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Abstract:
The contribution of biofuels to the saving of greenhouse gas (GHG) emissions has recently been questioned because of emissions resulting from land use change (LUC) for the bioenergy feedstock production. We investigate how an expanding biofuel feedstock production impacts on land use dynamics if LUC is included into the biofuel carbon accounting framework as scheduled by the European Commission. We first illustrate the change in carbon balances of different biofuels, using methodology and data from the IPCC Guidelines for National Greenhouse Gas Inventories. It turns out that the conversion of natural land except for grassy savannahs impedes meeting the EU's 35% minimum emissions reduction target for biofuels. We show that the current accounting method promotes biofuel feedstock production mainly on former cropland, thus increases the competition between food and fuel production on the currently available cropland area. We further discuss whether it is profitable to use degraded land for commercial bioenergy production as requested by the European Commission to avoid undesirable LUC and conclude that current regulation sets little incentives to use such land. The exclusive consideration of LUC for bioenergy production minimizes direct LUC at the expense of increasing indirect LUC but a convincing approach to implement indirect LUC into the framework does not exist. To overcome this problem, we propose the inclusion of all agricultural activities into a regulatory framework for carbon accounting, thus eliminating the indirect LUC risk.

Keywords: land use change emissions, bioenergy, biofuels, European policy, land use dynamics, indirect land use change (ILUC)

JEL classification: Q58, Q42, Q24, Q17

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1. Introduction

The expansion of biomass production for energy uses is seen as one of the strategies to replace fossil energy sources by non-fossil renewable sources. The European Union for example seeks to achieve a minimum target of 10% renewables in the transport sector until 2020 and many countries are promoting the conversion of existing agricultural land and the conversion of land previously not used for crop production for the production of feedstock for biofuels and other bioenergy. The contribution of bioenergy to the saving of greenhouse gas emissions has recently become criticized because – according to previous practice – the inclusion of the carbon balance of LUC has not been included in the greenhouse (GHG) balances of bioenergy production. Previously greenhouse gas balances were computed by netting out the gross GHG savings of a particular bioenergy product such as a specific biofuel with the fossil based GHG inputs needed to produce the bioenergy. This approach has ignored the fact that in the process of production not only the flow of GHGs in the production process need to be accounted for but also the change in the stock of carbon that is contained in the biomass above ground and in the soils and roots below ground.

This practice leads to an overestimation of the carbon mitigation potential of bioenergy considering that today, deforestation and forest degradation for agricultural expansion, conversion to pastureland, infrastructure development, destructive logging and fires cause nearly 20% of global greenhouse gas emissions (UN-REDD 2009). This figure is greater than that of the entire global transportation sector and second only to that of the energy sector. In particular, Brazil and Indonesia reveal a coincidence of large emissions from LUC - accounting for 61% of world CO_2 emissions from LUC (Le Quéré et al. 2009) - and of having the largest increase in the production of feedstocks for biofuels which is second only to the USA. It is widely agreed that in order to maintain climate change impacts within limits with which societies will be able to cope, the rise of the global average temperature must not surpass two degrees Celsius. This cannot be achieved without reducing emissions from the land use sector (UN-REDD 2009).

The change in the stock of carbon is of particular importance if land comes into use for bioenergy production that has not been used before or has been subject to other uses such as forestry or as pasture. The direct LUC can release carbon if, e.g., forest area is converted to the production of energy crops. The carbon stored in the wood and leaves of the trees and the carbon in roots and soils would need to be added to the fossil GHG inputs as the production of energy crops mobilizes carbon that would not have been released into the atmosphere without the activity.

Some argue that the GHG balance including the change in carbon stocks of a particular area still does not account for the complete GHG balance of a particular bioenergy production activity. The so called "indirect LUC" (ILUC) should be also included in a complete GHG balance. This claim rests on the idea that the conversion of an area that has been used for food production will lead to an increase in the food production on another land area. It is then argued that the change in the carbon stock due to LUC on this indirectly affected land now in use for food production should be added to the GHG balance of the bioenergy production.

Until now, the European Commission has not published an approach to calculate the emissions from LUC. The purpose of this paper is to put forward such an approach and to display the consequences for bioenergy production and land use dynamics under unchanged emission reduction targets.

