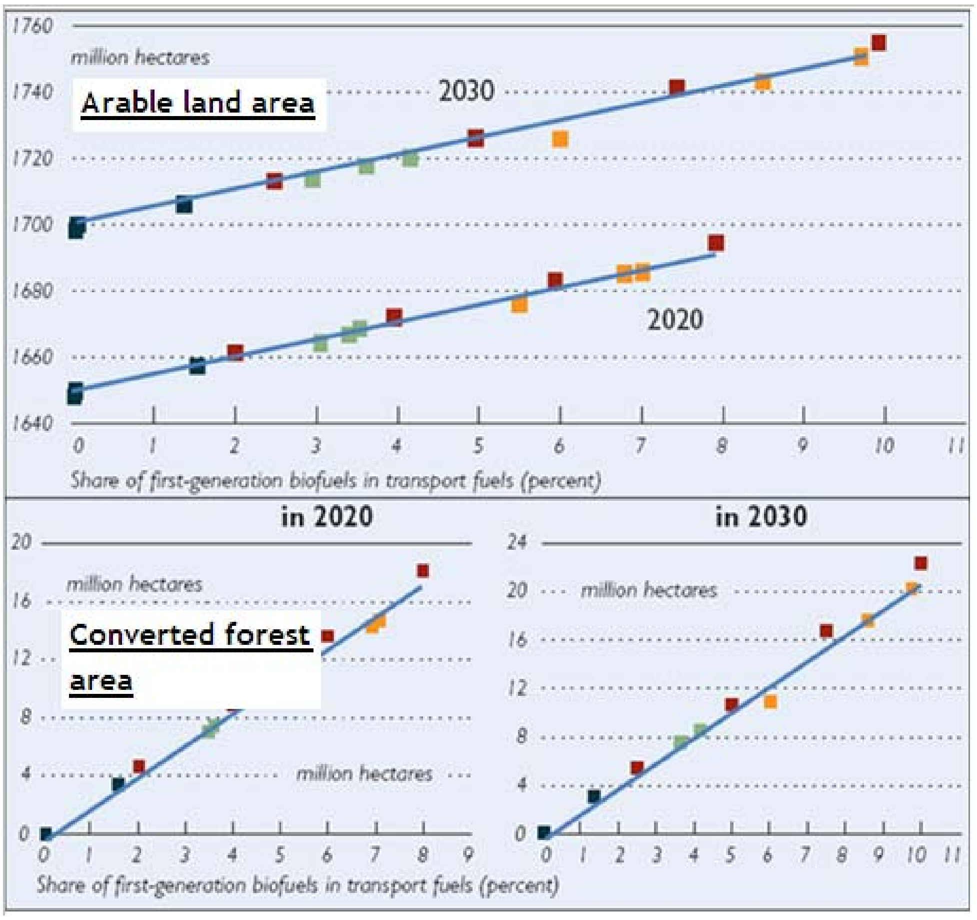
4 The ILUIC factors in these reports where adjusted to a 20 years time frame.

Table 6 General aspects of the approaches and studies considered, second table

	Banse et al.	JRC AGLINK model simulation	IFPRI GTAP-E model simulation	
Adopted approach	Partial equilibrium model	Partial equilibrium model	Computable general equilibrium model	
Refers to	Global agricultural scenario incl. biofuels; EU: country-specific, other: ROW	EU biofuels policy within global biofuels policy	EU biofuels policy within global biofuels policy	
Biofuels blends and volumes considered	25 Mtoe extra biofuels in EU (compared with 3% biofuels in reference)	18.3 Mtoe extra biofuels in the EU, of which 5.6 Mtoe 2^{nd} generation	17.8 Mtoe biofuels in the EU, of which 3.6 Mtoe ethanol	
Feedstocks considered	1^{st} generation	1^{st} generation impact assessed	1^{st} generation impact assessed	
Treatment of co-products	Extra co-products, lower feed price and meat prices	Extra co-products, lower feed price and meat prices		
Trend in yields	Iso-elastic yield function, exact number unclear	Iso-elastic yield function, exact number unclear		
Food/feed demand	Included	Included	Included	
Relation between price and food/feed demand	Included – prices decrease less compared with reference	Included	Included – no indication of food price changes	
Relation between price and intensification	Included	Included	Included	
Arable land increase, Mha)	15	5.2	In Business As Usual: 8.2	In Free Trade: 9.8
ILUC factor, kg/GJ (20 years depreciation)		Cereals based bio-ethanol: 5-15 Rapeseed and soybean based biodiesel: 10–45	In Business As Usual: Ethanol, average: 18 *sugarbeet = 16, sugarcane = 18, maize = 54, wheat = 37* Biodiesel, average = 59 *rapeseed = 54, palm oil = 50, soybean = 75, sunflower = 61*	In Free Trade: Ethanol, average: 19 *sugarbeet = 65, sugarcane = 19, maize =794, wheat =167* Biodiesel, average = 56 *rapeseed = 51, palm oil = 48, soybean = 68, sunflower = 57*
Remarks		ILUC factors estimated by authors, based on indicated LUC (Mha)		

According to the illustrations presented in IIASA (2008), every extra percent or 20 Mtoe of 1st generation biofuels (on a global scale) results in an expansion of arable land of approximately 5.5 Mha, extra deforestation of approximately 2.2 Mha and a land use change-associated emission of approximately 110 tonne CO_2/ha.

Figure 5 Relation between percentage of 1st generation biofuels and arable land expansion and deforestation determined in IIASA, 2008



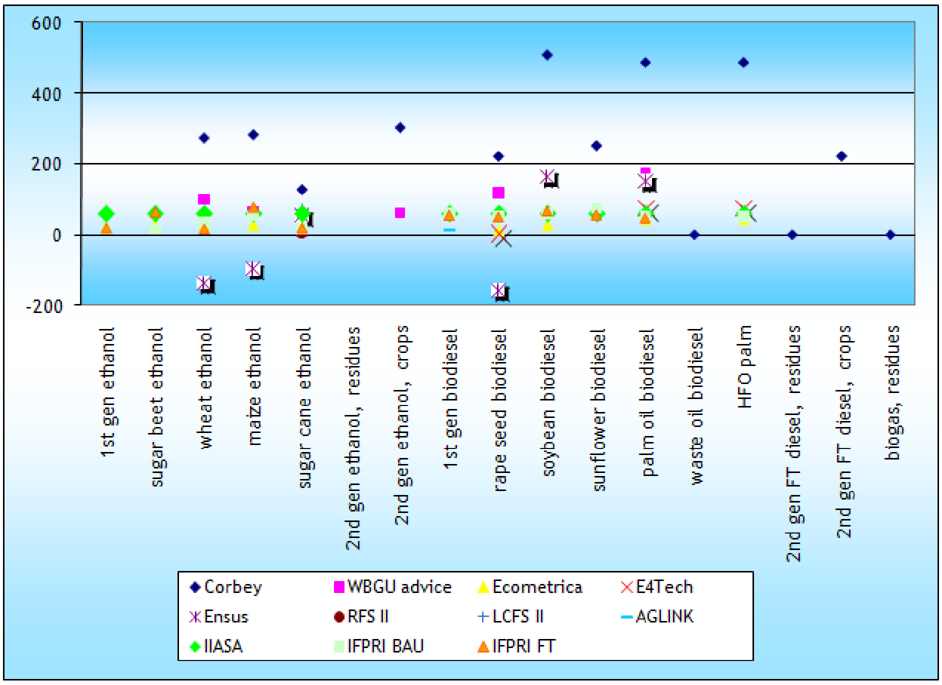
Source: Figures 13 and 14 in IIASA (2008), lines added by authors of present report.

The land use changes – with direct and indirect land use change aggregated to a single figure - calculated in the cited studies and the resulting GHG emissions per unit of fuel are given in Figure 6. For comparison, the figure also includes the emissions estimated in the different chain analyses and those that would result from using a standard emission factor per unit area of converted land.

Compared with the risk adder approaches proposed in the Corbey Commission Advice and as included in the WBGU advice, the model calculations give significantly lower ILUC emission factors. This illustrates the effects of by-products utilisation and feedback loops. It also illustrates the fact that land use change will relate not only or largely to deforestation, but will pertain far more to grassland conversion. According to the illustrations presented in IIASA (2008), every extra percent or 20 Mtoe of 1st generation biofuels (on a global scale) results i an expansion of arable land of approximately 5.5 Mha, extra deforestation of approximately 2.2Mha and a land use change-associated emission of approximately 110 tonne CO_2/ha.

The ENSUS results and the LCFS analysis for sugar cane ethanol demonstrate that it is possible to produce (very) positive effects depending on the assumptions applied. In the LCFS analysis this concerns the assumed intensification of livestock husbandry in Brazil, in the ENSUS chain analysis the substitution ratios of soy by biofuels by-products and the avoided level of deforestation and associated greenhouse gas emissions.

Figure 6 Estimated ILUC factors for biofuels (all figures in g/MJ)



If we skip the risk adder approaches, because they do not really model the world (Corbey and WBGU), and the Ensus model because this model employs different assumptions which are inconsistent with all the other models, we retain the values from seven model calculations. These results are shown in Figure 7.

