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Sustainability Standards for internationally traded Biomass

The "iLUC Factor" as a Means to Hedge Risks of GHG Emissions from Indirect Land Use Change

- Working Paper -

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1 Introduction and Overview

The use of biomass for energy production is rising globally in parallel to increasing oil prices, and concerns about energy security, and climate change. Many countries recognize biomass as a domestic energy resource, and some see opportunities for exports of liquid biofuels. With political goals of e.g., the EU to increase the use of biofuels in the transport sector from a current rate of 2% up to 10% in 2020, and domestic biofuel quota systems being introduced in many other countries as well, there is little doubt that biomass use for liquid transport fuels, as well as for electricity and heat production, will continue to rise in the future, and that global trade with bioenergy will rise in parallel. This will pose both opportunities and risks for sustainable development for regions, countries, and the world as a whole.

In this context, the German Federal Environment Agency (UBA), on behalf of the Federal Ministry for Environment (BMU), funded research on sustainable global biomass trade, carried out by Oeko-Institut and IFEU.

This "bio-global" project covers methodical aspects concerning climate protection, biodiversity, water and land use, but also aspects related to bioenergy trade and legal issues (e.g., WTO, bilateral agreements)[1].

A key element in that research is to consider and elaborate on opportunities for sustainable biomass feedstock provision which have no negative or even positive environmental, biodiversity, climate, and social trade-offs.

With regard to the greenhouse-gas (GHG) emission balance of bioenergy, the possible effects of direct and especially **indirect** land use changes (ILUC) associated with cultivating biomass feedstocks are vigorously discussed (Section 2).

The core of this paper introduces a **deterministic** approach developed by Oeko-Institut within the Bio-global project to include GHG emissions from ILUC in **regulatory policies** for biofuels (Section 3), and updates previous versions of this paper which have been published earlier by introducing a **revised 2005 iLUC factor estimate** (Section 3.2), and giving an outlook to the range of possible **future iLUC factor** values from 2010 to 2030 (Section 3.3).

The paper further discusses briefly **policy options** to include an iLUC factor in regulatory schemes for biofuels (Section 4), sketches **approaches to "offset"** ILUC emissions (Section 5), and alternative policy concepts which avoid quantifying ILUC effects (Section 6).

Finally, some conclusions are drawn and future work on ILUC is outlined (Section 7).

The Annex gives the data background for calculating the iLUC factor.

1 For details, see OEKO/IFEU (2010)

2 Bioenergy Greenhouse-Gas Emissions from Land Use Changes

The evidence of significant greenhouse gas (GHG) emissions from potential land use changes (LUC) has been increasingly recognized in the recent literature[2].

Cultivating biomass feedstocks for bioenergy in general and for biofuels in particular needs land, which might cause LUC regarding

- **direct** effects on the site of a farm or plantation, and
- **indirect** effects through "leakage", i.e. displacement of previous land use to another location where **direct** LUC could occur.

Both effects could have significant impacts on the overall GHG balance of bioenergy and biofuels, so that a methodology is needed to include both in GHG accounting.

2.1 Direct Land Use Changes

The GHG emissions of biomass feedstock production resulting from **direct** land use changes (dLUC) can be determined from the carbon balances of the previous land use and the land use for biocrops regarding **above**-ground carbon content of existing vegetation (if any), as well as the **below**-ground (soil) carbon[3]. Each balance might be negative or positive, so that the **total direct** C balance could also be negative or positive.

To derive the respective balances, the **default data** of the Intergovernmental Panel on Climate Change (IPCC 2006) for direct land use and soil-carbon changes can be used, and a time horizon of 20 years to allocate the net CO_2 balances to annual bioenergy production, i.e. the total net CO_2 emissions from dLUC is distributed over the total energy yield from biocrops for a 20 year time horizon.

As it is reasonable to assume that the location of any biomass feedstock production is known, one immediately **knows also which dLUC occurred**: is arable land converted, or pasture or permanent grassland, peatland, savannah, or (tropical) forests (OEKO/IFEU 2010)? Thus, using the IPCC default data, the GHG emissions from dLUC can be derived with rather low uncertainty[4].

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[2] See e.g., CDB (2009); Dale (2008); Ecofys (2009a); ELOBIO (2009); ESA (2010); Fargione et al. (2008); Fehrenbach/Fritsche/Giegrich (2008); GBEP (2009a+b); IEA (2009a+b); IFEU (2009); JRC (2008); Lapola (2010); MIT (2009); MNP (2008); OEKO (2008 + 2010a); ORNL (2009); PBL (2010a-e); RSB (2009); RFA (2008); Searchinger et al. (2008 + 2009); Searchinger (2009 + 2010); UNEP/RSB/IPIECA (2009); WBGU (2008)

[3] It should be noted that direct LUC not only affects the C balance, but could also cause emissions of CH_4, and N_2O. For reasons of data availability, only CO_2 from the net C balance is considered here for the direct and indirect GHG emissions from LUC.

[4] It should be noted that the IPCC default data have an **inherent uncertainty**, though, as they were derived for accounting of LUC in national GHG reporting under the UNFCCC which has a spatial scope of 100,000 to several million hectares. Their application to site-specific situations of a biomass feedstock plantation with a spatial scale in the order of 100 to 1,000 hectares introduces a possible range of error.

2.2 Indirect Land Use Changes (ILUC)

From a **global** perspective which takes into account **all** land use from all production sectors of biomass (agri- and horticulture, fishery, forestry), increasing biomass feedstock production has only **direct LUC** effect, as all interaction of markets, changes of production patterns and the respective conversion of land from one (or none) use to another will be accounted for.

The problem of possible **indirect** effects arises when a **partial** view of the

- **production** sectors (e.g. only agriculture), and/or
- biomass product **market** (e.g. only biofuels), and/or
- land use (e.g. only a certain region/country)

is taken in considering impacts. An example for this is a GHG reduction requirement which only addresses biofuels, i.e. not considering food and feed production.

Thus, it is a **problem of scope** – when the system boundary for an analysis is reduced, a "blindness" to possible impacts outside of the scope is the consequence.

In focusing only on the production of biomass feedstocks for bioenergy in general, or biofuels in particular, the direct effects outside of the scope become "indirect":

In that view, cultivating biomass feedstocks can have **indirect** LUC (ILUC) effects through displacing current agricultural (food, feed) or forest (fiber, timber) production to **other** areas[5] - e.g. grasslands or forested land – which causes **dLUC there**[6].

As the displacement could move previous agricultural production to areas outside of a country, could occur with significant time lags, and could be distributed through global trading, ILUC **cannot** be determined with respect to any individual feedstock production activity – it is "non-local".

The non-locality of indirect effects is a result of the non-locality of global commodity markets – unless one assumes a **full** global "tracing and tracking" for the origin of **all** traded commodities, one **cannot know** whether a production increase of an agricultural commodity such as wheat (and possibly a respective conversion of previously unused land) in a given country is "caused" by a rise in demand for bread in

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5 A key assumption for this is that demands for displaced production **remain on the same level, or even grow** – otherwise, the displacement could be reduced or even zero. For food and feed, though, demands are expected to rise more or less in the next decades, depending on population growth, income, and diets (which are interlinked). Still, one needs to consider the **price elasticity** of demands – if prices for e.g. food and feed rise due to land or price competition with biofuels, the demand for food/feed might be reduced to some extent, compared to the demand without additional biofuel production. Similarly, prices can have an effect on diets (share of dairy and meat), which in turn can "dampen" the actual displacement.

6 Note that indirect effects could occur also with regard to biodiversity impacts (CBD 2008; Hennenberg et al. 2009; OEKO/IFEU 2010), and food security implications (ELOBIO 2009b; Faaij 2008; FAO 2008+2009; IIASA 2009; Ratmann/Szklo/Schaeffer 2010).

another country, or by a change in trade relations, or by a rising demand for bioethanol produced from wheat somewhere else. Even if the feedstock into the ethanol plant would be "traced back" to its source(s), only full global tracing could reveal any implications this feedstock demand has on all other production – and not only for wheat, but also for interrelated feedstocks such as maize (corn) or rye which have a functional equivalent to wheat on the different markets and uses.

Besides assuming such a full track and trace system for all biomass production in all sectors, the **only** undisputed option to avoid (or control) indirect effects is to extend the scope to all land use for all commodities in all countries, i.e. taking a global perspective on all biomass production sectors[7].

For a variety of reasons, such a "full" scope is neither feasible in a **policy** context nor practical in the near future – the global governance of land and carbon is still in its infancy (WBGU 2009), and the monitoring of all land use changes has severe restrictions in spatial and time resolution, and the correlation between LUC and economic activities in a given country or region within a given time is **far beyond** all data availability.

In consequence, one will have to "deal" with indirect effects of incremental land use, and find ways to identify and quantify ILUC effects as long as specific policy goals such as net GHG reduction are related to e.g., biofuels[8].

In that regard, biomass for energy (or biofuels) is **only one** option for land use among others, and markets for bioenergy feedstocks and agricultural or forestry commodities are closely linked already and will become more so in the future.

Thus, LUC effects which are "indirect" to bioenergy are "direct" effects of changes in agriculture (food, feed), and forestry (fiber, wood products), and vice versa.

Before going into the problems of quantifying ILUC effects, a clarification is needed on what ILUC means in terms of "strictness":

In a **strict** definition, ILUC could occur for **all** biomass feedstocks derived from **any** land which has been used previously for food/feed or fiber production, or from land which has the **potential** to be used for food/feed/fiber production. In that regard, **all** arable or pasture land used for **additional** biomass feedstock production will induce at least some ILUC due to displacement, even if such displacement is hypothetical only. The underlying hypothesis of the strict definition is that **any** arable or pasture land has potential to be used for food/feed production, so that its **opportunity value** would be reduced by using it for biomass feedstock production.

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7 For a more detailed discussion of the carbon accounting under various regimes which lead to "indirectness" of CO_2 emissions due to limitations in the accounting system (boundaries, time dependencies etc.), see Joanneum (2010). This paper gives an excellent discussion of the issue with a focus on wood.

8 It is important to understand that for any partial analysis, ILUC is not only a possibility for incremental biofuel production, but a consequence of **any incremental** use of productive land.

Others consider the opportunity value of all arable or pasture land as a potential (non-permanent) **sink** of atmospheric C due to (natural) biomass growth.

A more “loose” definition assumes displacement from biomass feedstock production only for land which **actually was used** previously for food/feed/fiber production, thus excluding set-aside and abandoned land as well as biomass feedstocks derived from intensified land use which, due to higher yields, “frees” land for other uses.

In both definitions, though, biomass feedstocks derived from unused[9] biogenic residues and wastes and from abandoned and unused degraded land have a zero displacement risk, thus inducing **no** indirect land use change.

In the following, the “loose” ILUC definition will be used, as the paper addresses mainly the policy options in which analytical issues such as opportunity values and hypothetical future situation are of less importance.

2.3 Quantifying GHG Emissions from ILUC

Given the principal “non-local” nature of ILUC, the task to calculate possible GHG implications from ILUC is to establish quantitative relations between

- the additional biomass feedstock production and respective displacement of previous land use(s), and
- the displaced production and its possible direct LUC effects[10].

The first relation can, in principle, be derived from **economic models** for agricultural production which try to establish the trade relations between countries, commodities, and markets. In those models, land is an (economic) input factor for producing commodities so that any change in markets, trade, and production can be computed back into changes in land use.

The second relation needs **biophysical models** to derive direct LUC and the respective CO_2 emission balance.

Thus, the quantification of GHG emissions from ILUC requires to couple economic models with a biophysical component or to pre-calibrate biophysical models with economic data – in both cases, different model “worlds” are **coupled**[11].

9 The term “unused“ reflects that in case of existing uses of biogenic residues (e.g. straw for animal bedding, forest thinnings for pulp & paper), displacement could occur which would not follow land use change logics, but material flow substitution. Thus, it is important to clearly define that non-displacing residues are not in competition with other uses. For wastes which are subject to disposal, displacement could result in positive effects, e.g. reducing CH_4 emissions from landfilling. For wastes being subject to recycling, the material flow substitution logic need to be applied to check whether displacement causes positive or negative effects.

10 See also Ecofys (2009a) and RSB (2009).

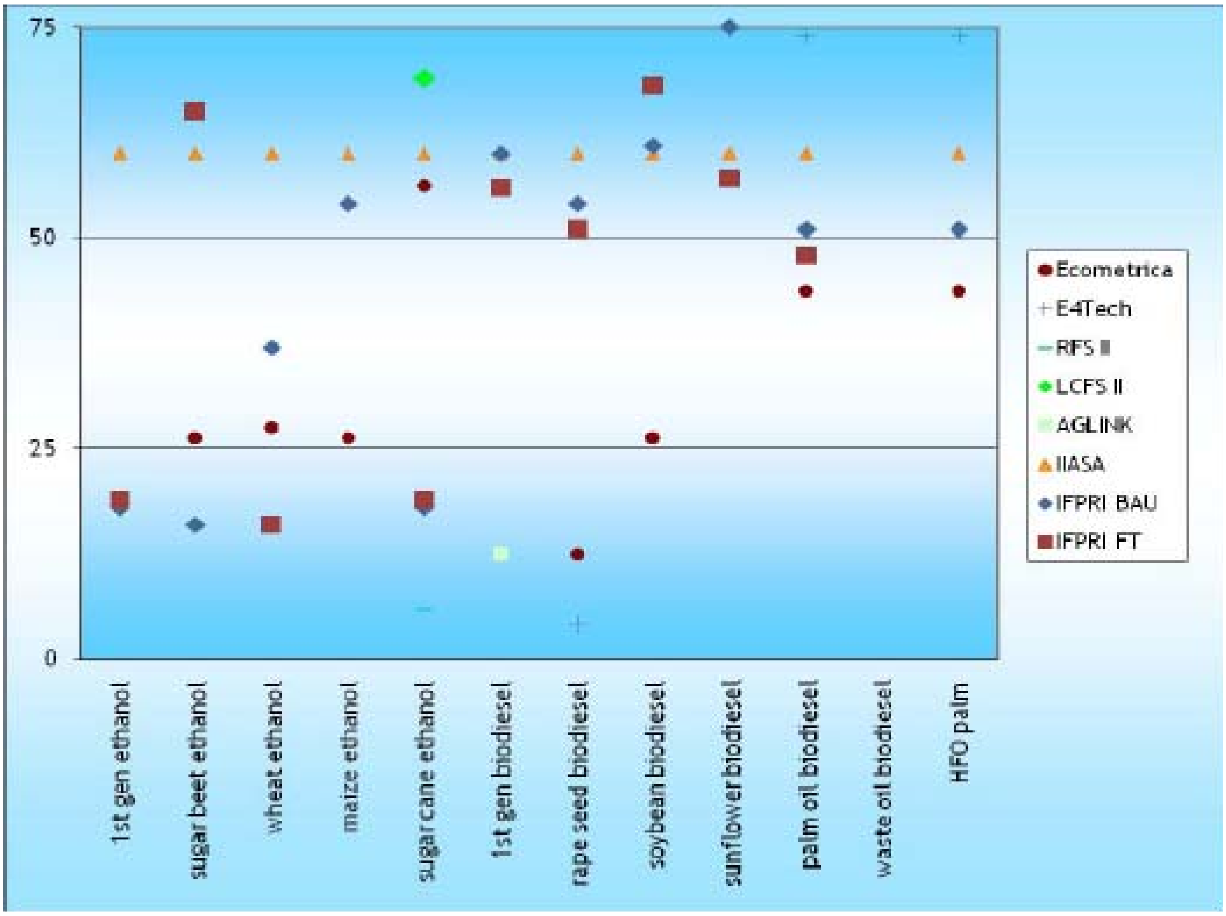
11 For a discussion see Banse/Eickhout (2009).