In the following we present and analyze in detail the political incentives set by the European Union to account for LUC in the bioenergy production so far. Therefore we first discuss in section 2 the current political framework, especially through the analysis of the Renewable Energy Directive of the European Commission. In section 3 we present a practical LUC emission calculation method on the basis of the IPCC Guidelines for National Greenhouse Gas Inventories. In a next step in section 4, we calculate concrete examples for LUC emissions based on the IPCC Guidelines and derive the consequences for the European biofuel policy accounting especially for degraded land. Furthermore in section 5 we discuss whether it is possible to account for indirect LUC and present as a last step a global carbon trading system including the whole agricultural sector as a policy instrument that creates the desired incentives to preserve high carbon land. Section 7 concludes the overall results and give further recommendations for action.

2. European bioenergy policy and LUC regulations

2.1. Towards the Renewable Energy Directive

Since the beginning of the century, the European Union has extended its efforts to increase the use of bioenergy within the Community mainly with the goal to lower its dependency on imported oil and to reduce greenhouse gas emissions in order to tackle global warming. Biofuels have received particular attention within the European bioenergy policy due to the fact that overall one third of the European emissions are produced by traffic and that in the transportation sector fossil fuels need to be mainly imported from outside the EU, whereas alternative energy sources such as the wind or solar energy in the electricity sector were not commercially feasible for use in the transport sector.

With the “Directive on the Promotion of the Use of Biofuels or Other Renewable Fuels in Transport” (Directive 2003/39 EC), the European Commission sets targets of a minimum proportion of 2% biofuels in 2005 and 5,75% in 2010 relative to the total final energy use in the transport sector. In the following, a “Biomass Action Plan” in 2005 and a report on “An EU strategy for biofuels” in 2006 demonstrated that a target of 20% renewable energy share of the overall energy consumption in the European Union and a minimum target of 10% biofuels in the transport sector in all member states are achievable and appropriate to reduce greenhouse gas emissions.

In the meantime a discussion arose about the sustainability of the worldwide biofuel production. Especially reports about high deforestation rates in the Amazon and in Southeast Asia, two regions with a large expansion of bioenergy production, aggravated the concerns of international organizations, scientists and NGOs about the risks of biodiversity loss and food and water shortages arising from an increasing biofuel production. In the same way the overall greenhouse gas reduction potential of biofuels were questioned if LUC emissions for the biofuel production were taken into account.

In January 2008 the European Commission presented a review of the 2003 biofuel directive which was endorsed in December 2008 with the "Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources" 2008/0016 (COD) (referred to as RES-D in the following). It includes a range of sustainability requirements to prevent the promotion of environmental harmful biofuels. Together with the so called "climate and energy package" it sets a minimum greenhouse gas reduction target of 20% (relative to 1990) and a share of 20% of renewable energy in the Communities total energy consumption in 2020. The 10% biofuel target was softened to a 10% target of energy of renewable sources, such that for example the use of electricity from renewable sources in electric cars also account to the target. The required sustainability criteria need to be fulfilled from both imported bioliquids and bioliquids produced within the Community in order to account for the national targets of renewable energy to have eligibility for financial support for the consumption of biofuels and other bioliquids (RES-D Art. 15 (1)).

2.2. Sustainability requirements in the RES-D

The sustainability requirements set up in the RES-D mainly tackle the problem that an increasing bioenergy production might cause undesirable LUC. The European Commission states that it is likely that the promotion of biofuel production leads to an expansion in the land used for agricultural production. To avoid the negative impact of such LUC, such as the destruction of natural habitats and land with high carbon contents or soil erosion and the shortage of water in regions where it is already a scarce factor, the European Commission sets different requirements to account for LUC.

According to the RES-D *undesirable LUC* can be categorized as LUC for bioenergy crop production from:

- **high-biodiverse land** and
- **land with a high carbon stock**.

The latter is necessary to guarantee that the European biofuel policy actually contributes to the European climate change mitigation strategy. As desirable LUC, the RES-D defines especially the conversion of **degraded land**. In the following we give a detailed account of the regulatory set up for each of these land categories in the RES-D.