Figure 7 **Close-up of previous figure, with extremes omitted (all figures in g/MJ)**

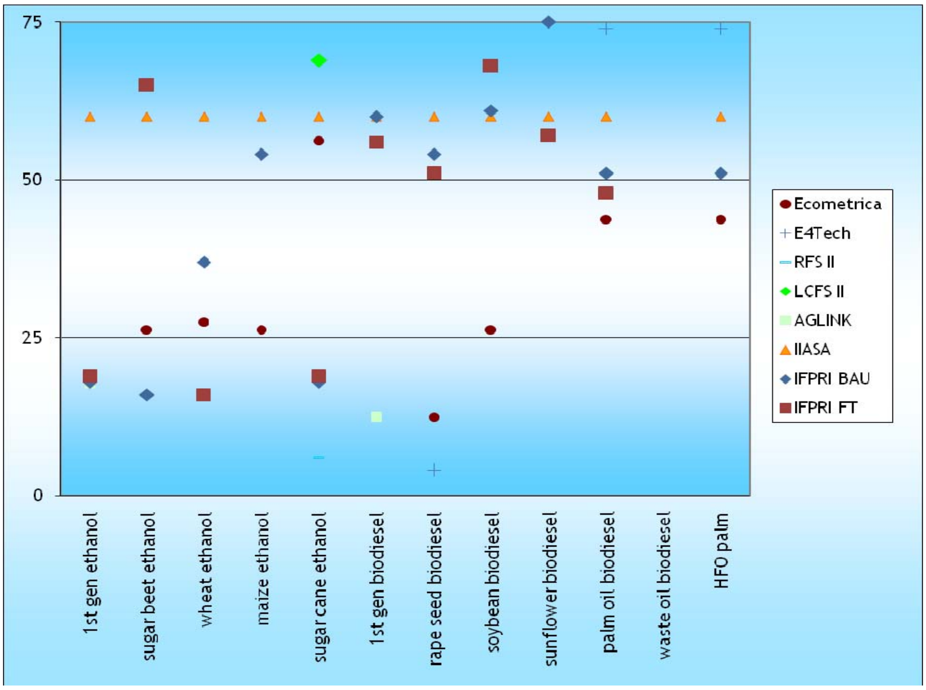


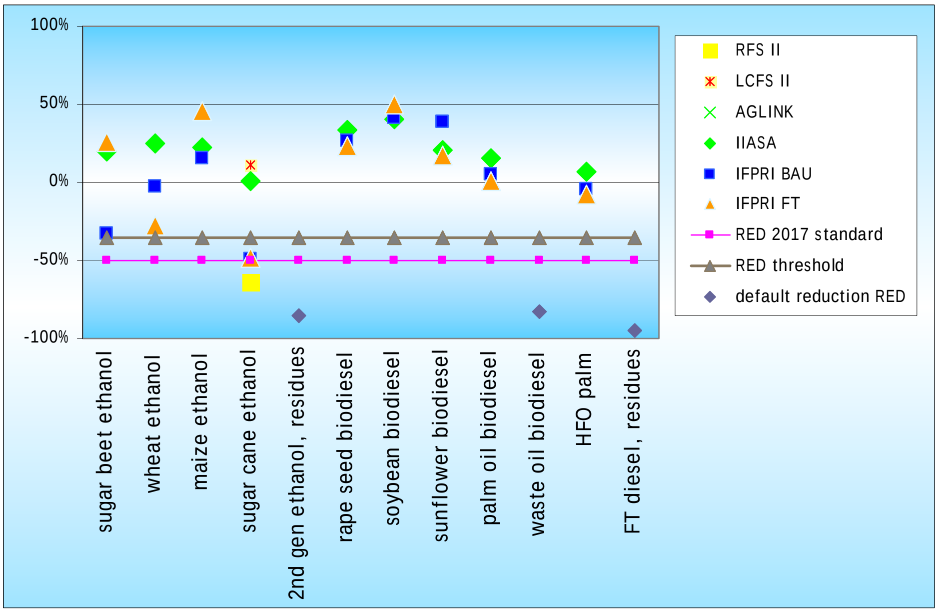
Table 7 shows, for the major biofuel crops, the minimum, maximum and average values for the ILUC effect from the seven models. These values are also reported as percentage points.

Table 7 **ILUC effects calculated in the models considered (Econometrica, E4tech, LCFS II, EPA, AGLINK, IIASA, IFPRI BAU, IFPRI FT)**

	ILUC effect in gram/MJ biofuel			ILUC effect in % points		
	Lowest value	Highest value	Average	Lowest value	Highest value	Average
1st gen. ethanol	18	60	29	21%	72%	34%
Sugar beet ethanol	16	65	42	19%	78%	50%
Wheat ethanol	16	60	35	19%	72%	42%
Maize ethanol	26	79	55	31%	94%	65%
Sugar cane ethanol	6	69	38	7%	82%	45%
2nd gen. ethanol, residues	0	0	0	0%	0%	0%
2nd gen. ethanol, crops	Not analysed					
1st gen. biodiesel	12	60	47	14%	72%	56%
Rapeseed biodiesel	4	60	36	5%	72%	43%
Soybean biodiesel	26	68	54	31%	81%	64%
Sunflower biodiesel	57	75	64	68%	89%	76%
Palm oil biodiesel	44	74	55	53%	88%	66%
Waste oil biodiesel	0	0	0	0%	0%	0%
HFO Palm	44	74	57	53%	88%	68%

The percentages are illustrated in Figure 8.

Figure 8 **Net greenhouse gas reductions of various biofuels, taking ILUC emissions into account**



Conclusions from the model calculations

The graph shows a wide spread in modelling results for ethanol, with results depending on the basic assumptions employed and simulated relations being either approximately 20 g/MJ or about 60 g/MJ, depending on the study and assumptions. The results for biodiesel show a more even distribution, with an average value of approximately 60 g/MJ. The only exception seems to be the estimated ILUC factor based on the AGLINK simulation by JRC (see 0 for calculations), which gives an estimate of approximately 20 g/MJ.

We see four possible conclusions from these ILUC modelling calculations:

A: Minimum ILUC risk: Use maximum ILUC factors from models

To ensure that every ILUC risk is eliminated, the maximum calculated ILUC factor from model calculations for the different individual crops can be taken as representative. This would mean an ILUC factor between 60 and 79 gram CO_2/MJ biofuel (72-94% would then have to be added to the GHG calculation).

B: Low ILUC risk: Use an average and general ILUC factor

Using one or a selected number of models, an average ILUC factor is estimated for the complete biofuel policy target; see the example provided by the IIASA study. Given the results of the simulations considered in this study, an average value of 60 gram CO_2/MJ biofuel appears to be a good first estimate. Alternatively, an average factor for diesel substitutes and for gasoline substitutes could be applied. In that case, 60 gram CO_2/MJ biodiesel and 40 gram CO_2/MJ bio-ethanol (see Figure 7) could be applied as a first estimate.

C: Medium ILUC risk: Use crop-specific average ILUC factors
If a certain level of ILUC risk is deemed acceptable in biofuel policies and model simulations are considered sufficiently accurate, one could conclude that the average crop-specific ILUC emissions calculated using model simulation(s) are a reasonable prediction of the ILUC effect. This approach will lower the ILUC risk but will not completely eliminate it, because the actual ILUC may be higher if the more pessimistic models prove to be more representative of real-world effects. With this approach, the ILUC factor for the crops will be between 35 and 64 gram CO_2/MJ depending on the biofuel feedstock (42 to 76%).

D: Eliminate any ILUC risk: Do not apply model simulations but use a direct link between biofuels and land use
If the model simulations are considered insufficiently accurate, a risk adder approach as suggested by the Dutch Corbey Commission or applied in the WBGU advice for the German government could be applied. These approaches are often intended as a stop-gap until more reliable models become available. As previously indicated, in these approaches a maximum risk scenario is applied in which the basic assumption is that each hectare of land used to produce biofuels leads to a conversion of one hectare of natural forest. For the associated loss of carbon sinks a global averaged factor is applied, e.g. 105 tonnes/ha (= 120 to 500 gram CO_2/MJ biofuels) in the Corbey Advice.

Pragmatic approach, does the approach matter in practice?
For all four approaches pros and cons can be formulated. Given the results of the model simulations considered, however, the differences between the three approaches is probably small. In many of the proposed approaches the RED GHG emission reduction goal of 50% will not be met by any current biofuels grown on existing agricultural land:
- With the 'average estimates' approach (suggestion C) HFO palm will yield a net GHG emission reduction of 27%.
- Ethanol from sugar cane will yield a net GHG emission reduction of 42%.

For the current 35% GHG threshold the discussion on methodology is more important because bio-ethanol form sugar cane can meet this standard with the 'average estimates' approach but not with the other approaches.

In Table 7 the different ILUC approaches are compared with the typical reduction percentages reported in the RED documents. There is also discussion about these values (allocation methods, N_2O calculation methods, etc.) but for the purposes of the present report on ILUC these direct emissions reduction figures have been used without any such discussion. In the last three columns the net emissions are calculated.

Table 8 Direct GHG reduction, ILUC effect and net GHG effect of selected biofuels

	RED typical reduction percentages	ILUC percentage in the three approaches			Net GHG effect in ILUC approaches (+ = extra emission, - = reduction)		
		Avoid risk (max. /crop)	Avoid risk (crops the same)	Reduce risk (average ILUC)	Avoid risk (max./ crop)	Avoid risk (crops the same)	Reduce risk (average ILUC)
1st gen. ethanol	-61%	72%	72%	34%	11%	11%	-27%
Sugar beet ethanol	-53%	78%	72%	50%	25%	19%	-3%
Wheat ethanol	-56%	72%	72%	42%	16%	16%	-14%
Maize ethanol	-71%	94%	72%	65%	23%	1%	-6%
Sugar cane ethanol	-87%	82%	72%	45%	-5%	-15%	-42%
2nd gen. ethanol, residues	-76%	0%	0%	0%	-76%	-76%	-76%
2nd gen. ethanol, crops		?	?	?	?	?	?
1st gen. biodiesel	-45%	72%	72%	56%	27%	27%	11%
Rapeseed biodiesel	-40%	72%	72%	43%	32%	32%	3%
Soybean biodiesel	-58%	81%	72%	64%	23%	14%	6%
Sunflower biodiesel	-62%	89%	72%	76%	27%	10%	14%
Palm oil biodiesel	-88%	88%	72%	66%	0%	-16%	-22%
Waste oil biodiesel	-69%	0%	0%	0%	-69%	-69%	-69%
HFO palm	-95%	88%	72%	68%	-7%	-23%	-27%

According to the studies considered, it is only sugar cane ethanol that would meet the standard under certain conditions. For biodiesel, on the other hand, no first generation technology route would meet the target. This is consistent with the fact that the EU biofuels policy has a significant impact on the vegetable oil market and will require an increase in vegetable oil production (compared with current consumption levels) of approximately 20%.

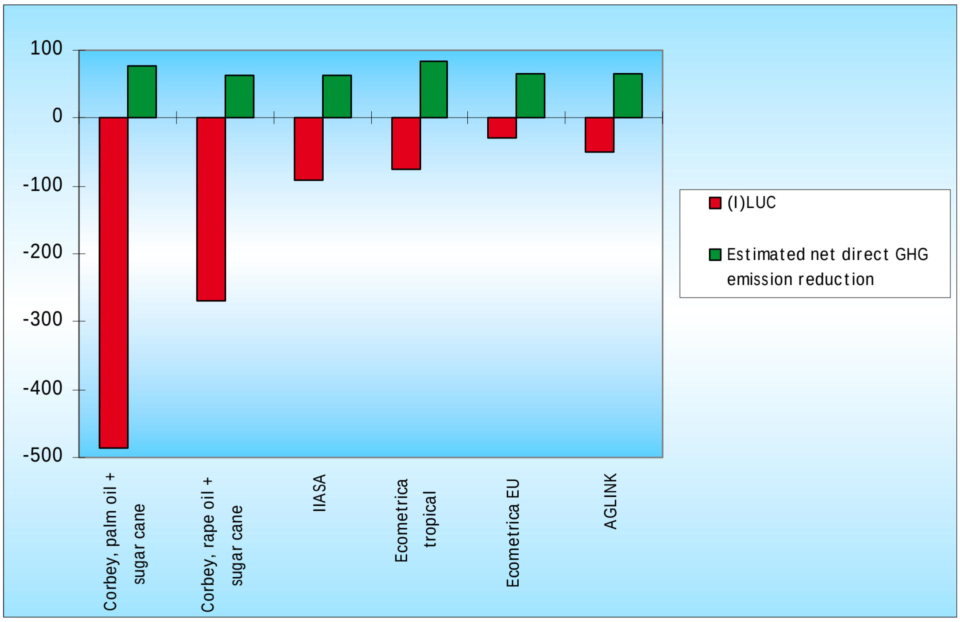
4.3 Impact of working assumptions on calculated (I)LUC factors

As indicated in the previous section, for all the biofuels considered assumptions and scenarios can be defined in which (I)LUC-related emissions are so high that the net GHG emission balance does not meet the RED 50% reduction standard. Indeed, in most cases there is even in a net emissions increase compared with the fossil fuel being replaced.