This implies a need for coherent data definitions, and compatible spatial as well as time resolution of both "worlds", which puts quite some burden on constructing and maintaining the interfaces between the models. In reality, this requirement can be met only partially due to data availability and model structure restrictions.

Accordingly, there is a lively debate in the literature (and beyond) on how to model (and interpret) ILUC and the respective potential GHG emissions[12].

A recent study of CE Delft for a consortium of European NGOs discussed ILUC values (from various approaches and models) which could be included in possible future revisions or extensions of the RED methodology to calculate life-cycle GHG emissions for biofuels (CE 2010). The following figure represents the respective data for GHG emissions from ILUC.

Figure 1 Modeling Results for GHG Emissions from Indirect LUC



Source: CE (2010); AGLINK data on LUC were converted by CE into GHG emissions

12 The key references for this debate are given in footnote 2.

This figure should only give an impression on the overall “spread” of results from various models – it can be seen that there is a range of roughly 10 to 100 grams of CO_2 per MJ of biofuel resulting from ILUC.

2.3.1 Agro-economic models for ILUC

Without going into details[13], it can be argued that agro-economic models depend extensively on critical input parameters such as land and commodity prices, and internal resolution and structure (e.g., conversion of pasture land, handling of by-products etc.). Basically, such models derive “indirect” impacts from the difference of two model scenarios - one scenario with a bioenergy policy (or assuming that the global system is exposed to a “shock” from producing a certain amount of biofuels), and one scenario without (e.g., a reference case excluding the bioenergy policy, or the respective amount of biofuels).

The models **simulate** future worlds, and the quality of the simulation depends on appropriate data inputs, their (recursive) handling to derive future trends, and the overall completeness of interactions between commodities and markets handled within the model[14].

By **necessity**, the outcome of such modeling varies between models, studies, and scenarios resulting from modeling.

Furthermore, it is currently not possible to run one model with the database of another one (or vice versa) or several models with on identical database to identify model-specific deviations (or shortcomings) – this is part of an ongoing discussion, especially in the Europe (EEA, EU Commission, JRC)[15] and the US (DOE, EPA)[16].

There is some exchange between these discussions, and international bodies such as FAO and OECD, and their respective research teams, participate as well[17].

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13 For a recent review of models for ILUC, and the respective implications for policy, see PBL (2010c).

14 For example, the role of by-products from biofuel feedstock conversion is a key issue – until recently, only few agricultural models considered this, although the treatment of by-products will have a dominant role regarding ILUC results (PBL 2010e).

15 As part of the work of the Joint Research Centre (JRC) for the European Commission with regard to including ILUC in the EU Renewable Energy Directive (RED, see Section 4.1), a literature review of estimates on future land use changes associated with increasing the biofuels share in the EU fuel matrix was carried out (JRC-IPTS 2010), but this study did not translate the LUC into GHG emissions.

16 The US discussion around ILUC is mainly focusing around the EPA approach (see Section 4.2) and the Californian LCFS (see Section 4.3). For the latter, an international expert group is currently working on improving the ILUC modeling for CARB.

17 This discussion is mainly organized in transatlantic workshops (JRC/EE/OECD 2009), but also as part of the IEA Bioenergy Task 38 exchanges (IEA 2009b).

In political discussions around ILUC, the range of results from ILUC modeling has been translated into “uncertainty” – which is **quite misleading**, as the future – by definition – cannot be known with any “certainty” today.

There is a fundamental gap between now and the future - say, 2020 - which no model will ever be able to bridge, even assuming the “best”” accuracy, resolution, and complexity of the database, or model algorithms.

Global commodity markets have an **intrinsic** uncertainty, because important drivers are unknown in their future values, or subject to a range of possible expressions – or, as Timothy Searchinger put it:

“*All models suffer from the uncertainty about whether past economic relationships will hold true in the future*“. (Searchinger 2010; p. 9)

Thus, any future projection for markets will necessarily show a significant error range which will increase with projected time horizons.

2.3.2 Deterministic Approaches: Simplified Modeling

In contrast to data-intense and rather intransparent economic models, **deterministic** approaches use simplified calculations (mostly spreadsheet-based) in which the basic idea is that complex simulations of trade and respective LUC effects can be shortcut with a set of statistical data on trade, and assumptions on, e.g., future trade patterns, and displacement ratios for incremental land use for biomass feedstock production[18].

An ongoing study for the UK Department of Transport tries to develop fuel-chain specific ILUC values using a “descriptive-causal” approach for several EU-relevant biofuel life-cycles.

A study objective is to demonstrate the validity of the approach, and a crucial part of the work is to capture views and insights of a range of stakeholders who have an understanding of the systems involved in ILUC to ensure that the ILUC factors calculated are based on the best available scientific and economic evidence (E4tech 2010).

As of now, this study resulted in various drafts for biodiesel from European rapeseed, and imported soybean and palm oil, as well as for ethanol from European wheat, and imported ethanol from sugarcane. Due to the ongoing work, no final results are available[19].

[18] Besides the iLUC factor approach presented in Section 3, such approaches are e.g., Ecometrica (2009), and Scott-Wilson (2009), among others. A brief summary is given in Ecofys (2009a) and IFEU (2009).

[19] As the authors of this paper are part of the external review committee for this study, we refrain from citing preliminary results. Any interested party can obtain available texts from the study’s website (see E4tech 2010).

3 The iLUC Factor: A Simplified Approach

As one of the early approaches to determine GHG emissions from potential ILUC using deterministic**,** simplified analysis, Oeko-Institut developed a methodology to include potential GHG emissions from ILUC in **regulatory policies** for biofuels. This approach has first been called “risk adder” (Fehrenbach/Fritsche/Giegrich 2008), but was renamed during 2008 into **iLUC factor**[20].

The key simplifying assumption of the iLUC factor approach to avoid complex modeling of agricultural markets (see Section 2.3.1) is that **current patterns** of land use for producing traded agricultural commodities are an adequate **proxy** to derive global **averages** of potential GHG emissions from indirect LUC.

The second underlying assumption is that for the near future, the **pattern of global trade** in agricultural commodities can be derived from observed trade trends.

3.1 Key Considerations for the iLUC factor

The iLUC factor approach assumes that the **potential** release of CO_2 from LUC caused by displacement is a function of the land used to produce agricultural products **for export** purpose, as trade flows will be affected by displacement[21].

As the overall global agricultural production and trade system is changing only slowly over time due to internal inertia[22], the **pattern** of agricultural production and trade from the last years can be assumed to be rather similar to the near future development.

Second, the “disturbance” of the global agricultural production and trade system arising from increase bioenergy (and especially biofuels) demands will remain **comparatively small in the next decade** or so, even if the EU and the US implement their policy targets for increasing biofuel use. The reason for this is that the share of biofuel feedstocks is, in quantitative terms, far below 10% of the overall mass of non-bioenergy feedstocks traded globally.

The following table shows the respective mass flows.

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[20] The renaming reflects the applicability in both “malus” and “bonus” schemes for GHG accounting: a malus system will **add** a certain amount of GHG emissions from ILUC to those biofuels which are derived from feedstocks with a **non**-zero risks for displacement, while a **bonus** system would **credit** zero-risk biofuels (e.g. from wastes, or feedstocks grown on degraded land) with the amount of indirect GHG emissions they **avoid.**

[21] Due to this key assumption, the iLUC factor approach cannot be applied to potential ILUC occurring **within** a country, as there is usually no intra-national trade information.

[22] The inertia of the ”overall“ global system of agricultural trade is a result of the aggregation of a broad variety of decision-makers (e.g. millions of farmers, several thousands of commodity traders, hundreds of banks issuing credits for agricultural investment etc.), and the “dampening” of quick changes due to political decision making on trade. For example, the GATT/WTO negotiations on agricultural trade (tariffs, subsidies etc.) typically run for several years. There is quite a

Table 1 Global Biomass Production and Trade in the Year 2006

Product	World production	Internationally traded	Unit	International trade/world production
Industrial wood, forestry products	**3009**	**424**	**Million t**	**14%**
Industrial logs	1684	120	Million m^3	7%
Wood chips and chippings	232	37	Million m^3	19%
Saw logs	427	120	Million m^3	31%
Cellulose pulp	190	42	Million t	22%
Cardboard and paper	354	100	Million t	31%
Agricultural products	**2214**	**290**	**Million t**	**13%**
Corn	695	83	Million t	12%
Wheat	606	118	Million t	19%
Oats, barley, rye	175	27	Million t	15%
Rice	635	28	Million t	4%
Palm oil	37	23	Million t	62%
Rapeseed, rapeseed oil	66	11	Million t	17%
Bioenergy	**1284**	**15**	**Million t**	**1%**
		300	**PJ**	
Ethanol	51	4,3 (120 PJ)	Million m^3	8%
Bio diesel	5	< 0,5 (15 PJ)	Million t	8%
Palm oil	1,4	1,1 (40 PJ)	Million t	79%
Firewood	1827	4 (40 PJ)	Million m^3	0%
Charcoal	43	1,4 (20 PJ)	Million t	3%
Pellets	8	3,6 (60 PJ)	Million t	45%
Indirectly traded bioenergy carriers		**630**	**PJ**	
Industrial logs		480	PJ	
Wood chips and chippings		150	PJ	
Total bioenergy traded		**930**	**PJ**	

Source: OEKO/IFEU (2010) based on Heinimö, J./Junginger, M. 2009: Production and trading of biomass for energy – An overview of the global status; in: Biomass & Bioenergy vol. 33, p. 1310-1320

As can be seen, the bioenergy mass share in total global biomass trade is so small that even massive increases will not – on average – result in significant changes of the global system[23].

The globally traded bioenergy and biofuel feedstocks represent about 1 % of all global bioenergy production, and traded biofuel feedstocks account for approx. 5% of all traded agricultural products. If wood and timber products are added, biofuel feedstocks are 2% of all anthropogenic biomass production traded globally, while **all** bioenergy production represents 20% of all agricultural and forestry production.

23 Within countries, though, the changes can be far higher, for example in Argentina, Brazil or India, or within the EU countries, and the US.

Thus, there is a factor of 10 between overall bioenergy production, and traded biofuels and respective feedstocks. Even if trade in biofuels would increase by a factor of 5 in the next years, it would still represent a small fraction of overall biomass trade.

The iLUC factor approach takes into account that **all** countries trading agricultural products across borders might be subject to LUC from displacement, so that displacement can impact different land with different (above- and below-ground) carbon stocks.

Countries participating in global trade are potentially incited to increase food/feed production to “balance” the global market if increased feedstock production for biofuels displaces previous food/feed production through respective land use.

The iLUC factor as a deterministic approach aims to describe **average** impacts for a given year or period.

For that, the share of land utilized for producing the amount of food/feed displaced by increased bioenergy feedstocks production is derived from the share of land used in each country for agricultural exports, taking into account country-specific yields (based on FAO data for 2005)[24].

Thus, the share of land in each export country was calculated using the respective amounts of traded key agricultural commodities **which are influenced** by bioenergy feedstock production, i.e. rapeseed, corn (maize), palmoil, soy, and wheat, and these amounts were divided by the respective country-specific yields[25].

To simplify the overall data, only key countries/regions were considered: Argentina (AR), Brazil (BR), the European Union (EU), Indonesia (ID, together with Malaysia), and the United States of America (US). These countries/regions represent more than 80% (in mass terms) of the global trade in the selected agricultural commodities in 2005, thus giving a good proxy of the overall pattern of land use. The following table shows the first steps of this calculation for selected commodities.

24 See Annex for detailed data on export shares, and yields derived from FAOSTAT.

25 Note that biofuel feedstocks can be cultivated also on (former) pasture and grasslands where they might displace not food/feed/fiber crops, but cattle ranching or sheep herding, etc. This could, in principle, be also factored into the global trade “pattern” derived here and the respective land use changes. Due to restrictions in time and available data, this could not be included in the calculations given here, though.

Table 2 Maize, Soybean and Wheat Exports and Associated Land Use

	exports, million t		land for exports, million ha	
	2005	**2010***	**2005**	**2010***
maize				
AR	14.6	16.0	2.0	2.1
BR	1.1	11.0	0.4	2.8
EU	8.8	25.0	1.0	2.8
ID	0	0	0	0
US	45.4	55.0	4.9	5.5
total	**69.9**	**107.0**	**8.3**	**13.2**
soybeans				
AR	9.9	12.0	3.6	4.2
BR	22.4	24.0	10.1	10.2
EU	0	0	0	0
ID	0	0	0	0
US	25.7	30.0	9.0	10.1
total	**58.0**	**66.0**	**22.7**	**24.5**
wheat				
AR	10.4	10.0	4.1	3.8
BR	0.2	0	0.1	0.0
EU	22.6	32.0	3.2	4.5
ID	0	0	0	0
US	27.2	35.0	9.4	11.7
total	**60.4**	**77.0**	**16.7**	**20.0**

*Source: own calculation based on FAOSTAT data; * = based on trend 2003-2007*

The land use for agricultural exports determined for each country/region was then totaled, and the shares of countries/regions in that total was derived as the "world mix" of land used for total exports of the selected agricultural commodities.

The world mix is used as a **proxy** for the **average pattern** of all displaced land, i.e. the mix does not discriminate between agricultural commodities, but gives an **average per hectare**.

The logic of this key assumption is that the trade flow **pattern** and respective land use shares of agricultural commodities will be, on average, **the same** for the displaced commodities, expressed by the displaced land use. With future changes in trade patterns, and changes in associated LUC, the "world mix" of land use must be adjusted.

The next step in deriving the iLUC factor is to combine the land use shares in the "world mix" with assumptions on **which direct** LUC occurred when producing export commodities, e.g.

- shares of arable and grassland to produce rapeseed and wheat in the EU, and maize (corn) in the US,
- share of converting grassland or savannah in AR or BR for soybean farming,
- tropical forests converted to oil palm plantations in Indonesia[26].