High-biodiverse land

Concerning high-biodiverse land, the RES-D specifies the categories of undesirable LUC as follows: If no evidence is provided that the production of the raw material does not change the status of an area as high-biodiverse land in January 2008, *primary forest and other wooded land*[1], which the RES-D defines as *forest and other wooded land of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed* as well as *areas designated by law or by relevant competent authority for nature protection purposes; or areas for the protection of rare threatened or endangered ecosystems or species recognized by international agreements or included in lists drawn up by (recognized) intergovernmental organizations or the International Union of the Conservation of Nature* are generally excluded areas for the bioenergy feedstock production. This accounts especially for *highly biodiverse natural grassland,* which is defined as *grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and the ecological characteristics and processes.* The same shall account for *highly biodiverse non natural grassland* defined as *grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded,* unless the feedstock production is necessary to preserve this status (RES-D Art 15(3)).

Land with high carbon stocks

The RES-D also prohibits the production of bioenergy crops on land with high carbon stocks. But as the carbon stock of different land types depend on various factors, the RES-D avoids undesirable emissions from LUC for the bioenergy feedstock production through two channels:

- via a general exclusion of some land types from the suitable land type options for bioenergy production
- via a minimum emission saving target

Concerning the first channel it is widely agreed that some land types are always carbon rich and therefore, in the same way as high-biodiverse land, are generally excluded from the suitable land type options for the bioenergy feedstock production. In particular this refers to *wetlands, that is to say land that is covered with or saturated by water permanently or for a significant part of the year as well as peatland* unless these land types are not disturbed or drained by the raw material production. Equally excluded are *continuously forested areas, that is to say land spanning more than 1 hectare with trees higher than 5 meters and a canopy cover of more than 30%, or trees able to reach these threshold in situ* (RES-D Art.15(4)). This also applies to forest with a canopy cover of 10%-30% unless evidence is provided that their carbon stock is low enough to justify their conversion in accordance with the rules laid down in the RES-D (RES-D Art.15(4)). These rules are part of the second channel:

[1] Whenever we use cursive letters we cite literally from the respective source

For the production on all other area the emissions savings of the use of biofuels or other bioliquids need to be at least 35% when accounting for the emissions caused in the whole value chain including LUC emissions. This threshold shall rise to 50% in 2017 and to 60% for installations whose production will start from 2017 onwards (RES-D Art 15(2)). This implies that biofuel crops produced on land with a high carbon content before the conversion are less likely to achieve this target and will therefore not be used for bioenergy production.

According to the RES-D, method and data for the calculation of emissions from LUC should be based on the IPCC "Guidelines for National Greenhouse Gas Inventories" (IPCC Guidelines) and should be practically implementable (RES-D Annex VII C(8)). We will further discuss this source in section 3.

Degraded land

In general, the European Commission wants to promote the cultivation of crops on degraded land for bioenergy crop production. The RES-D attributes a bonus of 29 gCO2eq/MJ in the computation of the carbon balance if evidence is provided that *the land was not in use for agriculture or any other activity in January 2008 and is severely degraded land, including such land that was formerly in agricultural use or heavily contaminated land.* The bonus of 29 gCO2eq/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, *provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena are ensured and that soil contamination for land is reduced.* According to the RES-D *severely degraded land* refers to land that, *for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded*; *heavily contaminated land* refers to land *unsuitable for the cultivation of food and feed due to soil contamination* (RES-D Annex VII C(7a)).

2.3. The general sustainability concept in the RES-D – A convincing approach?

The increasing concern in Europe about undesirable ecological impacts of the expansion of biofuel production mainly in Indonesia, Brazil and other countries gave rise to proposals to ban all imports of bioenergy from these countries. However, such policies would punish all producer regardless of the individual ecological impact of their production. The identification of eco-friendly biofuels as required in the RES-D thus represents a better alternative to the complete closing of the market for biofuels from outside of Europe. This is especially the case because sugarcane bioethanol and palm biodiesel have higher energy yields per hectare than the biofuel crop options produced inside the European Union such as wheat, sugarbeet or corn. As both are perennial crops they do not consume energy for a annual replantation, the energy densities of these crops are higher and production costs are lower. Therefore, the 10% biofuel target could be achieved in a cheaper way and less land consuming by allowing for bioenergy imports.

Biodiversity is more difficult to account for than carbon stocks as biodiversity is more difficult to quantify and therefore there cannot be a minimum target of biodiversity to exclude an area from the conversion for bioenergy production. Consequently a qualitative evaluation of land with a rich biodiversity is needed. In the RES-D this is done partly by defining primary forest as bio-diverse land and by excluding natural forest that is modified by human activity from the primary forest definition. As forest, that is naturally carbon rich, is already excluded from bioenergy production by the rules for the carbon content of land, this case is less problematic, even though probably a precise definition of *human activity* is needed.