A comparison between the JRC AGLINK and IFPRI GTAP simulation results also illustrates the influence of the applied assumptions on the simulation outcomes (see also Table 9 and Figure 9):

– Although JRC (2009) considers a larger volume of biofuels than IFPRI (2010) – 28 Mtoe versus 18 Mtoe – the latter reports a higher (I)LUC-related emission. The differences are primarily a function of level of trade liberalisation and associated imported amounts of bio-ethanol and biodiesel (see Figure 7).
– Another determining factor explaining the differences in simulation results are the assumed increases in crop yields in EU and other regions.

Figure 9 **Annual GHG emissions related to use of biofuels, estimated with various approaches**



This raises the question of how realistic the various assumptions in the different simulations are. In the following subsections we offer some remarks on the sense of reality of the assumptions employed.

4.3.1 Applied assumptions and real-world trends: a comparison

Ethanol/biodiesel split

The IFPRI analysis considers a 45-55% split between bio-ethanol and biodiesel, while in the JRC AGLINK simulations this is 35-65%. The latter is more in line with trends in the EU automotive transport fuel market, which shows an increase in the market share of diesel of approximately 1% per annum and is currently already at 63%[5]. The split taken in the JRC study is also clearly more in line with existing and future[6] production capacity for bio-ethanol and biodiesel in the EU. Current biodiesel production capacity already amounts to 19.5 Mt of biodiesel (17.3 Mtoe), while bio-ethanol production capacity is only 7 Mt (4.5 Mtoe).

5 See http://ec.europa.eu/environment/air/transport/fuel_quality_monitoring.htm.

6 'Future' as being under construction or having been announced.

Table 9 **Overview of assumed biofuel mixtures and crop yield increases**

	AGLINK BAU	AGLINK HY	IFPRI BAU	IFPRI FT	Banse
Biofuels (Mtoe) consumption EU	18.3 Increase from current 10 Mtoe consumption level		17.8		36
Ethanol	5.8	5.8	7.99	8.01	
of which imports	1.5	1.5	5.82	7.57	
of which 2nd gen.	1.7	1.7			
Biodiesel	12.4	12.4	9.78	9.82	
of which imports	1.8	1.8	0.74	0.75	
of which 2nd gen.	2.8	2.8			
Mha/Mtoe	0.29	0.04	0.46	0.55	0.42
Yield increases EU					
Cereals	0.90%	1.20%	0.50%	0.50%	
Oil seeds	1.80%	2.10%	0.50%	0.50%	
Sugar beet	0.80%	1.10%	0.50%	0.50%	

Table 10 **Overview of calculated arable land expansion (in '000 ha)**

	AGLINK BAU	AGLINK HY	IFPRI BAU	IFPRI FT	Banse
Arable land increase					
EU	1,463	808	780	460	4,000
Outside EU	3,753		7,420	9,290	11,000
USA	269	-140			
Canada	130	105			
Australia	279	129			
Africa	247				1000
China	30	-359	80	80	
Other Asia	573		140	140	
CIS	377	196	649	563	
Brazil	989	506	4,810	6,860	6,000
Other Latin America	669	516	400	410	
The rest	190	-1,574	1,341	1,237	4,000

Share of second generation biofuels

The JRC AGLINK simulation explicitly assumes production and imports of 7 Mtoe of 2nd generation biofuels in the EU in 2020. The IFPRI GTAP simulations probably also assume significant consumption of these fuels. However, the first commercial-scale 2nd generation technology plants will not commence operation before 2012 and will not be situated in the EU but in the USA (see also Chapter 5). This implies that global production capacity will be limited at best and will probably not be available for the EU market.

Location of land use changes

The two studies predict a different geographic distribution of centres of gravity for land use change.

The JRC simulation with AGLINK predicts that a significant part of the expansion of arable land – one-third of the total - will occur in the EU itself. Or rather, a decline is assumed in the rate at which arable land in the EU is being abandoned and is converted to grassland or abandoned to nature.

The JRC simulation predicts a similar expansion of arable land in Latin America for sugar cane and soybean cultivation. The last third of the estimated land use change consists of oil palm area expansion in South East Asia and cereals and oilseeds area expansion in the USA, Canada and CIS member states. As in the EU, these increases in cropped area translate primarily to a slow-down in the rate at which of arable land is abandoned.

In the IFPRI simulation, on the other hand, the land use change relates mainly (70% or more) to arable land expansion in Latin America for sugar cane and soybean cultivation.

The JRC simulation with the AGLINK model is clearly more in accordance with current situation in which almost all the biodiesel and three-quarters of the bio-ethanol consumed in the EU is produced domestically (see e.g. USDA, 2009). This situation may change for bio-ethanol if large volumes of competitive sugar cane ethanol from Brazil could be imported, an issue discussed in the following subsection.

Sugar cane ethanol imports

The future volume of imported Brazilian ethanol calculated in the IFPRI simulations is significantly higher than the volumes estimated by experts or assumed in other studies. The FAO-OECD 2009–2018 Outlook, EU Agri 2009–2015 Outlook and EU AGRI EIA for EU biofuels policy, for example, all project imports of between 1.5 and 2.5 Mtoe per year. The volume calculated in the IFPRI study, on the other hand, is between 5.8 and 7.6 Mtoe per year. In the other studies, imports are assumed to remain limited because of the anticipated rapid rise in domestic consumption in Brazil. In all these studies the volume available for exports is assumed to be limited in view of the fact that sugar cane ethanol in Brazil is cheaper than petrol. Production costs are expected to become ever lower as the costs of both sugar cane cultivation and ethanol production are steadily declining. In addition, recent car sales in Brazil have shown a sharp increase in flex-fuel cars, allowing a high share of ethanol in transport fuel consumption. Thirdly, the USA seems a more attractive export market, with two-thirds of Brazilian exports going to that country.

Palm oil utilization in biofuels production

In both the JRC AGLINK and IFPRI GTAP simulations, the amount of palm oil used directly for biofuels production is assumed to be limited. However, this is at odds with the 2.2 Mtoe of HVO production capacity already operational, under construction or announced. As a result, the role of palm oil and associated land use changes and greenhouse gas emissions may be underestimated.

Soy and rapeseed feedstocks

In addition, the USDA and EU reports clearly indicate a growing supply of rapeseed and rape oil from Canada and Ukraine to the EU. This is not readily traceable in the results of the two simulations, however, as the land use changes calculated for both countries are rather limited compared with current exports. The estimate that Latin American soy oil and biodiesel will be exported in large quantities to the EU, on the other hand, matches USDA observations that several Mtoe of biodiesel production capacity is being realized in Argentina, all of it aimed at exports to the EU.

Crop yield increases

Concerning crop yield increases, IFPRI assumptions for increases in the EU are lower than the most pessimistic FAO forecasts we found in the literature considered (see e.g. Table 11 and Figure 12). The AGLINK-based JRC simulation seems defensible for cereals, but is on the other hand fairly optimistic with respect to the yield increases anticipated for oilseed and sugar crops.

4.3.2 Synthesis

The overall picture appears to be that the simulations contain a number of assumptions that may be debatable or do not match real-world trends. This applies more to the IFPRI report than to the JRC report. The questionability of assumptions will probably mean the calculated ILUC factors are uncertain, but it is beyond the scope of the present study to indicate to what extent.

The simulations and chain analyses, on the other hand, indicate the factors that can reduce the risk of ILUC-related GHG emissions. ILUC emission factors will generally be limited if:

- imports are not from regions where the agricultural frontier is moving into naturally carbon-rich ecosystems;
- feedstock production is concentrated on arable land that would otherwise be abandoned;
- yield increases are maximized in a sustainable manner which avoids increased emissions from fertilizer use.

4.4 Synthesis

According to the simulations considered in this study there is no 1st generation biofuel that unambiguously meets the RED GHG emission reduction standard. For all 1st generation biofuels, assumptions and scenarios can be defined in which (I)LUC-related emissions are so high that the net GHG emission balance exceeds the RED 50% reduction standard.

According to the studies considered, only sugar cane ethanol, sugar beet ethanol and wheat ethanol could meet the standard under certain conditions. For biodiesel, in contrast, there is no first generation technology route that would meet the target.

The simulations and chain analyses, on the other hand, indicate the factors that can reduce the risk of ILUC-related GHG emissions. ILUC emission factors will generally be limited if:

- Imports are not from regions where the agricultural frontier is moving into naturally carbon-rich ecosystems.
- Feedstock production is concentrated on arable land that would otherwise be abandoned.
- Yield increases are maximized in a sustainable manner which avoids increased emissions from fertilizer use.

The consequent potential for reducing (I)LUC emissions is discussed in the next chapter.

5 Reducing the risk of land use change

Key message

The risk of indirect land use change-associated greenhouse gas emissions being induced by the EU's biofuels policy can be partly mitigated through:
- maximum use of by-products as biofuels feedstocks;
- maximum use of residues as biofuels feedstocks.

The potential for residue-derived biofuels is limited to several Mtoe, or approximately 1% of EU transport fuel demand, but these biofuels will count double for the target, thereby doubly reducing the requirement for food crop-based biofuels.

In the short term, crop cultivation on degraded arable land is an unlikely option for mitigating ILUC risks. Creating extra arable land for biofuels feedstock cultivation by stimulating increased yields for food and feed crops would appear to be a process requiring more time than the period up to 2020 considered in this study.

The availability of abandoned land in the EU and neighbouring former Soviet states now and in the coming decades is unclear, with various sources giving very different estimates. This potential may be very significant, though, up to 10–35 Mha or 15–50 Mt biofuels.