The regional LUC assumptions were then coupled with the respective IPPC factors for C, and **weighted** with the share of the country/region in the world mix (see last column in Table 3). The result of this is the CO_2 emission from LUC associated with the average world mix, i.e. the average emissions per hectare of land used for globally traded commodities (see last two lines in Table 3).

Table 3 Matrix for World Mix of Land associated with ILUC and respective CO_2 Emissions from LUC for 2005

	assumption on C for LUC, based on IPCC				
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	2%
EU, rapeseed, grassland	6	63	69	254	2%
AR/BR, soybean, grassland	6	63	69	254	20%
ID, oil palm, trop. forest	165	100	265	972	3%
EU, wheat, arable land	5	50	55	202	4%
EU, wheat, grassland	6	63	69	254	2%
US, maize, arable land	5	50	55	202	20%
US, maize, grassland	6	63	69	254	26%
BR, sugarcane, arable land	5	50	55	202	7%
BR, sugarcane, grassland	6	63	69	254	9%
BR, sugarcane, savannah	66	68	134	491	5%
weighted world mix based on domestic land shares for export				**270**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare per year				**13.5**	**t CO2/ha/a**

Source: own calculations based on IPCC (2006), and FAOSTAT (for world mix); red shading: high GHG emissions from LUC due to carbon-intense land

The **theoretical** "full" – i.e. 100% **-** iLUC factor would be applicable only if the certainty of displacing a given amount of biofuel feedstock production would be 100%, i.e. if

[26] These assumptions were checked against the 1980-2000 land conversion trends for several world regions established by Gibbs et al. (2010) using remote sensing data and using Lapola (2010) data for Brazil. This check lead to a revision of the earlier reported iLUC factor for 2005 - see column "2005 (old)" in Table 4.

each hectare of bioenergy feedstock production would displace **1** hectare of previous production.

3.2 The iLUC factor: Realistic Levels

In reality, though, the ratio between the land used for biofuel feedstock production and displaced land (i.e., the ILUC risk level) **will be lower than 1**, as biofuel feedstocks come from a variety of sources, and circumstances, such as use of set-aside and abandoned land, intensification of existing cultivation schemes, and price-induced changes of commodity consumption must be considered as well.

It is assumed that in the longer-term, 25% of all biofuels will come from feedstocks grown on land “set free” through yield increases for which the “loose“ definition assumes a zero displacement risk. The 25% figure is derived from an average yield increase of 1% per year until 2030 which is used in various studies (e.g. IEA 2009c).

Thus, the maximal iLUC factor will be only 75% of the theoretical full iLUC factor.

To derive **practical** values for the iLUC factor, i.e. numbers which could be used in a regulatory context, the following cases were defined:

- “low level”, assuming that 25% of all biofuel feedstocks are subject to the theoretical full iLUC factor, which gives 3.4 t of CO_2/ha/year for the year 2005
- “medium level”, meaning a 50% share of all biofuel feedstocks are subject to the theoretical full iLUC factor, resulting in 6.8 t of CO_2/ha/year for the year 2005.

Still, the displacement risk will change over time, i.e. the more biofuel feedstocks are produced from cultivating land being subject to competition, the higher the cumulative risk of displacement will become for the average biofuel feedstock, as land is a finite resources, and competing demands for land use increase as well.

Therefore, the iLUC factor should be **dynamic**, as presented in the following section.

3.3 The iLUC factor: Future Levels

The approach for using the “world mix” of land use implied by agricultural exports and explicit assumption on respective LUC in each country/region can be projected also over time to derive future iLUC values for given risk levels.

For this, the yield data of the biofuel feedstocks were projected from the 2005 levels to 2030 (see Annex), and the IPCC factors for dLUC were held constant.

Next, the trade shares for 2010 were estimated based on FAOSTAT data trends from 2000 to 2008, and the possible changes in LUC due to national/regional land use policies[27] factored in. For 2030, **a range** of LUC figures was derived in three scenarios to reflect possible longer-term developments:

[27] For example, Brazil has introduced a law on ”agro-environmental zoning“ for sugarcane expansion.

- The "HIGH" case assumes that conversion of carbon-rich land especially in AR, BR and ID **cannot** be stopped, so this scenario indicates the maximum (upper) range of possible LUC emissions.
- The "LOW" case assumes that policies to **ban** conversion of carbon-rich land are successful, and also that degraded land is increasingly used for feedstock production. Thus, this scenario describes the "optimistic" (lower) range of possible GHG emissions from LUC.
- The "REF" case is the middle path between HIGH and LOW, but leaves out the use of degraded land.

The following table gives the development of the "world mix" of land use, assumed direct LUC, and the respective iLUC factor figures derived.

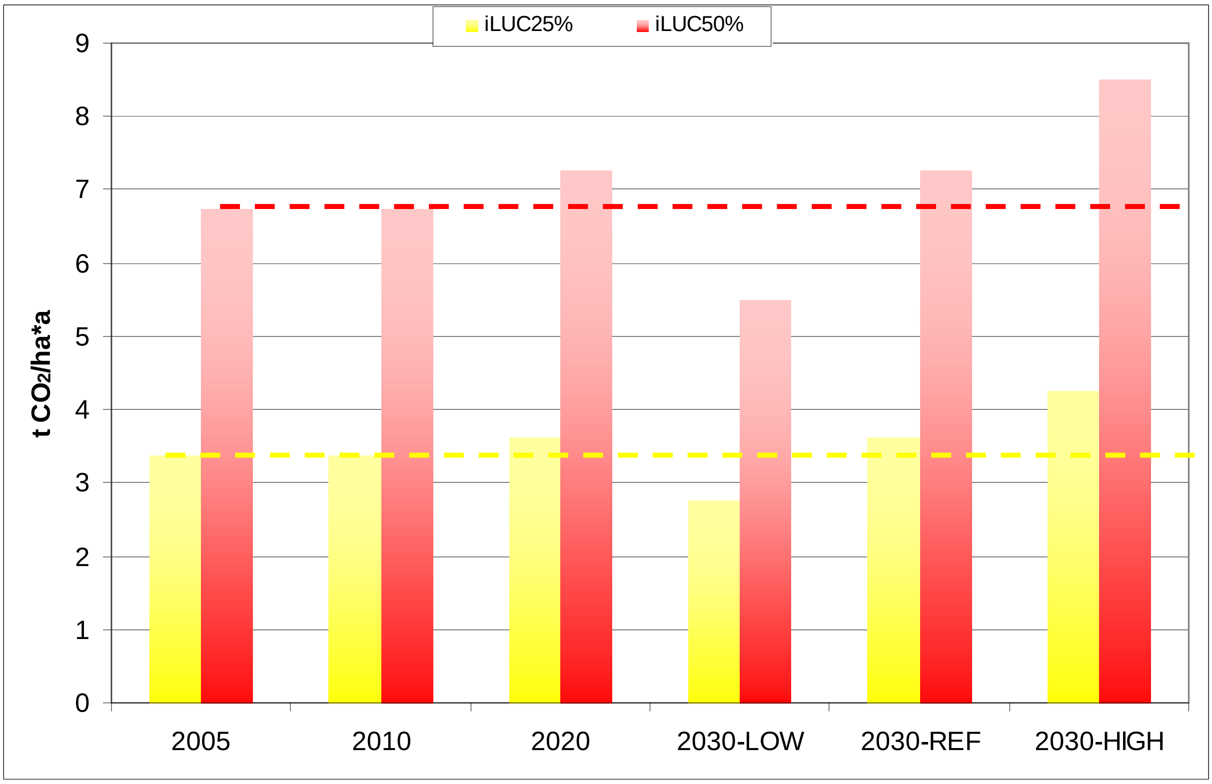
Table 4 Range of iLUC Factors for Biofuel Feedstocks, 2005-2030

	share in world land mix for agricultural exports					
region, crop, previous land use	**2005**	**2010**	**2020**	**2030-REF**	**2030-HIGH**	**2030-LOW**
EU, rapeseed, arable land	2%	1%	0%	0%	0%	0%
EU, rapeseed, grassland	2%	3%	2%	0%	0%	0%
AR/BR, soybean, grassland	20%	20%	21%	23%	20%	26%
AR/BR, soybean, savannah	0%	0%	2%	3%	6%	0%
ID, oil palm, grassland	0%	0%	2%	4%	0%	5%
ID, oil palm, degraded land	0%	0%	0%	0%	0%	3%
ID, oil palm, trop. rain forest	3%	3%	4%	4%	8%	0%
EU, wheat, arable land	4%	3%	2%	0%	0%	0%
EU, wheat, grassland	2%	3%	4%	5%	5%	5%
US, maize, arable land	20%	20%	10%	0%	0%	0%
US, maize, grassland	26%	25%	30%	33%	33%	33%
BR, sugarcane, arable land	7%	4%	2%	0%	0%	0%
BR, sugarcane, grassland	9%	14%	18%	26%	24%	18%
BR, sugarcane, degraded land	0%	0%	0%	0%	0%	10%
BR, sugarcane, savannah	5%	4%	3%	2%	4%	0%
iLUC factor	**[t CO_2/ha/year]**					
maximal iLUC	10.2	10.2	10.9	10.9	12.8	8.3
iLUC25%	**3.4**	**3.4**	**3.6**	**3.6**	**4.3**	**2.8**
iLUC50%	**6.8**	**6.8**	**7.3**	**7.3**	**8.5**	**5.5**

Source: own calculation; grey values are reported for information only.

The following figure gives a graphical representation of the respective iLUC factor results over time.

Figure 2 Current and Projected Levels of the iLUC Factor



Source: own calculation; the dashed lines indicate the 2005 iLUC factor levels for 25% and 50%

To translate the iLUC factor to a given biofuel, the land-based values given above (t CO_2/ha/year) need to be divided by the fuel-specific yield ($GJ_{biofuel}$/ha/year), resulting in energy-specific emission factors (g $CO_2/MJ_{biofuel}$).

With a "typical" net energy yield of a biofuel life-cycle of 100 $GJ_{biofuel}$/ha, the 25% iLUC factor for 2010 translated into 34 g $CO_2/MJ_{biofuel}$, while the 50% iLUC factor would result in 68 g $CO_2/MJ_{biofuel}$.

In the following table, the life-cycle GHG emissions of "real" biofuels are shown, differentiating between the emissions from life-cycle analysis (LCA), LCA plus direct LUC (+dLUC), and this sum plus the 25%- and 50% iLUC factors, respectively (both for 2010). Note that biofuels using feedstocks from degraded land, the dLUC value is negative, while the iLUC factor is zero. Thus, the LCA emissions are reduced in the +dLUC column, and remain the same in the iLUC columns.

Table 5 Life-Cycle GHG Emissions of Biofuels and Impacts from ILUC in 2010

	GHG emission g CO_2eq/$MJ_{biofuel}$				reduction vs. fossil fuel			
Region, feedstock, previous land use	**LCA**	**+dLUC**	**+iLUC 25%**	**+iLUC 50%**	**LCA**	**+dLUC**	**+iLUC 25%**	**+iLUC 50%**
EU, rapeseed, arable	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rapeseed, grass	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF*, arable	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF*, grass	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soy, grass	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soy, sav.	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grass	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degr.	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
EU, wheat, arable	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grass	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugarcane, arable	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugarcane, grass	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugarcane, degr.	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugarcane, sav.	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

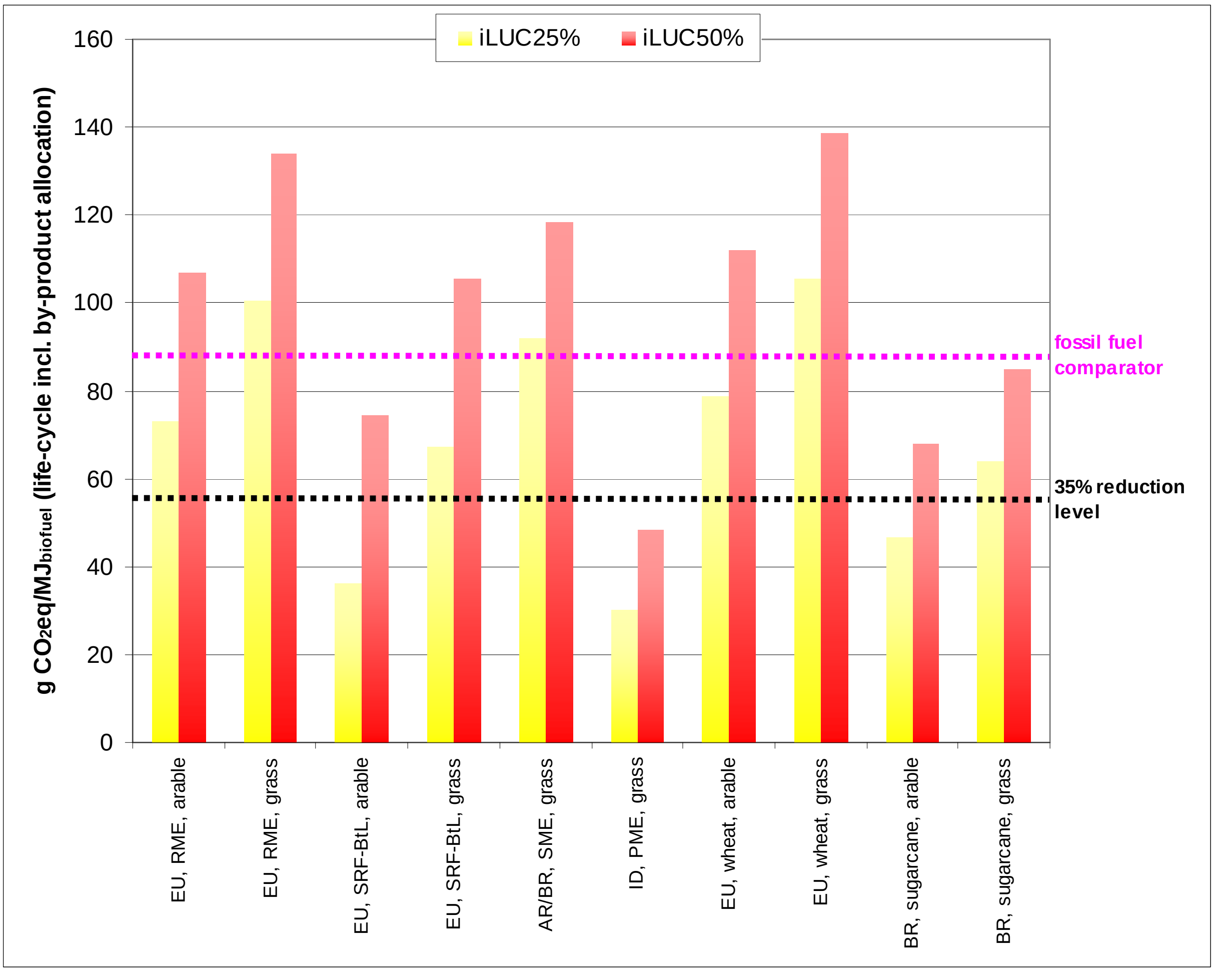
In the “reduction” columns on the right side, positive numbers for savings relative to fossil fuels mean that there is **no net** GHG saving.