Natural grassland, such as shrubland, bushland, savannah, is more complicated as their canopy cover is mostly too small to be treated as forest but it can be the most bio diverse land of all. The definition for high biodiverse grassland given by the RES-D is still quite general and the Commission wants to establish appropriate criteria and/or geographical ranges to define such highly bio-diverse grasslands (RES-D Art 15(3c)). This has not been done yet and is probably not an easy task as many of the worldwide natural grasslands, especially in Latin America, are not fully natural grasslands but used extensively for cattle ranching. The natural vegetation is often preserved and the transition to managed pasture land is gradual. It also can be the case that extensive cattle ranching allows for the rich biodiversity in the first case by avoiding a shrub encroachment of the grassland area.

The RES-D provides the opportunity that the European Union or its Member States sign bilateral contracts with third countries about the sustainability of the agricultural production in relation to the criteria in the RES-D, guarantying that all bioenergy product imports from these countries comply with the sustainability requirements (RES-D Art. 16(4)). However, at the moment this is not the case. In terms of creating individual incentives for using land and technologies with low GHG emissions it would not be desirable. Consequently, compliance with the sustainability criteria should be verified for each biofuel producer. This is to be done by some kind of auditing board which needs to be practical and manageable in terms of *avoiding imposing an unreasonable burden on industry* (RES-D Art. 16).

Even though accounting for LUC is required in the RES-D, the published default emission values for different biofuel options do not yet include emissions from LUC. What is captured in these default values are the emissions from the cultivation of the crop, harvesting, production process and distribution (RES-D Annex VII C). As it will be shown, emissions from LUC can have a huge impact on the emission balance of biofuels, thus it is crucial to incorporate these emissions in the calculation.

As the European Commission has not published an approach to calculate the emissions from LUC so far, the following section puts forward such an approach. Based on that in section 4 we display the consequences for bioenergy production under unchanged emission reduction targets with a range of examples: Which biofuel options meet the minimum reduction target of 35% greenhouse gas savings set by the European Commission so as to count for the 10% renewable energy target in the transport sector when adding LUC emissions to the carbon balance? Which consequences for the LUC dynamics can be deduced?

3. LUC emissions calculation

The contribution of biofuels to climate change mitigation can only be assessed if an exact calculation of the greenhouse gas emission balance and hence of the LUC emissions from the feedstock production is made in order to guarantee that the contribution of the biofuel production to climate policy is beneficial. In this section we first show how LUC emissions should be calculated from a theoretical point of view. As the theoretical approach is not practically implementable we then have a look at the calculation requirements for LUC emissions in the RES-D and show in detail how LUC emissions can be calculated based on the IPCC Guidelines.

3.1. Calculating LUC emissions exactly

For an exact analysis of the carbon loss or gain of an area due to its conversion for a bioenergy feedstock production, several parameters need to be quantified:

- the volume of the biomass above and below ground before the conversion
- the volume of the biomass above and below ground remaining after the conversion
- the respective carbon content in these biomass volumes
- the carbon content stored in the soil before the conversion
- the time path of the change in the soil carbon content after the conversion until a new equilibrium is reached.
- The effect of different management techniques and different types of crops on the soil carbon content, especially when perennial crops are used.
- The influence of local circumstances on all these parameters such as climate, temperature, rainfall, soil quality, etc.

On closer examination it becomes evident that these parameters vary substantially across regions or even from field to field. To quantify the volume of the biomass for example a detailed knowledge of the biomass volume in different age status and the respective change in this volume due to the biomass growth rates needs to be generated. These biomass volumes and growth rates will depend individually on the local circumstances such as rainfall, climate, soil quality etc.. The same is true for the soil carbon content. The amount of organic material in the soil will depend highly on the rotting rate of dead biomass and therefore on the former land use, temperature and rainfall. The loss or gain of carbon in the soil after the LUC will depend on all management techniques applied, crop rotation and also on the local climate circumstances. Summing up, on can state that *land use and management influence a variety of ecosystem processes that affect greenhouse gas fluxes such as photosynthesis, respiration, decomposition, nitrification/denitrification, enteric fermentation, and combustion* *involving involve transformations of carbon and nitrogen that are driven by the biological (activity of microorganisms, plants, and animals) and physical processes (combustion, leaching, and run-off***)** (IPCC 2006 1.2.1.). In other words, for an exact calculation of the carbon gain or loss due to LUC an analysis of the whole individual carbon dynamics of the respective area in a sophisticated biological model needs to be performed.