As stated in Chapter 3, there is a significant risk that the EU's biofuel policy target will lead to increased land use change. The growth of demand for biofuels will induce growth in crop demand and the associated requirement for cropland expansion. At the same time, however, various studies[7], including the simulations considered in previous chapter, indicate that the biofuels-induced risk of land use change can be limited by agro-economic mechanisms and can be further mitigated by technical developments. This chapter discusses these mechanisms and developments.

5.1 Cultivation on abandoned arable land

Crop cultivation for biofuels production will not lead to land use change or deforestation if the crops are cultivated on abandoned arable land. Arable land may be abandoned because of soil degradation or because agriculture on the land in question is uncompetitive owing to high production costs per unit of crop. For biofuels production to be competitive on this kind of abandoned land will require additional policies to lower the costs.

How much abandoned land is and will become available within the EU cannot be unambiguously determined on the basis of the sources reviewed.
- Eururalis simulations of the future of rural Europe conducted for the Dutch Ministry of Environment indicate that significant areas of arable land will be abandoned within the next two decades. Depending on the level of further liberalisation of the EU agro-economic market, 3.5–25 million hectares will be abandoned in the EU up to 2030 (see Rienks, 2008). For

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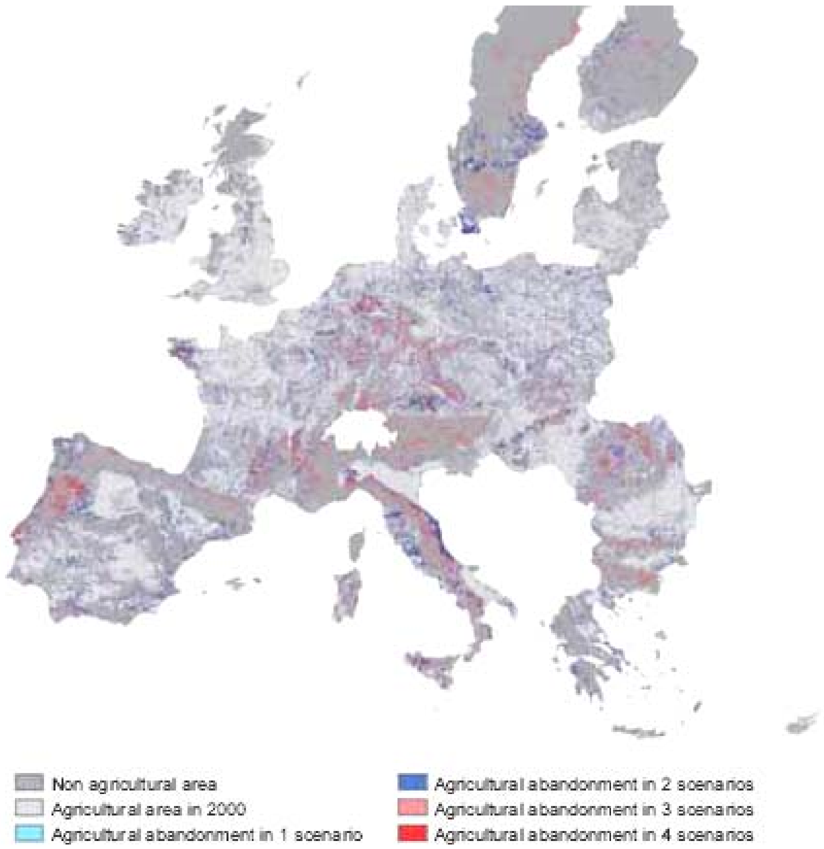
[7] See e.g. Dornburg, 2008; Refuel, 2008; Renew, 2008.

comparison, the current area of fallow land in the EU already amounts to approximately 5 Mha[8]. Abandonment is expected to occur in mountain ranges (Alps, Carpathians) and dry regions, but also in agricultural regions in France and Germany (see Figure 10). It is unclear how easily production could be maintained in these various areas or how easily they could be returned to production and how competitive feedstock cultivation would be.

- On the other hand, both the EU DG Agri 2009–2015 Outlook and FAO–OECD 2009–2018 Outlook indicate that the area of arable land in Europe will actually increase in the periods considered. The main reason for this expansion is cultivation of biofuels feedstocks. The EU Outlook also predicts a diversion of cereals from exports to bio-ethanol production. This probably implies a need for extra cereal cultivation in other parts of the world to balance the reduction in EU exports, although the FAO OECD Outlook in fact predicts an rise in cereals exports from the EU.
- Contrary to both Outlooks and consistent with the Eururalis simulations, (Banse, 2008) predicts a decrease in the area of arable land, which to some extent will be offset by crop cultivation for biofuels production.

Figure 10 Geographic presentation of arable land in the EU prone to abandonment



Source: Rienks, 2008.
Simulations for different scenarios with different levels of liberalisation. The number of scenarios indicates the probability of abandonment.

8 See (EU, 2009). This figure includes the effects of the 2007/2008 food prices spike.

In neighbouring Ukraine and Russia and in Kazakhstan almost 23 Mha of arable land has become idle over the past 15 years as a result of the break-up of the Soviet Union (see CE, 2008; USDA, 2006; USDA, 2008). The FAO stated in 2008 that of the 23 Mha idle land in the former Soviet Union, 13 Mha could be returned to use with little environmental impact[9]. In practice, this has already occurred with some of the abandoned land in Kazakhstan (see USDA, 2008).

In regions outside the EU, former Soviet Union and North America, land is rarely abandoned for economic reasons. On the contrary, in these regions arable acreage is continuously expanding, both for domestic food and feed supply and for exports. In consequence, biofuels imports from these regions will very probably be associated with conversion of natural areas.

In summary we would say there is no abandoned cropland to be found in developed countries. However, it is unclear how much abandoned land might become available within the EU and how much in neighbouring CIS member states.

From an environmental perspective, consideration needs to be given to one possible drawback of taking abandoned land back into production. If such land were returned to nature, it could sequester carbon by natural regrowth of vegetation. Depending on what kind of natural regrowth occurs – forest or grassland – up to 3 Mt C/ha/y could be sequestered[10]. In addition, biodiversity would also increase. By recropping abandoned land, these benefits would be forfeited.

5.2 Cultivation on degraded land

When it comes to the scope for biofuel feedstock cultivation on degraded lands, two recent authoritative Dutch advisory reports to the Dutch government on the potential availability of sustainably produced biomass– Dornburg (2008) and Bindraban (2009) – cast strong doubts on such possibilities.

Dornburg (2008) draws the following conclusions:

> *Cultivation on degraded arable land represents a significant share of possible biomass resource supplies.*
> *However experiences with recultivation and knowledge on these lands (that represent a wide diversity of settings) are limited so far. More research is required to assess the cause of marginality and degradation and the perspectives for taking the land into cultivation. Research and demonstration activities required to understand the economic and practical feasibility of using degraded/marginal land is needed.*

In Bindraban (2009) the following conclusion is given:

> *Based on our expert judgement we find it unlikely that much feedstock will be produced on marginal lands by 2020, as exploitation requires large amounts of external inputs including water and nutrients and because institutional and infrastructural conditions have to be put in place as well. Improving the ecological conditions of marginal lands takes decades, while yield performance will be low and highly variable. These conditions do not favour a rapid exploitation of these regions.*

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9 See http://www.fao.org/newsroom/en/news/2008/1000808/index.html.

10 See e.g. http://www.transust.org/workplan/papers/wp2_task_4_landuse1.pdf.

In summary, cultivation on degraded arable lands is presently an uncertain, expensive and probably unlikely option, in terms of both potential and yields. This may change if policies (including biofuel policies) substantially support the use of such marginal and degraded land.

The exception would be chemically polluted land within the EU that is unfit for food and feed crop cultivation, such as covered tailing reservoirs and landfills. According to Peck and Voytenko (Peck, 2008) there is at least 800,000 ha of chemically polluted land within the EU. Using this land would require secure separation of the contaminated crops from other crops. Although technically promising, this may therefore be a difficult market to develop.

5.3 Specific yield increases

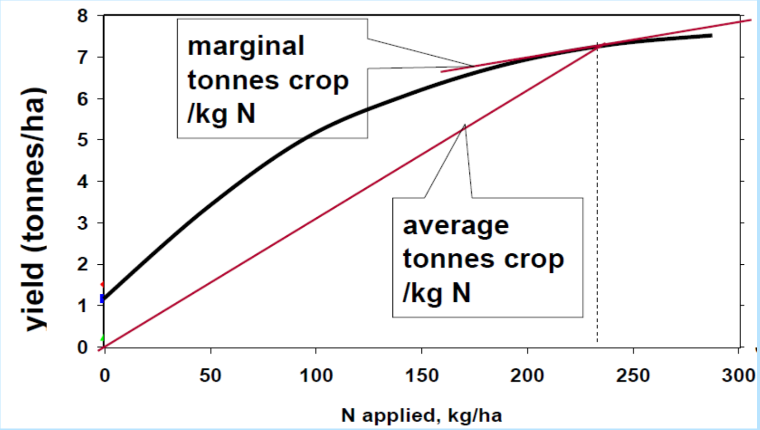
Increasing the yields of specific crops would reduce arable land requirements. This could theoretically reduce land requirements for food and feed and other non-biofuel agricultural products to such an extent that enough arable land becomes available for meeting the various global biofuels targets. Such increases require higher agronomic inputs (fertilizers, pesticides) and investments in higher-yielding crops, agricultural machinery and other aspects.

Specific yield increases are in principle stimulated by higher crop prices: the more a farmer can earn per unit of crop, the greater the feasible investments and operational costs (see Figure 11 for an example by way of illustration). In this sense the anticipated razing effect of biofuels policies on market prices for agricultural commodities will in itself act to reduce land requirements, as the higher prices will result in higher specific yields.

Potential negative impacts of higher agronomic inputs

If improperly managed, increasing agronomic inputs such as irrigation water, fertilizers and plant protection products can result in a series of negative environmental impacts. Examples include the hundreds of thousands hectares of arable land suffering from salinization as a result of unsound irrigation and the 'nitrate bomb' in the groundwater of north-west Europe (see e.g. UNEP's GEO 4 report).

Increasing N-fertilizer inputs can lead to increased N_2O emissions per unit crop. As crop yield is not a linear function of fertilizer input, the extra fertilizer is used less efficiently by the plant, with a greater percentage being converted directly to N_2O or leached or volatilized and subsequently converted into N_2O. This relative increase in N_2O emissions per unit crop reduces the GHG emission savings associated with the biofuel produced from the crop.