Even if **no direct** land-use change is assumed, the iLUC factor will worsen the GHG balance for all non-zero displacement risk biofuels, depending on its level of application: with a 25% ILUC factor, 1st generation biofuels from rapeseed, soy, wheat and maize (corn) will only in some cases reduce GHG emissions compared to their fossil fuel competitors, and all will not achieve the 35% reduction level required by the EU RED by 2012, nor the 50% reduction level required by 2017 onwards.

For the 50% iLUC factor, only sugarcane ethanol from degraded land and palmoil from grass- or degraded land could meet the 35% reduction requirement of the EU RED.

This is shown graphically in the following figure.

Figure 3 Life-Cycle GHG Emissions of Biofuels and Impacts from ILUC in2010

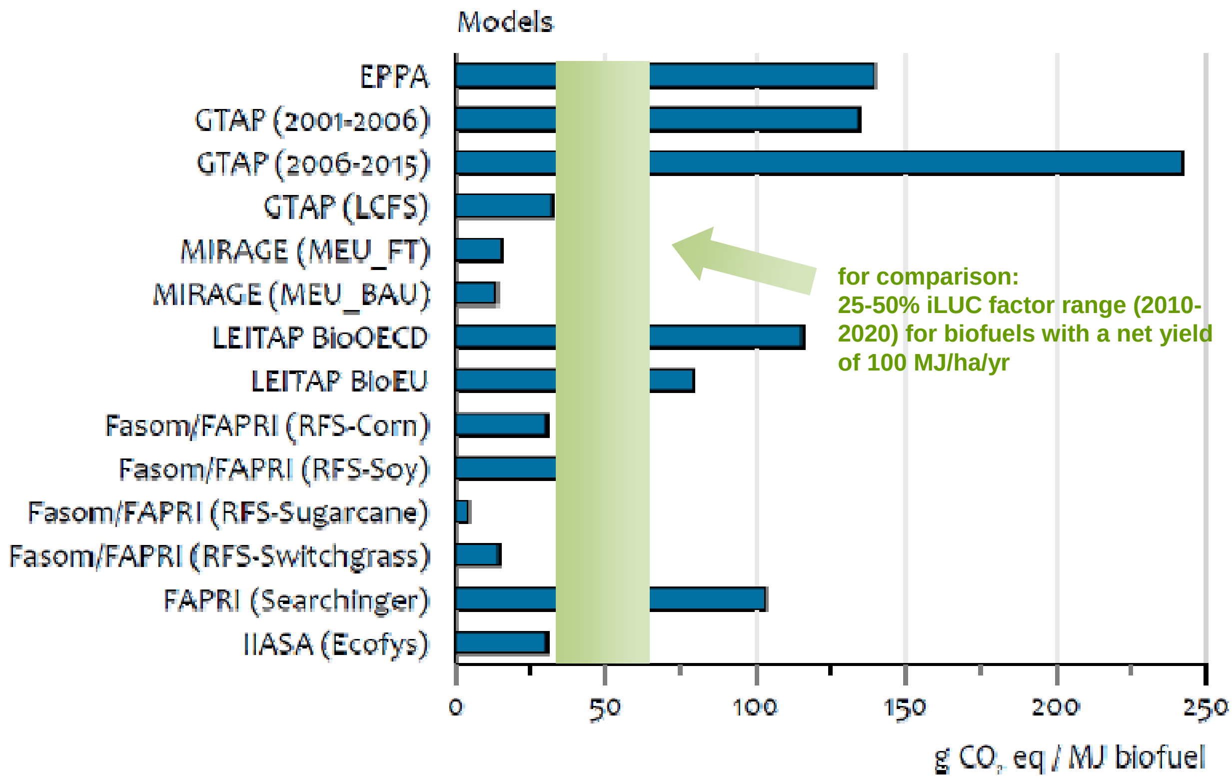


Source: own calculation with GEMIS 4.6, iLUC factor for 2010, fossil comparators from EU RED
RME = rapeseedoil methylester; SRF = short-rotation forestry; BtL = biomass-to-liquid (Fischer-Tropsch) diesel; SME = soybeanoil methylester; PME = palmoil methylester

How will the results for the iLUC factor presented here compare with other results, especially from more “sophisticated” models (see Section 2.3.1)?

The following figure summarizes such results from a variety of studies and models, and indicates that the life-cycle GHG emissions including ILUC are in the range of 50-150 g $CO_2/MJ_{biofuel}$, which is the **same range** as the results from the iLUC factor approach.

Figure 4 Model Results for GHG Emissions of Biofuels including ILUC



Source: PBL (2010b); the MIRAGE results are for 2nd generation biofuels only; for acronyms, see Annex

In that regard, the iLUC factor as presented here seems an **adequate proxy** for **policy makers** to address potential GHG emissions from ILUC.

Given the **deterministic** nature of the iLUC factor approach, it should contribute to minimize the discussion on "uncertainties", and to re-focus the debate on the key issue:

How and by whom can indirect effects from ILUC be translated into policy?

In the following sections, this will be discussed briefly.

4 Options and Problems to Include Quantitative iLUC Factors in Policy-Making

Several European countries and the US (including several US States) started discussing and considering biofuel policies to regulate GHG emissions from ILUC in 2006-2007. In the following, a brief summary of the current status of such policies is given, and problems in translating ILUC factors into regulation are addressed especially for the EU.

4.1 The EU Renewable Energy Directive (RED)

The EU Renewable Energy Directive (RED, see EC 2009) sets a binding target of 10% renewables in transport to be achieved in each Member State by 2020, with environmental criteria to be met **for biofuels and other bioliquids**[28]:

Up from 2011, the life-cycle GHG emissions of biofuels must be at least 35% less than fossil gasoline or diesel, rising to 50% reduction by 2017, and 60% for new installations after that.

The reduction requirements are against a “fossil fuel comparator” specified in the RED for gasoline and diesel, and include life-cycle and direct LUC emissions (with the base year of 2008), but do **not** consider ILUC yet.

During the intense discussions around and negotiations for the RED taking place in 2007 until the end of 2008, several parties and countries did propose to include an ILUC factor into the GHG balance of biofuels, but the final decision of the European Parliament and the Council refrained from doing so – only a report of the EU Commission is required until December 2010 which will review the impact of ILUC on GHG emissions and will address ways to minimize that impact, e.g. through legislation on ILUC, or other policy options.

In summer 2010, a formal consultation will be carried out in which the EU Commission seeks feedback from Member States and stakeholders on a variety of ILUC issues, including quantification, and regulative action[29].

In preparing for the report and consultation, the EU Commission requested several studies[30], but has not yet published any official material for the upcoming consultation.

In parallel to the EU Commission, Member State and NGOs are preparing studies on ILUC (see Section 2.3.2), and this working paper should also be seen in that context.

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[28] Besides GHG emissions, RED also introduces other sustainability requirements, e.g. that biofuels and other bioliquids shall not be made from feedstocks obtained from land with high biodiversity value, nor from carbon-rich or forested land, or wetlands. Currently, the Commission is trying to define “high biodiverse” grasslands.

[29] In Summer 2009, The EU Commission already held a “pre-consultation” on ILUC – for results, see http://ec.europa.eu/energy/renewables/consultations/2009_07_31_iluc_pre_consultation_en.htm

[30] For a listing, see http://ec.europa.eu/energy/renewables/studies/land_use_change_en.htm

Disregarding how and in which quantitative figures the possible GHG emissions from ILUC are expressed, it should be noted that the EU RED scheme in its current format is, in comparison to the Californian LCFS, **fundamentally flawed** with regard to favoring low-ILUC risk biofuels[31]:

The fixed RED thresholds set to 35% (in 2011) and 50% (in 2017) GHG emission reduction can be either met – and then a biofuel is eligible to be accounted under the 10% renewable fuel quota for 2020 – or not. There is **no dynamic** or flexibility to encourage biofuels which perform better than the required reduction thresholds.

Thus, if a quantitative ILUC factor – either as a bonus or a malus[32] - would be included in the current RED calculation scheme for GHG emission reduction, the net impact might be marginal (for ILUC factors around 10-50 g $CO_2eq/MJ_{biofuel}$), as it would only change the in- or exclusion of biofuels in the 10% quota which are close the threshold. Those which are performing better would not be influenced at all.

Without an ILUC factor, though, the consequence of the RED calculation is that through the inclusion of **direct** LUC, low carbon stock land comes under pressure to be used in order to pass the threshold, which could lead to **increased indirect** land use change, as arable or low-C pasture land show low direct LUC emissions.

4.2 The US National Renewable Fuel Standard (RFS)

As part of revisions to the National Renewable Fuel Standard program (RFS) as mandated in the Energy Independence and Security Act of 2007 (EISA) which established eligibility requirements for renewable fuels, including mandatory life-cycle GHG reduction thresholds (specified by EPA), which determine compliance with four renewable fuel categories.

These GHG emission thresholds require a 20 % improvement compared to the 2005 life-cycle GHG emissions of fossil (gasoline or diesel) fuels for any renewable fuel produced at new facilities (those constructed after enactment), a 50% reduction in order to be classified as biomass-based diesel or advanced biofuel, and a 60% reduction in order to be classified as cellulosic biofuel.

For this, EPA published a final methodology and assessment in 2010 (see EPA 2010) which **includes ILUC** quantitatively[33], and is performing further analysis and review with input from the US National Academy of Science.

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[31] It should be noted that the EU Fuels Quality Directive (FQD) which was discussed and enacted in parallel to the RED in 2010, includes an obligation for fuel suppliers to monitor and reduce the GHG **intensity** of fuel sold on the EU market by 6% by 2020. Producing biofuels would be one option to meet this obligation, on the condition that biofuels demonstrate net GHG emission reductions. Thus, the FQD is similar to the LCFS approach in allowing a dynamic GHG accounting, and avoiding fixed “thresholds”.

[32] see footnote 20

[33] see RFS values in Figure 4.

4.3 California Low Carbon Fuel Standard (LCFS)

On 1 January 2010, the California Low Carbon Fuels Standard (LCFS) regulation became effective after several years of intense discussion which especially focused on the quantification of GHG emissions from ILUC caused by increased use of biofuels.

The LCFS aims to reduce California's GHG emissions from transport fuels by reducing the **carbon intensity** of the overall fuels in the state. The reduction, starting in 2011, aims to achieve a 10% reduction by 2020.

The California Air Resources Board (CARB) determines the carbon intensity of all fuels, including biofuels, by calculating life-cycle GHG emission factors which include direct **and indirect** impacts, especially ILUC.

CARB created, similar to the default values of the EU RED, so-called "lookup tables" for the most relevant fuels in California – but in stark contrast to the EU, the CARB data already **include fuel-specific ILUC factors** which were determined based on modeling (CARB 2010).

A summary of selected GHG emission factors including ILUC from the CARB work are given in the following table.

Table 6 Selected Life-Cycle GHG Emissions of (Bio)Fuels in the LCFS Carbon Intensity Lookup Tables

		Carbon Intensity (CO_2eq. in g/MJ_{fuel})		
Fuel	**Pathway Description**	**Direct Emissions**	**Land Use or Other Indirect Effect**	**Total**
Gasoline	average crude oil delivered to CA refineries, average efficiencies	95.9	0	95.9
Ethanol from Corn	Midwest average 80% Dry Mill, 20% Wet Mill, Dry DGS	69.4	30	99.4
Ethanol, CA average	80% Midwest average 20% CA Dry Mill, Wet DGS, NG	65.7	30	95.7
Ethanol from BR sugarcane	average production processes	27.4	46	73.4
Diesel	average crude oil delivered to CA refineries, average efficiency	94.7	0	94.7
Biodiesel	from Midwest soybeans	21.3	62	83.3

Source: extracted from CARB (2010), colors added; CA = California; DGS = Distillers Grains and Solubles; NG = natural gas; BR = Brazil

Compared to the EU "fossil comparators", the Californian data on gasoline and diesel are approx. 10% higher, but the life-cycle GHG emissions of biofuels are rather similar to the data given here (see Table 5), with ILUC factors similar to the 25% iLUC factor determined in this paper for the 2010 time horizon.

While the LCFS is becoming operational in 2010, the data for the GHG balances are subject to further review and adjustment to reflect growing knowledge. In that regard, CARB operates several expert groups and works with US EPA, universities, and other experts to improve its figures, and extend the work to other biofuel pathways.

CARB's Expert Group on Indirect Effects will prepare an input for this until end of 2010 on which CARB will consider changes or adaptations of its ILUC values.

It should be noted also that other US States have legislation under way which is quite similar to the LCFS, and most probably will use similar GHG values.

4.4 Voluntary Standards: RSB, CEN/ISO and the GBEP

In addition to governmental mandatory regulations, several initiatives exist to establish voluntary sustainability standards for bioenergy, and biofuels in particular[34].

The most comprehensive initiative is the Roundtable on Sustainable Biofuels (www.rsb.org) which released, after extensive consultations, a version 1 of its standard in 2009, and currently carries out pilot applications, and operates several expert groups to detail the requirements, especially for GHG emissions.

With regard to ILUC, the RSB is not ready to include such a factor, but its inclusion in the standard is a possibility in the future[35]. The RSB sustainability standards require minimizing ILUC risks, though, and aim to do so using low-risk feedstocks (see Section 5) and/or offsets (see Section 6.1)..

In parallel, the European Standardization Body CEN (since 2009) and the International Standardization Organization (ISO, since April 2010) work on voluntary sustainability standards for bioenergy which also tries to address ILUC, but it will take several years before results of both can be expected[36].

The Global Bio-Energy Partnership (GBEP, see www.globalbioenergy.org), an intergovernmental body established by the G8 countries in 2005 in which many industrial and developing countries and international bodies participate, is compiling sustainability standards and criteria for bioenergy, aiming at an agreed list by 2011 which could serve as a coordinated base for voluntary implementation by all countries.

The GBEP Sustainability Task Force is dealing with ILUC issues (GBEP 2009a+b), and will hold a 2nd international workshop on ILUC in late 2010.

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34 Feedstock-specific initiatives such as the Roundtable on Sustainable Palm Oil (**RSPO**), the Better Sugarcane Initiative (**BSI**), the Round Table on Responsible Soy **(RTRS)** and the Forest Stewardship Council (**FSC**) represent collaborations of supply chain stakeholders of the respective feedstocks, and have (or are in the process to) established sustainability requirements to be met **within the supply chains**. In most cases, independent verification is required to demonstrate compliance, but the initiatives differ in their specific requirements (see Dam et al. 2010 for more details).