However, it is not feasible and not economical to invest such an effort for each LUC that occurs for an expansion of bioenergy production, as its cost would exceed all possible gains. In the following we present the approach of the European Commission to standardize the LUC calculation process.

3.2. Calculation requirement for LUC emissions in the RES-D

The Commission requires the LUC emissions to be calculated and summed up for a 20 year timeframe after the conversion, the actual land use in January 2008 serving as the benchmark (RES-D Art. 15). This is due to the fact that some emissions occur immediately in the conversion process and others during a long time period after the conversion. For the simplification of the calculation the LUC emissions shall be summed up and be allocated to each year in equal parts (RES-D Annex VII C(7)). This approach is in line with the method proposed in the IPCC Guidelines and the RES-D recognizes them as *an appropriate basis* for the LUC emission calculation though it is *currently not expressed in a form that is immediately usable by economic operators*. Both *standard values* and *actual values for the carbon stocks associated with the reference land use and the land use after the conversion* should be usable (RES-D (37a)). In both documents, the basic concept for the emissions calculation from LUC is to quantify the carbon content of a certain area before the conversion and 20 years after the conversion process. The difference of both values then defines the emissions caused by the LUC.

In the following section we will show the calculation method and data for LUC emissions in the IPCC Guidelines by first analyzing the database contained in the IPCC Guidelines and by second presenting the different calculation steps in the IPCC Guidelines for deriving the complete land use change carbon balance of biofuels. This deatiled decomposition is important because we draw first conclusions from the calculation method on the land use incentives set by such an regulatory framework.

We will concentrate our analysis on the so called “Tier 1” method in the IPCC Guidelines as this is the channel to use already existing default values in the IPCC Guidelines without an individual carbon cycle assessment. The RES-D provides the possibility to rely totally or partly on own calculations instead of using default values. On the basis of the IPCC Guidelines this is also possible for the emissions from LUC based on the Tier 2 or Tier 3 method.

3.3. The calculation method and data for LUC emissions in the IPCC Guidelines

The calculation procedure in the IPCC Guidelines must indeed be modified to a certain extend as it was originally developed for countries to calculate their yearly land use emissions or emission savings of greenhouse gases. Therefore, growth rates of different vegetation types and their carbon sequestration potential are originally included in the calculation. However, for the purpose of calculating emissions from LUC for bioenergy production, the carbon content of a certain area at the time of land conversion is needed and the age structure of different biomass types is not accounted for in the standard values. Therefore, growth rates were excluded from our calculations.

3.3.1. The database of the IPCC Guidelines

The IPCC Guidelines contain inventory lists for the carbon content of different biomass categories, soil types and soil management systems. Some of these categories are differentiated by climate zones and/or regions. Depending on the available research results at the time of writing of the IPCC Guidelines, some inventory lists are quite detailed and specific, others are relatively general. There is especially a need to update the data base and to include a further differentiation of natural grasslands based on new research results. This is also recognized in the RES-D demanding from the Commission to *establish criteria and geographic ranges* for high-biodiverse grasslands and to give within the guidance for the calculations for LUC emissions special attention to *forest with a canopy cover of between 10% to 30%, savannahs, scrublands and prairies* (RES-D (37a) and Art. 15(3c)).

The categorization inside the inventory tables of the IPCC Guidelines follows mainly the categorization of the studies that they are based on. This gives rise to different categorizations among the different vegetation types causing problems in the comparison of different land use types. A consistent categorization would be desirable and probably preferable to create consistent default values. Nevertheless, the IPCC Guidelines are the most extensive source available for this purpose.

3.3.2. The calculation procedure

The calculation of the carbon content of an area that is to be cleared for bioenergy crop production according to the IPCC Guidelines consists mainly of two parts:

- The carbon content in the **living and dead biomass** and
- the carbon content in the **soil** carbon (IPCC 2006 2.2.1. and 5.3.).

As the calculation process of the two parameters differ, we will go more into detail for both methods in the following. All parameters required in the calculation process can be taken from the inventory tables within the IPCC Guidelines.