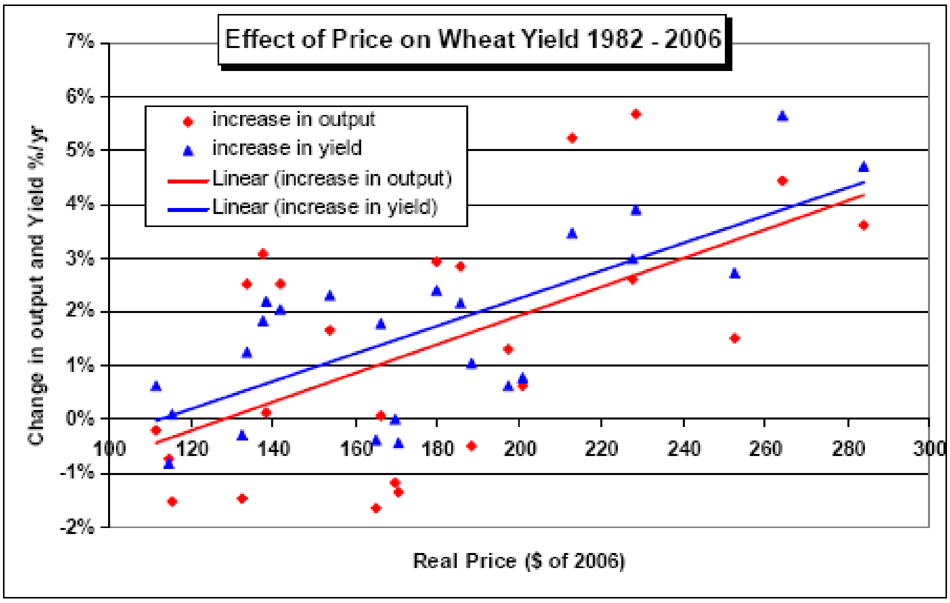
Source: Marelli, 2009.

The sensitivity of yield to market prices is very region-specific, however. In the EU most of the production growth comes from extra yield. In Brazil and Indonesia, the extra production comes partly from area expansion. In certain other parts of the world, exposure to global markets is very limited and the yield response is consequently very limited.

The actual sensitivity of yields to prices in markets that are exposed to global commodity markets and the potential for yield improvements remain uncertain and a subject of debate among researchers and scientists.

The potential for crop yield increases will certainly vary for different regions. In the EU potential is limited, partly because of CAP and environmental constraints; examples include the water framework directive and associated legislation concerning nutrients management, which aim to tackle the significant environmental impacts of past productivity increases. Besides, in most regions of the EU, annual crop yield improvements are dwindling as the crops concerned have limited remaining scope for improvement. In other regions there is more potential for specific crop yield increases (see Table 11 and Figure 12).

Figure 11 **Indication of relation between yield and commodity price**



Source: ENSUS, 2008, R^2 = ± 55%.

According to Bindraban (2009), however, general expectations as to future improvements in crop yields are not high:

> *The decreasing availability of water, fertile land and other natural resources, decreasing increase in crop production potential, decreasing investments in agricultural infrastructure such as irrigation facilities, and the decrease in the overall investments in agricultural research and development over the past decade or two are likely to put limitations to yield increases in the coming decade or more. Agricultural development is a long term process because of large time lags. Reviving the speed of agro-technical innovations, such as breeding a new variety, installing a dam, designing modified agronomic practices, may take a decade or more. This is also true for their implementation because these require socio-economic and institutional changes including a change in behaviour of farmers and other actors in and outside the sector.*

Similar constraints on any rapid increase in productivity are cited by Miller (2009).

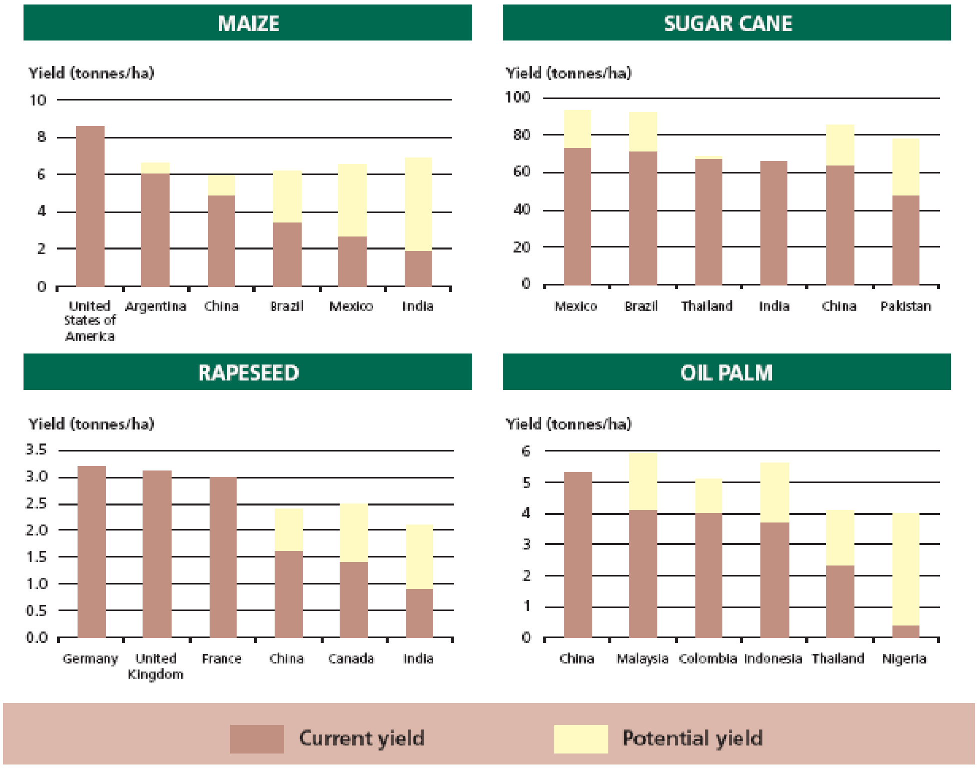
The overall conclusion seems to be that yield increases will not generate extra arable land for producing biofuels feedstocks within the period up to 2020 considered in this study.

Table 11 **FAO prognosis for land productivity (% change per year from 2001 to 2030)**

	EU-15	CEEC_EU	USA	Oceania	E_Asia	SE_Asia	S_America	M_Africa	S_Africa	World
Rice	0.67	-0.23	0.83	0.20	0.93	1.10	1.57	2.40	3.47	1.10
Grains	1.17	0.60	0.73	1.40	1.60	1.40	1.53	2.13	1.60	1.17
Sugar	0.93	1.10	0.67	0.73	2.80	1.13	1.13	2.13	0.60	1.33
Oils	0.40	0.90	2.63	1.03	1.30	0.97	1.10	2.43	2.03	1.23
Horticulture	0.50	0.60	1.30	1.20	2.80	1.83	1.30	1.77	0.73	1.60
Other crops	0.60	1.17	1.57	1.73	2.20	0.80	1.00	1.97	1.50	1.50
Cattle SG	0.40	0.00	0.20	0.37	1.50	2.77	0.87	2.97	1.40	0.77
Pigs, poultry	0.17	-0.30	0.97	0.63	0.43	2.33	1.33	3.37	1.07	0.40
Dairy	0.20	0.10	0.33	0.87	1.53	3.50	0.57	1.23	0.60	0.23

Source: Bindraban, 2009, based on FAO sources.

Figure 12 **Potential for yield increase for selected biofuel feedstock crops**

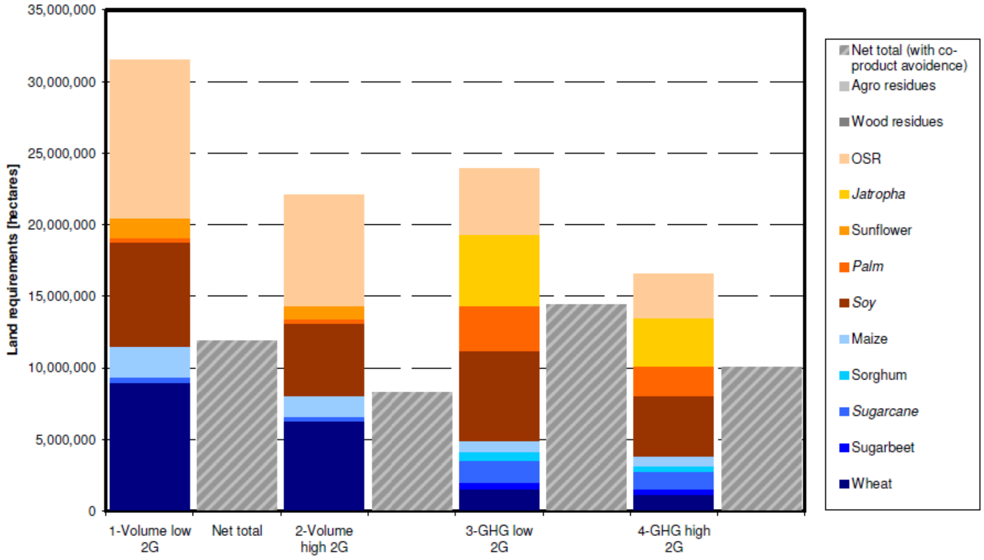


Source: FAO, 2008.

5.4 Utilization of biofuels production by-products as feed

The by-products of ethanol production and biodiesel production are suitable as feed and using them as such can potentially replace primary feeds in the shape of cultivated crops like wheat, coarse cereals, silage, grass, peas and derived products (e.g. oilseed meals) and lead to a reduction in the arable acreage required for growing these crops. It has been calculated that such substitution of primary feed crops by biofuel by-products may reduce land requirements for fodder cultivation by 30% or more (see also Figure 13).

Figure 13 Illustration of the impact of high-protein by-products on net land requirements



Source: Ecofys, 2008.

In Gallagher (2008) and CE (2008b) the evidence cited in the textbox below was included with respect to the value of by-products for feed.

By-products utilization in feeds

As mentioned in several sources, Distiller Grains (DG) the by-product of ethanol production is readily applied in the USA – where large and increasing amounts are being produced - as feed for cattle and dairy livestock. DG contains higher levels of digestible fibre and higher levels of bypass protein than alternative feeds, making it an ideal feed for ruminants and especially dairy livestock. In dairy livestock DG seems to enhance milk production per unit of feed.
DG was until recently viewed as a less suitable feed for non-ruminants. However, new dry milling ethanol plants seem to produce a (far?) more digestible product that yields comparable digestive energy compared with corn and which can be used as a protein source. DG in poultry diets is probably limited to 20% weight due to the high content of fibres and because of the risk of colour change of egg shells. In pigs an inclusion rate of more than 20% weight results in soft fat due to the oil content and oil quality of DG.