35 Internal discussions in the respective RSB expert groups on GHG calculation and indirect effects, no agreement is yet reached on those requirements.

36 The CEN mandate is mainly to support the implementation of the RED, but CEN operates also a working group in indirect effects.

5 Pairing and Trading: "Offsetting" Options for ILUC Risks

The discussion of ILUC policies should also reflect how GHG emissions from ILUC could be reduced – disregarding how a quantification of such emissions would be done[37]. Evidently, any regulation which includes a quantitative ILUC factor might favor those biofuels which show low overall GHG emissions including those from ILUC – but as discussed briefly with reference to the EU RED calculation scheme, it could be that the impact might actually be marginal.

Whatever the ILUC factor may be, there are more options to reduce the "net" total GHG emissions from biofuels by expanding the accounting scope of the GHG balance. With GHG emissions being a global concern without spatial distinction, the share of GHG emissions from ILUC could be "offset" – either by GHG emission reductions somewhere else (in case of a quantified ILUC risk), or by reducing the net land use by considering virtual LUC "bubbles".

The latter has the benefit of not relying on a "full" calculation of GHG emissions from ILUC, as it already nets out land use before LUC emissions are calculated.

5.1 Offsetting Through GHG Emission Reduction

Given a quantitative expression of potential GHG emissions from ILUC, any biofuel with a positive GHG emission burden from ILUC could "offset" this share of total life-cycle emissions through GHG emission reduction achieved by another project, actor, or emission trading scheme.

On the project level, emission credits from the Clean Development Mechanism (CDM) or the future REDD scheme[38]. As ILUC-related GHG emissions are, in principle, the same emissions than those from any other source of CO_2, the mechanisms acknow-ledged under the UNFCCC to "offset" GHG emissions are applicable also for ILUC emissions.

It must be noted, though, that both CDM and REDD projects are quite sensitive to the establishment of a **baseline** to which GHG reductions of a project must be **additional,** and it is not an easy task to determine baselines.

Another option to "offset" ILUC emissions is to make use of the European Emission Trading System (EU ETS) which allows "retiring" emission credits from trade, thus assuring that the respective GHG emission equivalent is not longer subject to emission within the EU ETS scope.

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37 Further options to reduce potential GHG emissions from ILUC without relying on quantitative expressions are discussed in Section 6.

38 Reduced Emissions from Deforestation and Degradation – a mechanism under development under the UNFCCC which credits avoided CO_2 emissions especially from forests.

With current price levels of CO_2 certificates in the order of 10-20 €/t, offsetting ILUC emissions of a liter of biofuel through the EU ETS would be far **less than 1 cent** – not a major cost element when compared to typical production costs of 50 cents/l.

5.2 The Virtual LUC Bubble: Offsetting Through Increased Yields

The second option to reduce ILUC risks is to consider **above-average** yield increases. As ILUC– whatever the quantification approach – is depending on the yields of **both** biofuel feedstocks and displaced agricultural production, there is, in principle, the possibility to avoid ILUC through yield increases if, at a given demand level of agricultural production, either the biofuel feedstock production or the displaced production would come **entirely** from land “set free” by such increases.

There are many parts of the world in which agricultural systems are quite extensive (low yields, few external inputs), especially in the cases of small-scale and subsistence farming. Furthermore, yields and external inputs (fertilizer, water…) for agricultural crops vary widely over production systems and regions, as FAOSTAT data show.

Methods to improve yields could increase external inputs (pesticides and fertilizers), make use of genetically improved plants and farming practices, intercropping, and growing leguminoses in parallel with crops which increased nutrient recycling through N fixation, among others.

Intensification and the respective amount of land possibly “set free” can be measured for a given production systems so that land used on one location for biofuel feedstock production would be “offset” by yield increases somewhere else. This **virtual LUC bubble** concept could, in principle, be applied on a regional or country level, but also on a project or farm/plantation level by “pairing” the biofuel feedstock producer with a yield-increasing farmer somewhere else.

In the simplest form, a farmer would intensify production on own land by e.g. 10% compared to a baseline, and could then cultivate biofuel feedstocks on 10% of the land without any ILUC risk[39].

Similarly, the use of grassland for pasture could be intensified by a higher animal stock density, e.g. in replacing shares of grazing cattle with protein-rich feed, and determining the net land (and GHG emission) gains, if any[40].

A more refined and statistically more significant model would **aggregate** farmers, crops, regions, and production cycles (at least several years) to determine ILUC-free land offsets which are **robust** against natural fluctuation in yields due to external

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39 The potential increase in direct and indirect N_2O emissions from increased fertilizer application would have to be considered in the life-cycle GHG emissions as well.

40 Again, the net balance must be established with considering all changes of inputs, and their life-cycle GHG and land implications. For example, the partial replacing of grazing by corn feed must consider the GHG emissions and land use from corn cultivation, the energy use for ventilation, lighting etc. Furthermore, the direct LUC emissions from converting grassland to biofuel feedstock production must be factored in.

factors such as weather, or pests. For schemes aiming to intensify pasture, similar aggregation would be needed.

There are various **problems** associated with the virtual LUC bubble concept, though:

- Yield increases to "free" land must be **additional to a baseline**. As yields show a variation over time even on the same land, establishing a reference is a challenge in its own, and a baseline would also need to consider "business-as-usual" trends for the future.
- The data on future (projected) yield increases is rather scarce, and evidently subject to debate (see e.g. Johnston et al. 2009). Climate change might well have a negative impact on yields, as Schlenker/Roberts (2009) showed for corn and soybeans in the US, and IFPRI (2009) for irrigated crops in South Asia.
- Intensification could cause **negative tradeoffs** for (agro)biodiversity by reducing the genetic pool, impacting species by direct effects of increased pesticide use and more intense harvesting cycles, or indirectly through N and P leaching which could pollute (ground) water.

The possible negative tradeoffs might be ultimately controlled through a certification system or regulatory requirements, but the problem of establishing adequate baselines and demonstrating additionality seems quite massive unless levels of aggregation are used which would allow to derive statistically significant figures and trends.

The RSB (see Section 4.4) is considering a variation of the virtual LUC bubble on the level of individual economic operators for its ILUC requirements, and the Responsible Cultivation Area approach (see Section 6.2) is testing to what extent one can measure intensification levels in practice.

Still, the overall concept of avoiding ILUC through "netting out" additional land use is a potentially valid approach which should receive further attention, study, and practical testing in the field.

6 Beyond Quantification: Policy Options to Address ILUC without Quantifying Indirect GHG Emissions from Bioenergy

Given the ongoing scientific and especially political debate over quantifying ILUC or using “offsetting” approaches, it is noteworthy to consider alternative policies which address and reduce ILUC risks **without quantifying** displacement and potential GHG emissions from ILUC.

In principle, there are five basic options for this:

1. prioritizing low- or no-ILUC risk feedstocks in bioenergy and biofuels policies
2. prioritizing land for biofuel feedstocks which is not in competition with other uses
3. improving the carbon accounting under the UNFCCC to a fully global system, and establishing a global cap on LUC-related emissions for all countries
4. accounting for all LUC-related emissions in product carbon footprints for all products using biomass feedstock
5. increasing the overall efficiency of bioenergy (and especially biofuel) use.

These options will be discussed briefly in the following sub-sections. Other options not discussed here but being implemented are to address ILUC with specific laws and regulations, or funding and support schemes on better land use management and best agricultural practice for biofuels feedstock crops.

6.1 Feedstock Prioritization: Residues, Wastes…and Algae?

The iLUC risks are low or close to zero for bioenergy and biofuel feedstocks which do not require land for their production – thus, ILUC can be avoided through prioritizing the use of such feedstocks.

With some exceptions[41], residues from biomass production and conversion, e.g., agricultural residues such as manure or excess straw, forestry residues such as thinnings and harvesting leftovers, food processing residues (e.g. risk husks, tallow), wood processing residues such as sawmill dust, are not in competition with other uses due to their low-to-zero economic value, or use restrictions due to physical properties (e.g. water content, particle size). These residues do not imply indirect effects on land, and therefore, their use as bioenergy or biofuel feedstocks is preferable even if no clear ILUC emission factor is known.

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[41] A residue can have competing uses, ranging from improvement of soil organic carbon (e.g. straw) to fertilizers (e.g. potato leafs) and fiber (e.g. pulp & paper, wood panels). In those cases, indirect effects could occur from displacing those uses, with potential impacts on GHG emissions from e.g. fossil fuels being used to produce fertilizers, or additional cultivation of biomass is implied which could cause LUC.

Similarly, organic wastes from various conversion processes and use of food usually need treatment to be safely disposed. Their use as feedstocks could not only avoid ILUC, but might reduce other effects as well, e.g. CH_4 emissions from landfilling.

Algae as possible no-ILUC feedstocks for biofuels became an issue in the last years, with high expectations especially for land-based micro-algae due to assumed very high yields, and their insensivity to productive land. Still, there is little evidence today that algae-based biofuels are near-term options, and their overall economic and environmental performance is questionable unless significant progress – by a factor of 10 or more - is made[42].

6.2 Cultivation Area Prioritization: Feedstocks from Land Not in Competition with other Uses

The second option to reduce ILUC without quantifying GHG emissions is the cultivation of biomass feedstocks on land which – in the "loose" definition of ILUC - is not in competition with other uses, e.g. abandoned farmland and especially unused degraded land, could safeguard against ILUC effects from bioenergy development: As no displacement of previous cultivation occurs, biomass production from these lands will not result in any ILUC-related GHG emissions, and could reduce pressure on protected areas and unprotected biodiversity-relevant areas.

Thus, abandoned farmland and unused degraded land appear to be **priority areas** for biomass production. However, it is questionable to what extend these areas are available (OEKO 2010b). Furthermore, caution is required because some of these lands may constitute areas of high biodiversity value (Hennenberg et al. 2009), and degraded lands can be the base of subsistence for rural populations (Sugrue 2008).

In a two international workshops initiated by the Bio-global project, and held in collaboration with international partners, the overall concept has been discussed broadly[43], and – again as part of the Bio-global project – three case studies were carried out in Brazil, China, and South Africa[44] which aimed at:

- providing GIS data for mapping of abandoned and degraded land and biodiversity-relevant areas on a national and sub-national scale, and to compare these data with globally available results of mapping;
- identifying potential sustainable bioenergy production areas with a focus on degraded land, abandoned farmland as well as natural unused areas, and identifying sustainable cultivation systems for these areas;

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42 See e.g. OEKO (2009a-c) and NRDC (2009).

43 The workshops were a joint initiative of Oeko-Institut, RSB and UNEP in collaboration with CI, FAO, IUCN and WWF (see OEKO/RSB/UNEP 2008+2009a). A full documentation is available on the Bioenergy Wiki (see OEKO/RSB/CI 2008 + UNEP/RSB/UNEP 2009b).

44 see OEKO (2010b) for a summary, and OEKO/IFEU (2010) for the project context. The full texts of the country case studies will be made available over Summer 2010 on www.oeko.de/service/bio

- checking the achieved results of GIS analysis (top-down) with selected data from the field, involving respective stakeholders (bottom up).

Evidence from this work indicates that indeed degraded land could be available for biomass feedstock production without competing with other uses, but the overall potential of land “really” being unused seems far smaller than previously assumed in many top-down studies.

Furthermore, many of those lands seem to be located in rather remote areas which especially lack transport infrastructure, thus increasing costs of starting production there. Degraded land also requires some sort of reclamation to support biomass cultivation, and yields will be often lower than on competing, fertile land, thus increasing production costs.

Without major incentives to move biomass production into such areas, few investments can be assumed. Therefore, a prioritization of degraded land must be substantiated by an adequate support scheme.

The concept of “Responsible Cultivation Areas” (RCA) is heading in a similar direction. RCA focuses on identifying underutilized, “degraded” or “unused land” and intensification or integration models to avoid additional land use for biomass crop cultivation, thus minimizing ILUC as well as negative social and environmental impacts. (Ecofys 2009b). Funded by industry (BP, Nesté Oil, Shell) and private foundations, the RCA approach has been developed by Ecofys, Conservation International, and WWF, and field-tested in some smaller areas in Brazil and Indonesia (CI 2010). Preliminary results indicate similar findings than those of the country studies mentioned above, and it will be quite interesting to follow the implementation of the RCA component “intensification”, as this is burdened with specific problems (see Section 5.2).

6.3 Global LUC Accounting and Capping for all Counties

A third – and rather fundamental – option is to change the currently only partial accounting of CO_2 from LUC under the UNFCCC into a full, globally viable scheme, and to establish a binding “cap” on the overall CO_2 emissions from LUC for all countries (WBGU 2009).

This is clearly the preferable option, as it would extend the scope of LUC accounting to all “drivers” and, thus, effectively eliminate indirect effects.

Unfortunately, the UNFCCC process is rather slow, as the Copenhagen negotiations at COP15 in December 2010 and the follow-up process have shown. A full LUC accounting would clearly be opposed by some parties, and establishing a “cap” would face similar opposition than the non-LUC emission limits (or reduction targets) face already.

Still, it is important to recognize the link between ILUC and the UNFCCC implementation, even if it is only a long-term perspective to resolve ILUC problems.

6.4 LUC Emissions in Carbon Footprints for all Products from Biomass Feedstocks

A different option to account for all LUC-related emissions could, in principle, be implemented independently from the UNFCCC by requiring **product carbon footprints** for all products using biomass feedstocks[45] which would also effectively expand the accounting scope dramatically, and avoid the loopholes of current sectoral accounting logics.

Such a system could be introduced gradually for the key products, and with the major producers of feed, food, fiber and bioenergy feedstocks agreeing on such a system, avoiding the consensus-building process between all countries while still capturing the majority of possible displacement effects.

The drawback of this approach is, besides its questionable chances of near-term implementation, that it would rely on customer decision making to avoid products with a high carbon footprint. Experiences with “green” electricity in various countries indicate that there seemingly are limits to the private willingness to factor GHG emissions into decision making if cost implications are significant.

In that regard, the carbon footprint option in itself might be applicable, but its effectiveness in reducing ILUC would depend on global customer acceptance.

6.5 Efficient Bioenergy Use to Reduce ILUC

Last but not least, any increase in the overall efficiency of bioenergy (and especially biofuel) **use** would proportionately reduce ILUC risks, whatever its quantitative expression. For example, using liquid biofuels for transport is less efficient in terms of displaced fossil fuel per hectare of feedstock production than the same biofuel used in cogenerating electricity and heat, and electric cars running on high-efficient conversion of biomass feedstocks in to bio-electricity might be more favorable than using biofuels in cars with combustion engines[46].