Rape seed meal (RSM) is an established protein source in dairy and beef cattle diets and finds more and more application in pig diets (see e.g. OECD-FAO, 2007). Incorporation ratios in pig diet are however limited due to the presence of toxic substances and because RSM can give a fishy taste to pig fat.

The applications in which the by-products are utilized will probably also depend on national policies of by-products producing countries. The French government for example is actively involved in stimulation of RSM as an SBM substitute within the own country (USDA, 2005), not only in ruminants diets, but also in pig and poultry diets. USDA is actively supporting incentives for DG's exports to Mexico, Asia and Europe for application primarily in poultry and pig diets.

By-products utilization as feed is not a guaranteed use of by-products, however. In both the USA and the EU certain producers are using or planning to use Distiller Grains as a fuel, either by direct combustion in a boiler or by producing biogas for use as a fuel for heat and power or transportation[11]. Legislation may be required to stem this development and stimulate more land use-efficient use of biofuels feedstocks.

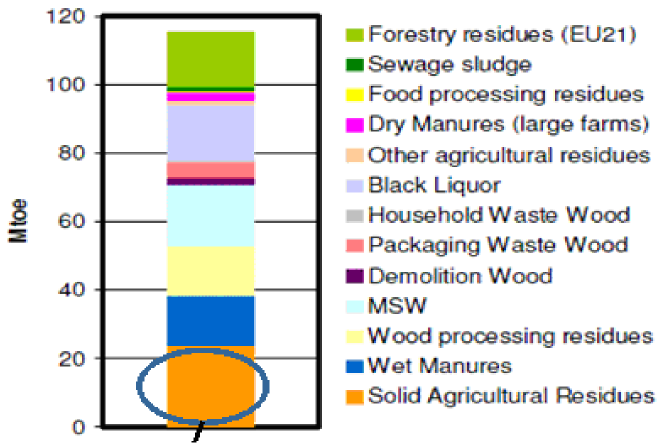
5.5 Utilization of wastes and residues as a feedstock and 2nd generation production technology

Land requirements may be reduced by using wastes and residues of low economic value like manure as biofuel feedstocks. This option requires no additional land. Useful application of these types of feedstocks is stimulated by the EU Renewable Energy Directive, under which residue-based biofuels contribute double to the 10% target.

Certain residues are already being used for biofuels production:
- Biodiesel from residual frying oil and low-quality residual fats from slaughterhouse waste already amounts to approximately 0.5 Mt of biodiesel (USDA, 2009). The EU maximum potential is estimated at 100 PJ/a or 2.3 Mt, tallow included (Ecofys, 2008).
- Biogas from residues, manure and dedicatedly cultivated substrate crops is increasingly being used in transportation in the EU (see Biogasmax, Madagascar and Biogas highway programmes).

On the other hand, the volume of residues readily available and collectable as biofuels feedstock and thus the potential volume of associated biofuels is limited (see Figure 14).

Figure 14 Availability of residues in the EU



Source: Ecofys, 2008.

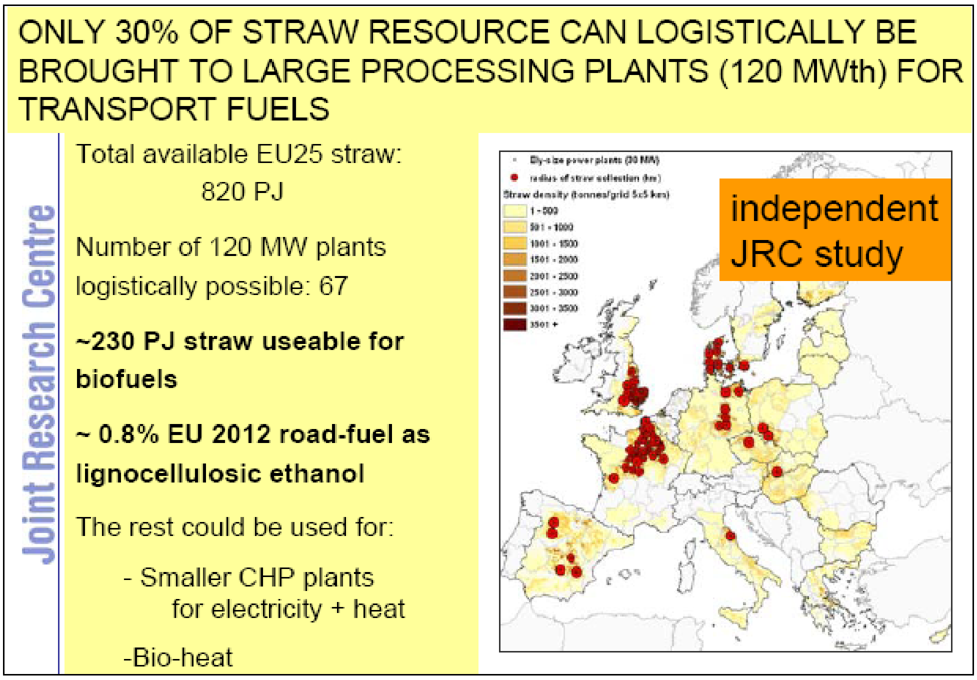
[11] See e.g. E'On's Malmo biogas initiative, Bioethanol Rotterdam initiative.

Besides these options, residues could also be applied for electricity and heat generation. Biofuels production would then in practice have to compete with bio-energy, since both use partly the same feedstock. This applies especially to biomass-based Fischer-Tropsch diesel and ligno-cellulosic ethanol[12] (see also JRC, 2007), as these production technologies are planned to be large-scale facilities requiring large volumes of feedstocks. According to (JRC, 2007) these technologies can be implemented only in regions where feedstocks are available in large quantities in a limited area, for otherwise the costs of feedstock collection and transportation will become prohibitive (see Figure 15, for example).

A third issue, effectively eliminating use of ligno-cellulosic residues (and ligno-cellulosic crops) as feedstocks for transport fuels in the coming decade is that the technology for converting such feedstocks is still under development and will not be available on a large scale for the EU before 2020:

- Technology development is slower than required for large-scale implementation before 2020. The first commercial-scale plants are expected to go on stream in 2011/2012 at the earliest. Any further increase in production capacity is likely to be postponed until these first facilities have been debottlenecked and the technology proven.
- Introduction of these technologies will probably not be concentrated in the EU but in the USA. Unlike EU biofuels policy, the US Renewable Fuels Standard requires an increasing volume of 2nd generation biofuels being the marketed from 2012 onwards. In the EU 2nd generation biofuels are credited as contributing double to the EU RED target, but are not mandatory. As a result, the first commercial-scale production units are being realized in the USA, not in the EU. This may be an indication of where the effort for further development of these technologies may be focused.

Figure 15 Illustration of the limited amount of residues potentially available for biofuels production



Source: JRC, 2008.

12 Ligno-cellulosic refers to wood-like biomass, lignin being the component present in wood that sets it apart from other types of biomass.

In the case of biogas, implementation is also limited by the need for adapted vehicles and a dedicated infrastructure, both of which are currently only available in a few regions of the EU, primarily in Italy. The production capacity of biomethane depends on the availability of manure and digestible organic wastes from households and food industries. In JRC (2007) the maximum potential production capacity for compressed biomethane is estimated at 200 PJ/a or 4.8 Mtoe. Current EU CNG[13] consumption is approximately 2 Mtoe/a, of which more than half is consumed in Italy[14]. The CNG could theoretically be replaced by biogas-derived CBM[15]. Enhanced implementation beyond this amount of 2 Mtoe/a requires not only investments in biogas production capacity but also increased penetration of CNG/CBG vehicles and an expansion of CNG/CBM infrastructure, e.g. filling stations.

In summary, residues already are an important feedstock within the EU biofuels market. Their role will remain important as the RED obliges to count biofuels from wastes, residues, non-food cellulosic and lignocellulosic (woody) biomass double. The potential that could be applied in the period until 2020 will however probably be limited to several Mtoes (approximately 1% of automotive transport fuel consumption) because of the constraints encountered in implementation.

5.6 Synthesis

Increasing production of biofuels leads inevitably to land use change. The impact can be mitigated, though, through agro-economic mechanisms or technical developments. Mitigation measures include the use of residues as feedstocks, cultivation of feedstocks on abandoned arable land and use of feedstock by-products as substitutes for primary crops as animal feed. The greatest scope for limiting land requirements for biofuel feedstocks will derive from maximum use of by-products as feed. The Potential for residues-derived biofuels is limited to several Mtoes, but these biofuels will count double for the target, thereby doubly reducing the need for food crop- based biofuels.

Cultivation on degraded arable lands, on the other hand, is currently unlikely to occur because of the high production costs. Creating extra arable land for biofuels feedstock cultivation by stimulating increased cultivation yields for food and feed crops will in all likelihood be a process requiring more time than the period up to 2020 considered in this study.

The availability of abandoned land in the EU and neighbouring former Soviet states now and in the coming decades is unclear, with various sources giving very different estimates. The potential could be very significant, however, amounting to 10–35 Mha or 15–50 Mt of biofuels.

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13 CNG = Compressed Natural Gas.

14 See http://www.ngvaeurope.eu/statistical-information-on-the-european-and-worldwide-ngv-status.

15 CBM = Compressed BioMethane.

6 Policies to prevent problems due to ILUC

6.1 What ILUC factor should be used?

The discussion in Chapter 5 and Section 4.3 indicates that the level of (I)LUC depends significantly on the nature of the policies implemented. The most relevant policies in this respect concern EU biofuels targets and sustainability criteria, (re)vitalization of EU rural regions, trade-related policies such as preferred supplier agreements and import fees. They could also include policies aimed at increasing crop yields, maximizing by-products utilization as feed, and production of biofuels from wastes.

If no policies are introduced for mitigating ILUC-related GHG emissions, or if future developments prove unfavourable with respect to ILUC-related emissions (e.g. no intensification of livestock breeding in Brazil when increasing sugar cane acreage), computer model simulations predict substantial ILUC emission factors for both bio-ethanol and biodiesel based on a range of crops.

Table 12 **CO_2 emissions due to ILUC, based on the models considered (Econometrica, E4tech, LCFS II, EPA, AGLINK, IIASA, IFPRI BAU, IFPRI FT), expressed as g CO_2/MJ biofuel and percentage of carbon emissions of fuel replaced**

	Highest value (1)	General value (2)	Average (3)	Highest value (1)	General value (2)	Average (3)
1st gen. ethanol	60	60	29	72%	72%	34%
Sugar beet ethanol	65	60	42	78%	72%	50%
Wheat ethanol	60	60	35	72%	72%	42%
Maize ethanol	79	60	55	94%	72%	65%
Sugar cane ethanol	69	60	38	82%	72%	45%
2nd gen. ethanol, residues	0	0	0	0%	0%	0%
2nd gen. ethanol, crops	?	?	?	?	?	?
1st gen. biodiesel	60	60	47	72%	72%	56%
Rape seed biodiesel	60	60	36	72%	72%	43%
Soybean biodiesel	68	60	54	81%	72%	64%
Sunflower biodiesel	75	60	64	89%	72%	76%
Palm oil biodiesel	74	60	55	88%	72%	66%
Waste oil biodiesel	0	0	0	0%	0%	0%
HFO Palm	74	60	57	88%	72%	68%

Notes:

- Highest value: highest ILUC emission per MJ biofuel as calculated with the respective model.
- General value: indicative average ILUC emission factor of the ILUC emissions per MJ biofuel, averaged over all the biofuels considered.
- Average: arithmetic average of the ILUC emissions per MJ biofuel as calculated with the respective model, for a specific crop.

A different approach to the issue was adopted by the Dutch Corbey commission (composed of industry, NGOs, scientists and government). Rather than taking a modelling approach, they propose an ILUC factor of 120 to 500 gram CO_2/MJ biofuels, estimated from direct linkage between biofuels and conversion of forests and grassland.

The ILUC effect of second-generation crops has not yet been predicted in the models and will need to be evaluated later.

We see four possible conclusions with respect to an ILUC factor:

A: Minimum ILUC risk: Use maximum ILUC factors from models
To assure that any ILUC risk is eliminated, the maximum calculated ILUC factor from model calculations for the different individual crops can be taken as representative. This would mean an ILUC factor of between 60 and 79 gram CO_2/MJ biofuel (72 tot 94% would then have to be added to the GHG calculation).

B: Low ILUC risk: Use an average and general ILUC factor
Using one or a selected number of models, an average ILUC factor for the complete biofuel policy target is estimated; see the example provided by the IIASA study. Given the results of the simulations considered in this study, an average value of 60 gram CO_2/MJ biofuel seems a good first estimate. Alternatively, an average factor for diesel substitutes and for petrol substitutes could be applied. In that case 60 gram CO_2/MJ biodiesel and 40 gram CO_2/MJ bio-ethanol (see Figure 7) could be applied as an initial estimate.

C: Medium ILUC risk: Use crop-specific average ILUC factors
If a certain level of ILUC risk is deemed acceptable in biofuel policies and model simulations are considered sufficiently accurate, one could conclude that the average crop-specific ILUC emissions calculated with model simulation(s) are a reasonable prediction of the ILUC effect. This approach will lower the ILUC risk but will not completely eliminate it, because actual ILUC may be higher if the more pessimistic models prove to be more representative for real-world effects. With this approach the ILUC factor for the crops will be between 35 and 64 gram CO_2/MJ depending on the biofuel feedstock (42 to 76%).

D: Eliminate any ILUC risk: Do not apply model simulations but use a direct link between biofuels and land use
If the model simulations are considered insufficiently accurate, a 'risk adder' approach as suggested by the Dutch Corbey Commission or applied in the WBGU advice to the German government can be applied. These approaches are often intended as a stop-gap until more reliable models become available. As previously indicated, in these approaches a maximum-risk scenario is applied in which the basic assumption is that each hectare of land used to produce biofuels leads to conversion of one hectare of natural forest to new farmland. In the Corbey Advice, for the associated loss of carbon sinks a globally averaged factor is applied, 105 tonnes/ha (= 120 to 500 gram CO_2/MJ biofuels).

Exemptions
All four approaches to an ILUC factor require exemptions for:
- Use of marginal, severely degraded or abandoned land which has not been used for food production in the last 5 years; in such cases only direct land use-related GHG emissions would need to be reported.
- Intensification of production over and above the 2% per year required for food output (over, on average, 5 years); in such cases there would be an exemption for the additional yield.
- Use of wastes and residues, as defined in the EU's waste framework directive and in compliance with the waste hierarchy defined in there. This means materials for which there is no alternative more beneficial use such as for material purposes or as soil improver.

6.2 Policy alternatives

The EU has cited several policy options for preventing ILUC, discussed below. With the conclusions of this study in mind, we conclude that of these only options G and H are real solutions. For each of these options we have estimated the ILUC effects.

A. Extend to other countries/commodities (food, for example) the restrictions on land use change that will be imposed on biofuels consumed in the European Union
This is a very complex solution that will be very difficult to achieve. Indirect land use change may also occur in countries with no direct biofuel link with the EU, moreover. The analyses in this report shows that land use change is particularly likely in South East Asia. The various scenario studies considered here as well as other sources like the FAO–OECD 2009–2018 Outlook indicate that direct imports of biodiesel feedstocks and biodiesel products from this region to the EU are currently limited, making it difficult to influence land use policies in this region. This option is politically very complex and fails to provide a solution for regions where ILUC is occurring in the absence of any substantial direct exports to the EU.
ILUC effect: 70 Mt CO_2 emissions per year in 2020.

B. Seek international agreement on protecting carbon-rich habitats
In the very-long term, protecting and expanding carbon-rich habitats is an important policy for climate change mitigation in general. However, the REDD system under discussion internationally with this aim in mind will take many years to develop and even longer to introduce globally (2020-2030). Until such time as a strong and global REDD system is in place, ILUC needs to be regulated by other means.
ILUC effect: 70 Mt CO_2 emissions per year in 2020.

C. Do nothing, on the assumption that the current wording of the Directive provides sufficient protection
As this report shows (see previous chapter), this option will result in a major risk of high GHG emissions due to ILUC associated with biofuels.
ILUC effect: 70 Mt CO_2 emissions per year in 2020.

D. Increase the minimum required level of greenhouse gas savings
As this report shows, land use change is associated with all biofuels, regardless of their consequences in terms of direct GHG savings. If the volume of biofuels remains unchanged, this option will have little effect on the ILUC effect. Although direct GHG savings will be better, overall this is not an appropriate

solution. This option will probably lead to greater use of palm oil and ethanol from sugarcane.
ILUC effect: The majority of the models indicate 70 Mt emissions per year in 2020. Some of the models point to the ILUC effect of palm oil possibly being substantially higher, thus potentially increasing the overall risk of ILUC. As this option will lead to more direct gains as well as a potentially greater risk of ILUC, then, the net effect is very uncertain.

E. Extend the use of bonuses in the calculation of greenhouse gas emissions
The present Directive specifies a bonus (29 gram CO_2-eq/GJ) in the GHG balance sheet for biofuels produced using severely degraded and polluted land. The reasoning is that in this case biofuel production competes less, or not at all, with existing agriculture and therefore causes no ILUC. The purpose of the bonus is to encourage utilization of such land. Ecofys, as well as UNEP and IIASA, are currently seeking a way to define these types of land. As this report shows, this kind of degraded and polluted land is scarce and crop production on such land is more expensive, moreover. This means that under this option conventional biofuels will still be produced on agricultural land, thus maintaining the ILUC effect.
ILUC effect: 70 Mt emissions per year in 2020.

F. Set additional sustainability requirements for biofuels from crops/areas where production is liable to lead to a high level of damaging land use change
Just like option D, this option fails to appreciate the real nature of ILUC. ILUC is an effect occurring on the global market for agricultural crops, attributable to increasing demand for crops for the production of biofuels. In general, it cannot be prevented locally or regionally by imposing supplementary sustainability requirements for biofuel production in specific areas.
ILUC effect: 70 Mt emissions per year in 2020.

G. Include an indirect land use change factor (ILUC factor) in the greenhouse gas balance sheet calculations
This seems to be the best way to prevent ILUC from biofuels. As a start, a general ILUC factor of 60 gram CO_2/MJ biofuel can be used until more accurate model calculations provide more precise ILUC effect factors per crop and region. In practice, this option will make biofuels production possible from:
- abandoned land;
- degraded land;
- waste streams;
- extra intensification over and above the need for food.

ILUC effect: virtually 0 Mt emissions per year in 2020.

H. Other policy elements: use only residual flows and degraded land
Restricting biofuels production to cultivation on degraded land and production from waste streams is also an option. In practice, this solution is similar to G.
ILUC effect: virtually 0 Mt emissions per year in 2020.

6.3 Carbon calculations for policy alternatives

Total EU emissions for 2020 can also be estimated on the basis of Section 4.3, as reported in Table 13.

Table 13 Emissions prognoses for several policy options, EU 2020 (minimum reduction 50%)

Policy option	Direct emission ($Mt\ CO_2$)	ILUC	Net emission	Reported emission	Reporting error
A, B, C, F, E	Ca - 70	70 models 200 max. risk	0 to 200	-70	70 to 200
D. a higher direct GHG goal	> -70 (maybe -100)	70 models 200 max. risk	-30 to +170	-70 to -100	70 to 200
G1. ILUC factor per crop	-70	0	-70	-70	0
G2. General ILUC factor	-70	0	-70	-70	0
G3. Average from models	-70	0	-70	-70	0
G4. Direct replacement risk	-70	0	-70	-70	0
H. Only waste and degraded land	-70	0	-70	-70	0

In general, some of these options reduce emissions to virtually zero and avoid the current reporting error in the GHG effect of the EU's biofuels policy, while others leave the current situation unchanged.

Option G3, an ILUC factor based on average ILUC calculations, reduces ILUC to zero if a minimum GHG score of 50% is introduced as planned.

6.4 Conclusion

All four options for introducing an ILUC factor can avoid the problem of ILUC.

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Annex A Description of ILUC estimates considered

A.1 E4Tech studies

E4Tech uses an approach previously applied by CE (2008b) in the Gallagher review for estimating ILUC factors for rapeseed and palm oil biodiesel, but with an updated and extended dataset and extended scope.

As in the Gallagher review, a LCA-like approach is applied in which the ILUC factor is determined by comparing the change in GHG emissions caused by a change in the way a functional unit is satisfied:

- Rapeseed is assumed to be cultivated on land within the EU that would otherwise have been abandoned and would have been either returned to nature (90%) or actively reforested (10%). The carbon that would have been assimilated in these situations is taken into account in the analysis. Rapeseed meal is assumed to replace soybean meal and a small amount of feed wheat. Soybeans are assumed to have been otherwise cultivated on newly generated arable land, created by conversion of natural areas (forest, grassland, savannahs), and this LUC and the associated GHG emissions are assumed to be avoided.
  Replacing soybean also substitutes soybean oil. It is assumed that this deficit is covered by extra palm oil production, resulting in conversion of natural habitats in South East Asia and associated GHG emissions.
- Palm oil is assumed to be cultivated on land that was previously natural area (forest, grassland, savannah) or used for other applications (arable land). The associated palm kernel oil and palm kernel expeller are assumed to replace coconut oil production and soybean and feed wheat, respectively. Production of 18.5 Mt of palm oil requires 5.8 Mha of new area, but substitution of coconut oil would reduce required coconut cultivation area by 2 Mha.