Similarly, the concept of biorefineries might reduce ILUC through improved conversion efficiency for all products delivered – but as biorefineries are still in the concept stage, it will take quite some time before biorefineries could make an impact, if at all.

More fundamentally, any improvement in the end-use efficiency of bioenergy and biofuels, from better insulation of homes, improved cooking stoves to less fuel-consuming airplanes, buses, cars, ships and trucks could contribute to reduce ILUC in proportion to the level of end-use reduction achieved[47].

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[45] The establishment of GHG footprints for biomass products is discussed in BMU/UBA/OEKO 2009

[46] This is being discussed more prominently in e.g., IEA (2009a), UNEP (2009) and WBGU (2009).

[47] Although outside of the scope of this paper, it should be noted that dietary changes (from meat and dairy toward vegetables and fish) could effectively reduce ILUC also.

7 Conclusions and Future Work

This paper tried to introduce and detail a simplified approach to quantify GHG emissions from ILUC with regard to policy implementation in regulation[48], and argues that the derived figures could, in principle, be implemented in respective policies.

Clearly, the approach can be refined and substantiated with better data on direct LUC trends from global monitoring, and be improved by adding more adequate estimates of future trade patterns.

The brief discussion of current policies and options to reduce ILUC resulted in a variety of approaches and options so that a quantified iLUC factor could be translated into practical regulation – both mandatory and voluntary – with few restrictions.

A more fundamental solution of ILUC could come from a revised LUC accounting under the international climate regime, but would require also a "cap" on LUC emissions which will be hard to negotiate within the near future.

Thus, approaches such as the iLUC factor and the other options presented here will be needed as "second best".

In 2010, both in the EU and in the US the quantification of ILUC will be discussed at least as prominently as in the last two years, and globally, the GBEP will contribute to a more intensive exchange of thoughts and views on ILUC.

Given this background, a few items of future work on ILUC are presented in the following.

7.1 "Tiered" iLUC Factors

The work on the iLUC factor and other ongoing studies – especially the UK ILUC study (E4Tech 2010) – together with the more "global" modeling carried out in the US by EPA and CARB should be developed further into an overall framework of "tiered" ILUC values for selected fuels, regions, and specific methods:

- Tier 1 would be a global average similar to the iLUC factor presented here
- Tier 2 would represent specific regionalized data e.g. for the EU, or the US
- Tier 3 would detail methodologies (e.g. different agro-economic or biophysical models).

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48 The iLUC factor approach is **not** meant as an **analytical** tool for policy analysis, as it treats in its current version - to be in accordance with the mandatory EU RED calculation requirements for GHG emission balances - the by-products of biofuel conversion systems by energy allocation. For policy analysis, this restriction is not necessary so that more adequate rules of accounting for by-products can (and should) be applied, as this is a key issue for the overall results (see e.g. E4Tech 2010; PBL 2010e).

This work would not “resolve” the dispute around ILUC, but could help to clarify limitations of approaches, increase understanding between different ways to calculate ILUC, and enhance overall consistency.

7.2 Detailing Offset Options

As briefly discussed in Section 5, “offsetting” possible ILUC emissions is neither depending on calculating a GHG emission factor for ILUC, nor must it be a costly option.

Thus, the different concepts should be researched and detailed further to allow both governments and market actors to consider approaches such as the virtual LUC bubble, or the intensification component of the RCA as means to reduce ILUC risks in their respective decision-making.

7.3 Risk Mapping

Last but not least, the spatial understanding and resolution of ILUC should be improved by considering **risk mapping**, an approach being suggested in late 2009. Risk mapping aims to

- identify potential countries/areas under significant (highly probable) thread of iLUC impacts using a combination of agro-economic model results, national maps on crops suitability, infrastructure, and carbon stocks
- in order to check if “regionalized“ ILUC predictions from models match GIS-based evidence, and to calculate the **risk distribution** for that.

Preliminary work in that direction is currently carried out by Oeko-Institut in cooperation with PBL, based on own funding.

Building on the outcome of this work might be a viable contribution to the further understanding and improvement of ILUC in general, and the “tier” approach suggested in the previous subsection.

References

Banse, M./Eickhout, B. 2009: From production to land use change: Combining economic and land use models - presentation at the JRC/EEA/OECD expert consultation on 'Review and inter-comparison of modeling land use change effects of bioenergy' in Paris on 29-30 January 2009 http://re.jrc.ec.europa.eu/biof/pdf/luc_bioenergy_policies_paris/banse_production_land_use.pdf

BMU (German Federal Ministry for Environment)/UBA(German Federal Environment Agency)/OEKO (Oeko-Institut – Institute for applied ecology) 2009: "Product Carbon Footprint Memorandum - Position statement on measurement and communication of the product carbon footprint for international standardization and harmonization purposes"; Berlin www.bmu.de/files/pdfs/allgemein/application/pdf/memorandum_pcf_en_bf.pdf

CARB (California Air Resources Board) 2010: Low Carbon Fuel Standard (LCFS) http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

CBD (Convention on Biological Diversity) 2008: The Potential Impacts of Biofuels on Biodiversity - Matters arising from SBSTTA recommendation XII/7, Note by the Executive Secretary; UNEP/CBD/COP/9/26 (draft)

CDB (Commissie Duurzaamheidsvraagstukken Biomassa) 2009: Make agriculture part of the solution - Recommendation on Indirect Land Use Change (ILUC); The Hague www.corbey.nl/includes/download.asp?media_id=585

CE 2010: Biofuels: indirect land use change and climate impact; report prepared for BirdLife International, T&E, and EEB; Delft http://www.ce.nl/publicatie/biofuels%3A_indirect_land_use_change_and_climate_impact/1068

CI (Conservation International) 2010: Identification of Responsible Cultivation Areas in Pará, Brazil - Pilot Test Focusing on Oil Palm; Washington DC

Dale, Bruce E. 2008: Life-cycle analysis of biofuels & land use change; presented at the 5th Annual California Biomass Collaborative, Sacramento, California, May 28-30, 2008

Dam, Jinke van et al. 2010: Initiatives in the field of biomass and bioenergy certification – 2010 update; IEA Bioenergy Task 40 www.bioenergytrade.org/downloads/overviewcertificationsystemsfinalapril2010.pdf

E4tech 2010: iLUC Study (various papers); London http://www.ilucstudy.com

EC (European Commission) 2009: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources; Official Journal of the EU, June 5, 2009 L 140, p. 16-62 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

EC (European Commission) 2010: Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling; SEC(2010)

65/SEC(2010) 66; Brussels http://ec.europa.eu/energy/renewables/transparency_platform/doc/2010_report/com_2010_0011_3_report.pdf

Ecofys 2009a: Summary of approaches to account for and monitor indirect impacts of biofuel production; prepared for VROM http://www.mvo.nl/Portals/0/duurzaamheid/biobrandstoffen/nieuws/2009/12/PECPNL084225%20Indirect%20land%20use%20change%20review%20VROM%20_11%20Nov%202009_%20print%20V.pdf

Ecofys 2009b: Responsible Cultivation Areas - Practical definition and methodology to identify areas for responsible energy crop cultivation; Dehue, B./Meyer, S; prepared for Shell Global Solutions and Neste Oil; Utrecht

Ecometrica 2009: A Practical Approach for Policies to Address GHG Emissions from Indirect Land Use Change Associated with Biofuels; Technical Paper - TP-080212-A commissioned by Greenergy; London http://www.ecometrica.co.uk/attachments/Technical_Paper_-_Practical_Approach_to_ILUC_V1.2.pdf

ELOBIO (Efficient and Low-disturbing Biofuels policies) 2009a: “Land use special” http://www.elobio.eu/fileadmin/elobio/user/docs/Elobio_policy_paper_4_final.pdf

ELOBIO (Efficient and Low-disturbing Biofuels policies) 2009b: Implications of an accelerated biofuels production on food security and the environment - Sustainability certification of biofuels http://www.elobio.eu/fileadmin/elobio/user/docs/Elobio_policy_paper_3.pdf

EPA (US Environmental Protection Agency) 2010: Renewable Fuel Standard (RFS2): Program Amendments; Washington DC http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm

ESA (Ecological Society of America) 2010: Biofuels: Implications for Land Use and Biodiversity; Dale, Virginia/Kline, Keith/Wiens, John/Fargione, Joseph; Biofuels and Sustainability Reports; Washington, DC http://www.esa.org/biofuelsreports/files/ESA%20Biofuels%20Report_VH%20Dale%20et%20al.pdf

EUCAR/JRC/CONCAWE 2007: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context - Well-to-Wheels Report Version 2c; Ispra http://ies.jrc.ec.europa.eu/WTW

EU-JRC/EEA/OECD Expert Consultation on “Review and inter-comparison of modelling land use change effects of bioenergy”, OECD Conference Centre, Paris, January 29–30, 2009 http://re.jrc.ec.europa.eu/biof/html/luc_bioenergy_policies_paris.htm

Faaij, Andre 2008: Bioenergy and global food security; prepared for WBGU; Berlin http://www.wbgu.de/wbgu_jg2008_ex03.pdf

FAO (Food and Agriculture Organization of the United Nations) 2008: The State of Agriculture 2008 - Biofuels: prospects, risks and opportunities; Rome ftp://ftp.fao.org/docrep/fao/011/i0100e/i0100e.pdf

FAO (United Nations Food and Agriculture Organization) 2009: The State of Food and Agriculture 2009; Rome http://www.fao.org/docrep/012/i0680e/i0680e.pdf

Fargione, J. et al. 2008: Land Clearing and the Biofuel Carbon Debt; in: Science vol. 319, p. 1235 – 1238 http://www.sciencemag.org/cgi/reprint/319/5867/1235.pdf and www.sciencemag.org/cgi/content/full/1152747/DC1

Fehrenbach, H./Fritsche, U./Giegrich, J. 2008: Greenhouse Gas Balances for Biomass: Issues for further discussion; Issue paper for the informal workshop, January 25, 2008 in Brussels http://www.oeko.de/service/bio/dateien/en/ghg_balance_bioenergy.pdf

Fritsche, Uwe 2007: GHG Accounting for Biofuels: Considering CO_2 from Leakage; Extended and updated version, Darmstadt (Germany), May 21, 2007; working paper prepared for BMU by Oeko-Institut; Darmstadt

Fritsche, Uwe R. 2008: Beyond the German BSO: Scope of Further Work on Land-use Related GHG; presented at the Brussels Workshop 'Sustainability requirements for biofuels - German Perspectives', January 25, 2008 http://www.oeko.de/service/bio/dateien/en/presbeyond_bso_fritsche.pdf

GBEP (Global Bioenergy Partnership) 2009a: Summary of the GBEP Workshop on Indirect Land Use Change: Status of and Perspectives on Science-Based Policies; held on May 15, 2009 in New York http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2009_events/Workshop_ILUC_NY_15May_2009/GBEP_iLUC_workshop_-_Summary.pdf

GBEP (Global Bioenergy Partnership) 2009b: GBEP Workshop on Indirect Land Use Change: Status of and Perspectives on Science-Based Policies; held on May 15, 2009 in New York www.globalbioenergy.org/events1/gbep-events-2009/other-events-2009/en/

Gibbs, Holly 2009: Mapping Land Sources for New Biofuel Croplands; presentation held at the AAAS Annual Meeting, Feb. 14, 2009;

Gibbs, Holly et al. 2010: Pathways of Agricultural Expansion Across the Tropics: Implications for Forest Resources; in: Proceedings of the National Academy of Science (forthcoming)

Hennenberg, K./Dragisic, C./Haye, S./Hewson, J./Semroc, B./Savy,C./Wiegmann, K./Fehrenbach, H./Fritsche, U. R. 2009: The Power of Bioenergy-Related Standards to Protect Biodiversity; in: Conservation Biology (published online: 16 Dec 2009) http://www3.interscience.wiley.com/cgi-bin/fulltext/123216075/PDFSTART

IEA (International Energy Agency) 2009a: Better Use of Biomass for Energy. Position Paper of IEA RETD and IEA Bioenergy. Final version as at 14 December 2009 http://www.iea-retd.org/files/IEA_RETD_BIOENERGY_position_paper091215.pdf

IEA (International Energy Agency) 2009b: Bioenergy – The Impact of Indirect Land Use Change - Summary and Conclusions from the IEA Bioenergy ExCo63 Workshop held at Rotterdam, 12 May 2009 http://www.ieabioenergy.com/DocSet.aspx?id=6214

IEA (International Energy Agency) 2009c: Bioenergy - a sustainable and reliable energy source. A review of status and prospects; Main Report http://www.ieabioenergy.com/LibItem.aspx?id=6479

IFEU (Institute for Energy and Environment Research) 2007: Greenhouse Gas

Balances for the German Biofuels Quota Legislation: Methodological Guidance and Default Values; Fehrenbach, Horst et al.; prepared for the German Federal Environment Agency (UBA); Heidelberg

IFEU (Institute for Energy and Environment Research) 2009: Synopsis Current Models and Methods Applicable to Indirect Land-Use Change (ILUC); prepared for BDBe; Heidelberg http://www.lab-biokraftstoffe.de/downloads/PDF/fachinformationen/ifeu-Studie_ILUC/ifeu_Kurzfassung_englisch.pdf

IFPRI (International Food Policy Research Institute) 2009: Climate Change Impact on Agriculture and Costs of Adaptation; Washington DC http://www.ifpri.org/sites/default/files/publications/pr21.pdf

IIASA (International Institute for Applied Systems Analysis) 2009: Biofuels and Food Security - Implications of an accelerated biofuels production; Vienna http://www.ofid.org/publications/PDF/biofuels_book.pdf

IPCC (Intergovernmental Panel on Climate Change) 2006: 2006 IPPP Guidelines for National Greenhouse Gas Inventories – Vol. 4: Agriculture, Forestry and Other Land Use; IGES (Institute for Global Environmental Strategies), Kanagawa http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Joanneum (Joanneum Research) 2010: The upfront carbon debt of bioenergy; Zanchi, Giuliana; Pena, Naomi; Bird, Neil; Graz http://www.transportenvironment.org/Publications/prep_hand_out/lid/591

Johnston, Matt et al. 2009: Resetting global expectations from agricultural biofuels; in: Environ. Res. Lett. 4 (2009) 014004 http://dx.doi.org/10.1088/1748-9326/4/1/014004

JRC (EU Joint Research Centre) 2008: Biofuels in the European Context: Facts and Uncertainties. Technical report of the EU Joint Research Centre, April 2008; Netherlands and Italy. www.jrc.ec.europa.eu/

JRC -IPTS (Joint Research Centre - Institute for Prospective Technological Studies) 2010: Impacts of the EU biofuel target on agricultural markets and land use: a comparative modelling assessment; report JRC 58484/EUR 24449 EN; Seville http://ec.europa.eu/energy/renewables/studies/doc/land_use_change/study_jrc_biofuel_target_iluc.pdf