This study is still in progress and the results calculated are still draft results. Perhaps as a consequence, certain aspects seem not to have been taken into account yet:

- In the preliminary E4Tech ILUC factor for palm oil biodiesel, emissions from peat soil have not been taken into account. In addition, it is unclear whether and how any reduction in the required coconut plantation area is factored in to the draft analysis.
- In the preliminary E4Tech ILUC factor for rapeseed biodiesel, the palm kernel expeller and oil production associated with the required increase in palm oil production have not yet been considered (or possibly explicitly ignored).

A.2 JRC AGLINK simulation

The AGLINK-based JRC study of EU biofuels policy-induced global land use changes embodies a differentiation approach in which global land use is compared in two scenarios: one with a mandatory 10% EU biofuels policy target in place (baseline), the other with biofuels utilization in the EU unregulated and solely market-controlled. The net change in arable land is then assumed to be attributable to the EU biofuels policy. This simulation is characterized by the following approaches and specifications:

- The analysis considers both 1st and 2nd generation biofuels, 2nd generation biofuels having no link with the agricultural sector or with agricultural land use. In practice this will mean that the 2nd generation biofuels are produced from residues.
- Biofuels implementation is regulated by mandates or by tax incentives, differing among the various member states.
- Imports of biofuels are subject to import levies. As a result, imports are limited.
- Specific crop yields, market demands for food and feed, the types of feedstock used for biofuels production and the biodiesel-bio-ethanol ratio are all governed by market price.
- The by-products of biofuels production are taken into account. In the model they are not tradable and are assumed to be applied in feed in the biofuel-producing region.
  - In the baseline case, DDG (Dry Distiller Grains) is assumed to be fed mainly (90%) to ruminants and to substitute almost exclusively (94%) coarse grains and a limited amount of oil meals (6%) in ruminants' feed regime. In non-ruminants' feed regimes 1 kg DDG replaces 0.3 kg of oil meal and 0.7 kg of coarse cereals, both in (probably) a 1 to 1 ratio.
  - In the sensitivity analysis the high DDG protein content is appreciated more, assuming coarse cereals substitution and oil meal substitution ratios of 0.68 and 0.6, respectively[16], for both ruminants and non-ruminants. The share of DDG supplied to the non-ruminant feed market is assumed to be increased to 32%, with DDG sales to ruminants feed market subsequently decreasing to 68% of DDG production.

Calculated consumptions and imports for 2020 are given in Table 14. Biodiesel imports concern soy methyl ester imports from Argentina. Ethanol imports concern Brazilian sugar cane ethanol, since Brazil is the only exporter mentioned in the report.

Table 14 Biofuels mixtures considered in the AGLINK simulation (all figures in Mt/a)

	Baseline scenario		Counterfactual scenario	
	Consumption	Imports	Consumption	Imports
Ethanol				
1st generation	14.2	2.7	5.1	0.4
2nd generation	2.6	0.0	0.0	0.0
Biodiesel				
1st generation	17.1	3.5	3.1	0.7
2nd generation	4.4	0.0	0.0	0.0

16 The ratios imply that 1 kg of DDG substitutes 0.68 kg of coarse cereals *and* 0.6 kg of oil meal.

Table 15 **Calculated change in global arable land area resulting from EU biofuels policy (in 1,000 hectares)**

	Baseline scenario	Counterfactual scenario	Net change
EU	-6,140	-4,677	1,463
USA	-1,082	-813	269
Canada	1,292	1,422	130
Australia	559	838	279
Africa	3,069	3,316	247
India	3,422	3,598	176
China	1,027	1,057	30
Other Asia	968	1,541	573
Russian Federation	535	701	166
Ukraine	3,166	3,377	211
Argentina	-2,173	-1,609	564
Brazil	13,696	14,685	989
Other Latin America	1,222	1,327	105
The rest	-555	-541	14
			5,216

In the EU and probably also in other countries with a diminishing area of arable land, the diminishing area would be converted into pasture if the EU biofuels policy were not implemented.

Land use change in Brazil includes expansion of both soy and sugar cane acreage. Given the calculated amount of imported Brazilian sugar cane ethanol (2,700 kt/a), the specific ethanol yield mentioned in the report (4.34 t/ha in 2008) and assuming a specific yield of 1%, the total land use change in Brazil is probably approximately attributable to soy and sugar cane in equal measure.

The calculated GHG emissions associated with arable land expansion are given in Table 16. Allocation of the arable land expansion to the various countries is based on information reported in JRC (2009). The changes in carbon stocks (far right column) are taken from the two E4Tech ILUC studies and from the background information given in the Corbey Advice. For the EU these changes represent the prevented assimilation of carbon that would have occurred if the arable land used for biofuels feedstock cultivation had been allowed to return to a natural state, primarily grassland and to a lesser extent forest. The factors for ‘Other Asia’, Argentina and Brazil have been taken directly from the E4Tech studies. They are based on emissions factors developed by Winrock International for marginal land use change and published by the EPA. They represent a mixture of grassland, forest, savannah and other types of land, differing per country.

For Canada, USA, the former Soviet Union states, Australia, Africa, India and China the assumed carbon stock change represents conversion of grassland to arable land. For the first three (groups of) countries this is consistent with the location of agricultural areas. For Africa, Australia and both Asian countries it is an estimate. However, using the Corbey average carbon stock change of 105 tonne C/ha will lead to little change in the net ILUC emission factor.

Table 16 **Calculated ILUC factors (in '000 hectares)**

	Net land use change (kha)	Allocation (kha) to		Emission factor	
		Biodiesel	Bioethanol	ton CO_2/ha/a	ton C/ha min
EU	1,463	556	907	0.95	5.19
USA	269	-72	341	0.95	5.19
Canada	130	401	-271	6.78	37.00
Australia	279	140	140	9.53	52
Africa	247		247	10.08	55
India	176		176	10.08	55
China	30	30		10.08	55
Other Asia	573	455	118	25.47	139
Russian Federation	166	134	32	9.53	52
Ukraine	211	170	41	9.53	52
Argentina	564	436	128	9.53	22.71
Brazil	989	410	579	11.77	64.19
Other L. America	105	81	24	7.97	43.45
The rest	14	7	7	33.18	181
Total kha	5,216				
Total 1st gen. PJ/a		518	244	518	244
Total CO_2 emission kt/a		23,493	8,254	5,349	3,133
kg CO_2-eq/GJ		45.4	33.8	10.3	12.8

A.3 Banse

The Banse study is based on ESIM, a price and policy-driven model with rich cross-commodity relations. ESIM depicts price and policy-driven instruments as well as direct payments. Policies are only modelled for the EU and accession candidates. For US and ROW consumption and production take place at world market prices. Production of biofuel crops is modelled by one iso-elastic yield function and two iso-elastic area allocation functions for each biofuel crop: one for no set-aside area (input prices, direct payments, output prices), the other for set-aside area (input prices, direct payments, outpriced biofuel crops that are an alternative on set-aside land).

Production of biofuels is modelled as an iso-elastic function of the respective biofuel price and the weighted net prices of the feedstock (corrected for feed output). The shares of feedstock in bio-ethanol and biodiesel are determined on the basis of crop prices. Biofuel demand is a function of price, crude oil price and the tax rates on biofuels and on mineral oil. The model assumes a 45 €/ha premium for biofuels to reflect the subsidy for the biofuels production. The EU target shifts demand for biofuels to a higher level. When set-aside land is taken into production, the increase in agricultural area is modelled as less than the decrease in set-aside area, reflecting the relatively low productivity of set–aside.

The study assumes that the EU offer in the DOHA round is implemented in the period 2009-2013. (As part of the Doha Round, the EU has offered to cut farm tariffs by 60%, reduce trade-distorting farm subsidies by 80% and eliminate farm export subsidies altogether. The EU also wants to see new market access opportunities for its own processed agricultural exports.) Tariff rate quota are assumed to remain constant.

A 10% target for biofuels in the EU will result in a 3% reduction of agricultural area instead of a 5% reduction (without the 10% target) as compared to 2005. The target will result in higher oilseed and plant oil prices, but lower beef and animal product prices owing to a decrease in feed prices. Biodiesel prices will increase by 15%. Biofuel demand will increase to 36 Mtoe, of which 22 Mtoe will be produced in the EU and 14 Mtoe imported. All in all, 38.2 Mtoe biodiesel, bioethanol, plant oils and oil seeds will be imported.

A.4 ENSUS

In the ENSUS study, ILUC factors are calculated taking into account:
- The proportion of increased biofuel crop demand met by increased arable acreage (as opposed to higher yields).
- Co-products displacing other products and the resulting land changes.
- The type of land used for growing more biofuel crops and the carbon stock of this land.

ENSUS relates yield and arable expansion directly to changes in output, rather than via prices. For wheat, below an 1.8% growth in demand no additional land is required, with growth being assumed to be covered entirely by higher yields. This is the approach adopted to determine the impact of increased output on changes in arable acreage. Furthermore, the model takes in account the use of co-products and the impact on land use. For example, using wheat for biofuels yields protein concentrates as a by-product that replace soy and thus land use for soy growth. Finally, the model assumes that the source for land expansion in the case of cereals is cropland, for sugar cane mainly grassland and for soy and especially palm mainly forest area. In determining ILUC factors, the carbon stock for these types of land were duly accounted for.

A.5 Corbey Commission

The emission factors proposed by the Corbey Commission amount to approximately 810 kg/GJ for palm oil biodiesel and may vary between 120 kg/GJ for sugar cane ethanol and 400 kg/GJ for rapeseed biodiesel.

A.6 Ecometrica

Ecometrica adopts an approach in which global deforestation and the associated GHG emissions are allocated on the basis of causal factors identified by FAO to the various drivers for deforestation, including expansion of arable area for biofuels feedstock cultivation. Just how the methodology works is not elaborated. The resultant emission factors are as follows:
- ethanol from wheat: 22 g/MJ;
- ethanol from sugar beet: 21 g/MJ;
- ethanol from corn: 21 g/GJ;
- ethanol from sugar cane: 45 g/MJ;
- biodiesel from rapeseed: 10 g/MJ;
- biodiesel from soy: 21 g/MJ;
- biodiesel from palm oil: 35 g/MJ.

These estimates are based on a global averaged emission of 0.286 tonne CO_2-eq/tonne crop.

In short, the studies conducted thus far in which (I)LUC-related GHG emissions have been estimated yield a wide range in emission factors, but all studies indicate that (I)LUC-related emissions are not insignificant and may actually be orders of magnitudes higher than the direct and saved emissions in the biofuels production chain.