JRC (EU Joint Research Centre)/EEA (European Environment Agency)/OECD (Organization for Economic Cooperation and Development) 2009: Expert Consultation on "Review and inter-comparison of modelling land use change effects of bioenergy", OECD Conference Centre, Paris, 29-30 January 2009 http://re.jrc.ec.europa.eu/biof/html/luc_bioenergy_policies_paris.htm

Lapola, David et al. 2010: Indirect land-use changes can overcome carbon savings from biofuels in Brazil; in: PNAS vol. 107 no. 8, p. 3388-3393 www.pnas.org/cgi/doi/10.1073/pnas.0907318107

Lywood et al. 2009: The relative contributions of changes in yield and land area to increasing crop output; in: Global change biology – Bioenergy http://dx.doi.org/10.1111/j.1757-1707.2009.01028.x

Lywood, Warwick/Pinkney, John/Cockerill, Sam 2009: The relative contributions of changes in yield and land area to increasing crop output; in: GCB Bioenergy (2009) 1, p. 360–369, http://dx.doi.org/10.1111/j.1757-1707.2009.01028.x

Macedo, I.C./Seabrab, J./Silva, J. 2008: Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020; in: Biomass and Bioenergy http://doi:10.1016/j.biombioe.2007.12.006

Melillo, Jerry M. et al. 2009: Indirect Emissions from Biofuels: How Important?; in: Science published online Oct. 22, 2009 http://dx.doi.org/10.1126/science.1180251

MIT (Massachusetts Institute of Technology) 2009: Unintended Environmental Consequences of a Global Biofuels Program; Melillo, Jerry M. e al.; Report No. 168; Cambridge http://globalchange.mit.edu

MNP (Milieu en Natuur Planbureau) 2008: Local and global consequences of the EU renewable directive for biofuels – testing the sustainability criteria. MNP Report 500143001; Bilthoven http://www.mnp.nl/nl/publicaties/2008/index.html

OEKO (Oeko-Institut - Institute for applied ecology) 2008: GHG Balances and cumulated primary energy demand of bioenergy conversion pathways including possible land-use changes (Treibhausgasbilanzen und kumulierter Primärenergieverbrauch von Bioenergie-Konversionspfaden unter Berücksichtigung möglicher Landnutzungsänderungen); Fritsche, Uwe R./Wiegmann, Kirsten; study prepared for WBGU; Darmstadt (in German) http://www.wbgu.de/wbgu_jg2008_ex04.pdf

OEKO (Oeko-Institut - Institute for applied ecology) 2009a: International Workshop on Sustainable Bioenergy from Algae; held in Berlin Nov. 2, 2009; co-funded by the German Federal Ministry for Environment (BMU) through the Federal Environment Agency (UBA) and the German Federal Ministry for Education and Research (BMBF) http://www.bioenergywiki.net/Sus_BioAlgae

OEKO (Oeko-Institut - Institute for applied ecology) 2009b: Aquatic Biomass: Sustainable Bio-energy from Algae? Issue Paper; Hennenberg, K./Fritsche, U./Herrera, R. (Oeko-Institut) in collaboration with Anja Eggert (Leibniz Institute for Baltic Sea Research Warnemünde), Morchio Renato (Sur Solutions, Chile), Suzanne Hunt (HuntGreen LLC, USA) and Boosya Bunnag (King Mongkut's University of Technology Thonburi, Thailand); sponsored by BMBF and BMU through UBA; Darmstadt http://www.bioenergywiki.net/images/8/8a/Input-paper.pdf

OEKO (Oeko-Institut - Institute for applied ecology) 2009c: International Workshop "Aquatic Biomass: Sustainable Bioenergy from Algae?" - Report on the Workshop Outcomes; in collaboration with Morchio Renato (Sur Solutions, Chile), Suzanne Hunt (HuntGreen LLC, USA) and Boosya Bunnag (King Mongkut's University of Technology, Thailand); sponsored by BMBF and BMU through UBA; Darmstadt http://www.bioenergywiki.net/images/3/32/Outcome-Report.pdf

OEKO (Oeko-Institut - Institute for applied ecology) 2010a: Report from the EEA-JRC Workshop "Biomass resource assessment for biofuels/bioenergy and competition with other biomass uses" held at Eberswalde from December 8 – 9, 2009; Fritsche, U../Hennenberg, K.; prepared for EEA; Darmstadt http://re.jrc.ec.europa.eu/biof/pdf/biomass_resource_eberswalde/eberswalde_report.pdf

OEKO (Oeko-Institut - Institute for applied ecology) 2010b: Sustainable Biomass Production from Degraded Lands – Summary of Country Studies; Hennenberg, K./Fritsche, U./Herrera, R.; funded by the German Federal Ministry for Environment (BMU) through the German Federal Environment Agency (UBA); Darmstadt http://www.oeko.de/service/bio

OEKO (Oeko-Institut - Institute for applied ecology)/IFEU (Institute for Energy and Environmental Research) 2009: 2nd Joint International Workshop on Bioenergy, Biodiversity Mapping and Degraded Lands held in Paris, France, 7-8 July 2009 jointly with the RSB and UNEP and in collaboration with CI, FAO, IUCN and WWF; sponsored by the German Federal Ministry for Environment (BMU) through the German Federal Environment Agency (UBA) http://www.bioenergywiki.net/index.php/2nd_Joint_International_Workshop_Mapping

OEKO (Oeko-Institut - Institute for applied ecology)/IFEU (Institute for Energy and Environmental Research) 2010: Sustainable Bioenergy: Summarizing Final Report for the research project "Development of strategies and sustainability standards for the certification of biomass for international trade", sponsored by the German Federal Ministry for Environment (BMU) through the German Federal Environment Agency (UBA); Darmstadt/Heidelberg (forthcoming, see http://www.umweltbundesamt.de and http://www.oeko.de/service/bio)

OEKO (Oeko-Institut)/RSB (Round Table on Sustainable Biofuels)/CI (Conservation International) 2008: Criteria and Indicators to Identify and Map High Nature Value Areas; Joint Issue Paper prepared for the Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands - June 30 to July 1, 2008 at UNEP, Paris; prepared by Klaus J. Hennenberg, Uwe R. Fritsche, Kirsten Wiegmann (OEKO), Sébastien Haye (RSB), Jenny Hewson, Christine Dragisic (CI) http://www.bioenergywiki.net/images/1/1e/OEKO_CI_RSB_2008_Joint_Issue-Paper_Criteria_WS_Paris_2008.pdf

OEKO (Oeko-Institut - Institute for applied ecology)/RSB (Roundtable on Sustainable Biofuels)/UNEP (United Nations Environment Programme) 2008a: Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands; held in Paris June 30 to July 1, 2008 in collaboration with CI, FAO, IUCN and WWF; sponsored by the German Federal Ministry for Environment (BMU) through the German Federal Environment Agency (UBA) http://www.bioenergywiki.net/index.php/Joint_International_Workshop_Mapping

OEKO (Oeko-Institut - Institute for applied ecology)/RSB (Roundtable on Sustainable Biofuels)/UNEP (United Nations Environment Programme) 2008b: Bioenergy and Biodiversity: Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands - NOTES and OUTCOME; Darmstadt/Lausanne/Paris http://www.bioenergywiki.net/images/f/ff/Paris_Workshop_HNV_Degraded_Lan d_Informal_Notes_final_%28OEKO_2008%29.pdf

OEKO (Oeko-Institut - Institute for applied ecology)/UNEP (United Nations Environment Programme) 2009: 2nd Joint International Workshop on Bioenergy, Biodiversity Mapping and Degraded Lands - Report on the Workshop Outcomes; sponsored by the German Federal Ministry for Environment (BMU) through the German Federal Environment Agency (UBA); Darmstadt/Paris
http://www.bioenergywiki.net/images/1/15/2nd_Paris_WS_Report.pdf

ORNL (Oak Ridge National Laboratory, Center for BioEnergy Sustainability) 2009: Sustainability of Bioenergy Systems: Cradle to Grave: Report from the 2009 Workshop; ORNL/CBES-002; Oak Ridge
http://www.ornl.gov/sci/besd/cbes/EPA/SBSWorkshop_Report.pdf

NRDC (Natural Resources Defense Council) 2009: Cultivating clean energy: The promise of algae biofuels; Washington DC
http://www.ascension-publishing.com/BIZ/cultivating.pdf

PBL (Netherlands Environmental Assessment Agency) 2010a: Identifying the indirect effects of bio-energy production; Bilthoven
http://www.mnp.nl/bibliotheek/rapporten/500143003.pdf

PBL (Netherlands Environmental Assessment Agency) 2010b: Evaluation of the indirect effects of biofuel production on biodiversity: assessment across spatial and temporal scales; Oorschot, Mark van/Ros, Jan/Notenboom, Jos; Bilthoven
http://www.mnp.nl/bibliotheek/rapporten/500143007.pdf

PBL (Netherlands Environmental Assessment Agency) 2010c: Are models suitable for determining ILUC factors?; Prins, A.G et al., Bilthoven
http://www.mnp.nl/bibliotheek/rapporten/500143006.pdf

PBL (Netherlands Environmental Assessment Agency) 2010d: Indirect effects of biofuels: intensification of agricultural production; Stehfest, Elke/Ros, Jan/Bouwman, L.; Bilthoven
http://www.mnp.nl/bibliotheek/rapporten/500143005.pdf

PBL (Netherlands Environmental Assessment Agency) 2010e: The contribution of by-products to the sustainability of biofuels; Ros, Jan/Born, GJ van den/Notenboom, Jan; Bilthoven
http://www.mnp.nl/bibliotheek/rapporten/500143004.pdf

Ratmann, R./Szklo, A./Schaeffer, R. 2010: Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate; in: Renewable Energy vol. 35 no. 1, pp. 14-22

RFA (Renewable Fuels Agency) 2008: The Gallagher Review of the indirect effects of biofuels production; St Leonards-on-Sea
http://www.dft.gov.uk/rfa/_db/_documents/Report_of_the_Gallagher_review.pdf

RSB (Roundtable on Sustainable Biofuels) 2009: Summary on ILUC: http://cgse.epfl.ch/webdav/site/cgse/shared/Biofuels/Documents%20and%20Resources/09-10-09_Ecofys%20-%20Summary%20of%20approaches%20to%20accounting%20for%20indirect%20impacts%20of%20biofuel%20production.pdf

Schlenker, W./Roberts, M. 2009: Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change; in: PNAS (published online before print August 28, 2009) www.pnas.org_cgi_doi_10.1073_pnas.0906865106

Scott-Wilson 2009: Developing a spreadsheet model for the calculation of the emissions from indirect land use change (ILUC) as a result of biofuel production - explanatory note; prepared for FoE UK; London http://np-net.pbworks.com/f/FOE,+Scott+Wilson(+2009)+Dveloping+a+speradsheet+model.+Biofuels+research+explanatory+note.pdf

Searchinger, Timothy 2010: Biofuels and the need for additional carbon; in: Environ. Res. Lett. 5 (2010) 024007, http://dx.doi.org/10.1088/1748-9326/5/2/024007

Searchinger, Timothy 2009: Evaluating Biofuels - The Consequences of Using Land to Make Fuel; Brussels Forum Paper Series of the German Marshall Fund of the United States, Washington DC http://www.gmfus.org/template/download.cfm?document=/doc/Biofuels final.pdf

Searchinger, Timothy et al. 2008: Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change; in: Science vol. 319, p. 1238-1240 http://www.sciencexpress.org;10.1126/science.1151861

Searchinger, Timothy D. et al. 2009: Fixing a Critical Climate Accounting Error; in: Science 23 vol. 326. no. 5952, pp. 527 - 528 http://dx.doi.org/10.1126/science.1178797

Sugrue, Annie 2008: Bioenergy production on marginal and degraded land: the potential social impacts; Issue Paper prepared for the Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands - June 30 to July 1, 2008 at UNEP, Paris http://www.bioenergywiki.net/images/a/a1/Bioenergy_and_land_use_social_impacts_A_Sugrue.pdf

Taheripour, Farzad et al. 2010: Biofuels and their by-products: Global economic and environmental implications; in: Biomass and Bioenergy vol. 34 no. 3, p. 278-289 http://dx.doi.org/10.1016/j.biombioe.2009.10.017

Tilman, David et al. 2009: Beneficial Biofuels - The Food, Energy, and Environment Trilemma; in: Science vol. 325, p. 270-271 (publ. online July 17, 2009)

UNEP (United Nations Environment Programme) 2009: Towards sustainable production and use of resources: Assessing Biofuels; Paris http://www.unep.fr/scp/rpanel/pdf/assessing_biofuels_full_report.pdf

UNEP (United Nations Environment Programme)/RSB (Roundtable on Sustainable Biofuels)/IPIEACA (International Petroleum Industry Environmental Conservation Association) 2009: Indirect Land-Use Change: A stakeholder debate on the science and policy impacts of sustainable biofuel production; Workshop Nov. 9-10, 2009, Lausanne http://www.ipieca.org/activities/fuels/workshops/nov_09.php

WBGU (German Advisory Council on Global Change) 2009: World in Transition - Future Bioenergy and Sustainable Land Use; Berlin http://www.wbgu.de/wbgu_jg2008_en.pdf

Annexes

A-1 Acronyms and Abbreviations

A-2 Data Background for the iLUC Factor Calculations 2005-2030

A-1: Acronyms and Abbreviations

AR	Argentina
BMU	German Federal Ministry for Environment, Nature Protection and Nuclear Safety
BR	Brazil
BtL	biomass-to-liquid (Fischer-Tropsch) diesel
C	carbon
CARB	California Air Resources Board
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CI	Conservation International
degr.	degraded
dLUC	direct land use change(s)
DOE	US Department of Energy
EEA	European Environment Agency
EISA	Energy Independence and Security Act
EPA	US Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute model
GBEP	Global Bio-Energy Partnership
GEMIS	Global Emissions Model for Integrated Systems (www.gemis,de)
GHG	greenhouse gas(es)
GJ	GigaJoule(s) = 10^9 Joules
GTAP	Global Trade Analysis Project
ha	hectare(s)
ID	Indonesia
IEA	International Energy Agency
IFEU	Institute for Energy and Environment Research
IIASA	International Institute for Applied Systems Analysis
ILUC	indirect land use change(s)

IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
JRC	European Commission Joint Research Centre
LCA	life-cycle analysis
LCFS	Low Carbon Fuel Standard (of California)
LUC	land use change(s)
MAX	Maximum Case
MJ	MegaJoule(s) = 10^6 Joules
MY	Malaysia
NGO	Non-governmental organization
OECD	Organization for Economic Cooperation and Development
OEKO	Öko-Institut (Institute for applied Ecology)
OPT	Optimal Case
ORNL	Oak Ridge National Laboratory
PBL	Netherlands Environmental Assessment Agency
PME	palmoil methylester
RED	EU Directive on the promotion of the use of energy from renewable sources (“Renewable Energy Directive”)
REDD	Reduced Emissions from Deforestation and Degradation
REF	Reference Case
RFS	Renewable Fuel Standard (US)
RME	rapeseedoil methylester
RSB	Roundtable on Sustainable Biofuels
sav.	savannah
SME	soybeanoil methylester
SRF	short-rotation forestry
UBA	German Federal Environment Agency (Umweltbundesamt)
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
WWF	World-Wide Fund for Nature

A-2: Data Background for the iLUC Factor Calculation 2005 - 2030

Table A- 1 Carbon Emissions from Direct LUC and World Mix of Land Used for Agricultural Commodity Exports in 2005

	assumption on C for LUC, based on IPCC				2005
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	2%
EU, rapeseed, grassland	6	63	69	254	2%
EU, SRF for BtL, arable land	5	50	55	202	0%
EU, SRF for BtL, grassland	6	63	69	254	0%
AR/BR, soybean, grassland	6	63	69	254	20%
AR/BR, soybean, svannah	66	68	134	491	0%
ID, oil palm, grassland	6	63	69	254	0%
ID, oil palm, degraded land	5	30	35	128	0%
ID, oil palmö, trop. rain forest	165	100	265	972	3%
EU, wheat, arable land	5	50	55	202	4%
EU, wheat, grassland	6	63	69	254	2%
US, maize, arable land	5	50	55	202	20%
US, maize, grassland	6	63	69	254	26%
BR, sugar cane, arable land	5	50	55	202	7%
BR, sugar cane, grassland	6	63	69	254	9%
BR, sugar cane, degraded land	5	30	35	128	0%
BR, sugar cane, savannah	66	68	134	491	5%
weighted world mix based on domestic land shares for export				**270**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare and year				**13.5**	**t CO_2/ha*a**

Source: own calculation based on IPCC (2006), and FAOSTAT

Table A- 2 Life-Cycle GHG Emissions of Biofuels and Impacts from iLUC in 2005

	GHG emission g $CO_2eq/MJ_{biofuel}$				reduction vs. fossil fuel			
Biodiesel	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, rape, arable	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rape, grass	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF-BtL, arable	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF-BtL, grass	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soy, grass	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soy, sav.	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grass	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degraded	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, trop. forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
Bioethanol	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, wheat, arable	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grass	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugarcane, arable	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugarcane, grass	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugarcane, degrad.	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugar cane, sav.	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

Table A- 3 Carbon Emissions from Direct LUC and World Mix of Land Used for Agricultural Commodity Exports in 2010

	assumption on C for LUC, based on IPCC				2010
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	1%
EU, rapeseed, grassland	6	63	69	254	3%
EU, SRF for BtL, arable land	5	50	55	202	0%
EU, SRF for BtL, grassland	6	63	69	254	0%
AR/BR, soybean, grassland	6	63	69	254	20%
AR/BR, soybean, svannah	66	68	134	491	0%
ID, oil palm, grassland	6	63	69	254	0%
ID, oil palm, degraded land	5	30	35	128	0%
ID, oil palm, trop. rain forest	165	100	265	972	3%
EU, wheat, arable land	5	50	55	202	3%
EU, wheat, grassland	6	63	69	254	3%
US, maize, arable land	5	50	55	202	20%
US, maize, grassland	6	63	69	254	25%
BR, sugarcane, arable land	5	50	55	202	4%
BR, sugarcane, grassland	6	63	69	254	14%
BR, sugarcane, degr. land	5	30	35	128	0%
BR, sugar cane, savannah	66	68	134	491	4%
weighted world mix based on domestic land shares for export				**270**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare and year				**13.5**	**t CO_2/ha*a**

Source: own calculation based on IPCC (2006), and FAOSTAT

Table A- 4 Life-Cycle GHG Emissions of Biofuels and Impacts from iLUC in 2010

	GHG emission g $CO_2eq/MJ_{biofuel}$				reduction vs. fossil fuel			
Biodiesel	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, rapeseed, arable land	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rapeseed, grassland	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF for BtL, arable land	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF for BtL, grassland	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soybean, grassland	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soybean, svannah	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grassland	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degr. land	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, trop. rain forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
Bioethanol	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, wheat, arable land	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grassland	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugarcane, arable land	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugarcane, grassland	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugarcane, degr. land	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugarcane, savannah	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

Table A- 5 Carbon Emissions from Direct LUC and World Mix of Land Used for Agricultural Commodity Exports in 2020

	assumption on C for LUC, based on IPCC				2020
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	0%
EU, rapeseed, grassland	6	63	69	254	2%
EU, SRF for BtL, arable land	5	50	55	202	0%
EU, SRF for BtL, grassland	6	63	69	254	0%
AR/BR, soybean, grassland	6	63	69	254	21%
AR/BR, soybean, svannah	66	68	134	491	2%
ID, oil palm, grassland	6	63	69	254	2%
ID, oil palm, degraded land	5	30	35	128	0%
ID, oil palm, trop. rain forest	165	100	265	972	4%
EU, wheat, arable land	5	50	55	202	2%
EU, wheat, grassland	6	63	69	254	4%
US, maize, arable land	5	50	55	202	10%
US, maize, grassland	6	63	69	254	30%
BR, sugar cane, arable land	5	50	55	202	2%
BR, sugar cane, grassland	6	63	69	254	18%
BR, sugar cane, degr. land	5	30	35	128	0%
BR, sugar cane, savannah	66	68	134	491	3%
weighted world mix based on domestic land shares for export				**290**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare and year				**14.5**	**t CO_2/ha*a**

Source: own calculation based on IPCC (2006), and FAOSTAT

Table A- 6 Life-Cycle GHG Emissions of Biofuels and Impacts from iLUC in 2020

	GHG emission g $CO_2eq/MJ_{biofuel}$				reduction vs. fossil fuel			
Biodiesel	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, rapeseed, arable land	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rapeseed, grassland	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF for BtL, arable land	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF for BtL, grassland	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soybean, grassland	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soybean, svannah	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grassland	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degraded land	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, trop. rain forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
Bioethanol	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, wheat, arable land	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grassland	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugarcane, arable land	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugarcane, grassland	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugarcane, degr. land	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugarcane, savannah	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

Table A- 7 Carbon Emissions from Direct LUC and World Mix of Land Used for Agricultural Commodity Exports in 2030 (Reference Case)

	assumption on C for LUC, based on IPCC				2030-REF
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	0%
EU, rapeseed, grassland	6	63	69	254	0%
EU, SRF for BtL, arable land	5	50	55	202	0%
EU, SRF for BtL, grassland	6	63	69	254	0%
AR/BR, soybean, grassland	6	63	69	254	23%
AR/BR, soybean, svannah	66	68	134	491	3%
ID, oil palm, grassland	6	63	69	254	4%
ID, oil palm, degraded land	5	30	35	128	0%
ID, oil palm, trop. rain forest	165	100	265	972	4%
EU, wheat, arable land	5	50	55	202	0%
EU, wheat, grassland	6	63	69	254	5%
US, maize, arable land	5	50	55	202	0%
US, maize, grassland	6	63	69	254	33%
BR, sugar cane, arable land	5	50	55	202	0%
BR, sugar cane, grassland	6	63	69	254	26%
BR, sugar cane, degr. land	5	30	35	128	0%
BR, sugar cane, savannah	66	68	134	491	2%
weighted world mix based on domestic land shares for export				**290**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare and year				**14-5**	**t CO_2/ha*a**

Source: own calculation based on IPCC (2006), and FAOSTAT

Table A- 8 Life-Cycle GHG Emissions of Biofuels and Impacts from iLUC in 2030 (Reference Case)

	GHG emission g $CO_2eq/MJ_{biofuel}$				reduction vs. fossil fuel			
Biodiesel	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, rapeseed, arable land	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rapeseed, grassland	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF for BtL, arable land	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF for BtL, grassland	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soybean, grassland	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soybean, svannah	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grassland	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degraded land	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, trop. rain forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
Bioethanol	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, wheat, arable land	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grassland	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugar cane, arable land	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugar cane, grassland	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugar cane, degr. land	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugar cane, savannah	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

Table A- 9 Carbon Emissions from Direct LUC and World Mix of Land Used for Agricultural Commodity Exports in 2030 (Maximum Case)

	assumption on C for LUC, based on IPCC				2030-MAX
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	0%
EU, rapeseed, grassland	6	63	69	254	0%
EU, SRF for BtL, arable land	5	50	55	202	0%
EU, SRF for BtL, grassland	6	63	69	254	0%
AR/BR, soybean, grassland	6	63	69	254	20%
AR/BR, soybean, svannah	66	68	134	491	6%
ID, oil palm, grassland	6	63	69	254	0%
ID, oil palm, degraded land	5	30	35	128	0%
ID, oil palm, trop. rain forest	165	100	265	972	8%
EU, wheat, arable land	5	50	55	202	0%
EU, wheat, grassland	6	63	69	254	5%
US, maize, arable land	5	50	55	202	0%
US, maize, grassland	6	63	69	254	33%
BR, sugarcane, arable land	5	50	55	202	0%
BR, sugarcane, grassland	6	63	69	254	24%
BR, sugarcane, degr. land	5	30	35	128	0%
BR, sugarcane, savannah	66	68	134	491	4%
weighted world mix based on domestic land shares for export				**340**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare and year				**17.0**	**t CO_2/ha*a**

Source: own calculation based on IPCC (2006), and FAOSTAT

Table A- 10 Life-Cycle GHG Emissions of Biofuels and Impacts from iLUC in 2030 (Maximum Case)

	GHG emission g $CO_2eq/MJ_{biofuel}$				reduction vs. fossil fuel			
Biodiesel	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, rapeseed, arable land	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rapeseed, grassland	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF for BtL, arable land	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF for BtL, grassland	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soybean, grassland	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soybean, svannah	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grassland	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degraded land	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, trop. rain forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
Bioethanol	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, wheat, arable land	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grassland	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugarcane, arable land	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugarcane, grassland	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugarcane, degr. land	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugarcane, savannah	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

Table A- 11 Carbon Emissions from Direct LUC and World Mix of Land Used for Agricultural Commodity Exports in 2030 (Optimal Case)

	assumption on C for LUC, based on IPCC				2030-OPT
region, crop, previous land use	**above ground [t C/ha]**	**below ground [t C/ha]**	**total [t C/ha]**	**emission [t CO_2/ha]**	**share in world mix**
EU, rapeseed, arable land	5	50	55	202	0%
EU, rapeseed, grassland	6	63	69	254	0%
EU, SRF for BtL, arable land	5	50	55	202	0%
EU, SRF for BtL, grassland	6	63	69	254	0%
AR/BR, soybean, grassland	6	63	69	254	26%
AR/BR, soybean, svannah	66	68	134	491	0%
ID, oil palm, grassland	6	63	69	254	5%
ID, oil palm, degraded land	5	30	35	128	0%
ID, oil palm, trop. rain forest	165	100	265	972	0%
EU, wheat, arable land	5	50	55	202	0%
EU, wheat, grassland	6	63	69	254	5%
US, maize, arable land	5	50	55	202	0%
US, maize, grassland	6	63	69	254	33%
BR, sugarcane, arable land	5	50	55	202	0%
BR, sugarcane, grassland	6	63	69	254	18%
BR, sugarcane, degr. land	5	30	35	128	0%
BR, sugarcane, savannah	66	68	134	491	0%
weighted world mix based on domestic land shares for export				**220**	**t CO_2/ha**
theoretical 100% iLUC factor, per hectare and year				**11.0**	**t CO_2/ha*a**

Source: own calculation based on IPCC (2006), and FAOSTAT

Table A- 12 Life-Cycle GHG Emissions of Biofuels and Impacts from iLUC in 2030 (Optimal Case)

	GHG emission g $CO_2eq/MJ_{biofuel}$				reduction vs. fossil fuel			
Biodiesel	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, rapeseed, arable land	40	40	73	107	-54%	-54%	-15%	**24%**
EU, rapeseed, grassland	40	67	100	134	-54%	-23%	**16%**	**55%**
EU, SRF for BtL, arable land	14	-2	36	75	-84%	-103%	-58%	-14%
EU, SRF for BtL, grassland	14	29	67	106	-84%	-67%	-22%	**22%**
AR/BR, soybean, grassland	20	51	92	118	-76%	-41%	**7%**	**37%**
AR/BR, soybean, svannah	20	188	188	188	-76%	**118%**	**118%**	**118%**
ID, oil palm, grassland	43	12	30	48	-50%	-86%	-65%	-44%
ID, oil palm, degraded land	43	-55	-55	-55	-50%	-163%	-163%	-163%
ID, oil palm, trop. rain forest	43	213	213	213	-50%	**147%**	**147%**	**147%**
Bioethanol	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**	**LCA**	**dLUC**	**iLUC25%**	**iLUC50%**
EU, wheat, arable land	45	45	79	112	-46%	-46%	-7%	**32%**
EU, wheat, grassland	45	72	106	139	-46%	-15%	**24%**	**63%**
BR, sugarcane, arable land	26	26	47	68	-69%	-70%	-45%	-20%
BR, sugarcane, grassland	26	43	64	85	-69%	-50%	-25%	**0%**
BR, sugarcane, degr. land	26	-1	-1	-1	-69%	-101%	-101%	-101%
BR, sugarcane, savannah	26	120	120	120	-69%	**41%**	**41%**	**41%**

*Source: own calculation with GEMIS 4.6; fossil comparators from EU RED; positive (bold in red) figures indicate that no emission reduction is achieved but an increase; *= short-rotation forestry as feedstock for biomass-to-liquid (Fischer-Tropsch) diesel in year 2030*

Table A- 13 Yield Assumptions for the iLUC Factor Calculations from 2005 to 2030

yield of crop system [$GJ_{feedstock}$/t]	**2005**	**2010**	**2020**	**2030**
rapeseed EU	84	88	93	108
SRF, EU	135	138	142	153
soybean, AR/BR	43	45	47	55
oil palm, ID/MY	500	526	552	641
oil palm, degraded land, ID/MY	350	363	377	422
wheat, EU	100	116	119	128
maize, US	159	55	57	61
sugarcane, BR	650	660	670	701
sugarcane degraded land, BR	600	609	618	647

Source: data for 2005 from FAOSTAT, for 2010 ff and degraded land own estimate based on trend projections for annual yield increases from various sources; data represent total ***gross*** *biomass growth (including by-products and residues); EU = European Union; SRF = short-rotation forestry; AR = Argentina; BR = Brazil; ID = Indonesia; MY = Malaysia; US = United States of America*