Biomass and dead organic matter

For biomass and dead organic matter the IPCC approach implicitly assumes that the whole biomass and dead organic matter are destroyed when the land is converted to cropland. Therefore at the Tier 1 method, *carbon stocks in biomass immediately after conversion are assumed to be zero* (IPCC 2006 p.5.26). Consequently, the total carbon content in biomass and dead organic matter before LUC represent the first part of the emissions caused by LUC. Therefore, it is logical that the emissions from LUC increase with the density and the extent of the vegetation.

To derive the explicit carbon content in biomass and dead organic matter no calculation is required. The value can be taken directly from the inventory lists. To choose the right value the respective area needs to be classified going through the different components that characterize a land category. The subsumption of a specific area into a particular land category is crucial for the emissions from LUC allocated to this area, hence it should be done carefully.

The categorization of the components of land categories starts with the climate zone. The IPCC Guidelines contain a world climate map (IPCC 2006 Annex 3A.5) from which the climate zone in question can be derived.

The categorization of the different biomass types is much more sophisticated. Biomass types in the IPCC Guidelines that are important for this calculation are forest, grassland and cropland, where forest is divided into natural forest and forest plantation. Whether natural grassland is subsumed under the forest or the grassland category depends on the density of the vegetation and the canopy cover. Natural grasslands such as steppes, cerrados and savannahs are subcategories of the forest category. Information on typical natural biomass types in different world regions can be taken from a FAO world biomass map in the IPCC Guidelines (IPCC 2006 map 4.1), but the categorization in that map is not fully consistent with the inventory table categories and can hence only serve as a general orientation.

The forest category is the most differentiated in the whole data sample, but especially here the differentiation in subcategories is not consistent throughout the sample. Furthermore, mainly for forest category the IPCC Guidelines contain not one single value but define a range in which the true value might lie. In that case, we use the average value or, if available, the default value of the range. However, this data range indicates that there is a need to augment and specify the database by differentiating more between different vegetation types in different world regions.

The most controversial cases are certainly the distinction between forest and natural grassland for savannah like vegetation as the transition between the two vegetation types is gradual in reality. We will illustrate the need to improve the data base in the exemplary LUC calculation in section 4.

Soil

As the carbon in the soil can not be removed as it is done with the biomass since it is subject to other carbon dynamics, the calculation of the change in the soil carbon content is done in a different way (IPCC 2006 Eq. 2.25). The procedure presented here as well as all our exemplary calculations in section 4 refer to mineral soils as organic soils are dominant only in wetland and peatland hence excluded by the RES-D as suitable for bioenergy crop production.

The IPCC Guidelines contain, based on FAO soil classifications, default values of the original or natural carbon content of different worldwide soil categories. This natural soil carbon content can decrease or increase by different land uses, management techniques or nutrition input. To what extend these factors have an impact on the soil carbon content differs across the different climate zones. A reduction in tillage and the use of degraded land increases the natural carbon content of the soil, the plantation of perennial crops stabilizes it. The plantation of annual crops with full tillage lower the carbon content of the soil assuming that former land use has not been characterized by annual crop production with full tillage as well. By accounting for these factors, the soil carbon content is calculated once for the former land use and once for the bioenergy crop production. The difference of the two values provides the soil emissions from LUC.

From the calculation setting for the change in the soil carbon content the following direct consequences can be derived:

- The use of degraded land is favorable for the LUC emission balance of the biofuel.
- There is an incentive to reduce the level of tillage in agricultural production.
- For annual crops for which the tillage level can not be reduced due to the cultivation process, the carbon balance would be improved if land that has been under a similar agricultural use before is used for the biofuel crop production. This reduces the difference in the soil carbon contents before and after the LUC.
- Different crops will cause different LUC emissions as they might use different management systems or are annual or perennial crops. Especially when the biomass carbon is relatively small, the used crop and management techniques become quite important for the carbon balance.

It needs to be pointed out that based on this soil carbon calculation method we also define a “conversion” from cropland to cropland as a LUC in our calculations in section 4. This is due to the differing impacts of different crop systems on the soil carbon balance. LUC emissions might be zero then but can be negative as well and hence the inclusion of former cropland into the LUC definition could create incentives to use less soil carbon emitting management techniques or perennial instead of annual crops. It is not defined explicitly in the RES-D which changes in the use of an area are included in the definition of LUC. Though it is recommendable to fill this lack in future regulations as to avoid misunderstanding and to account for LUC of former cropland. The German legislation for example explicitly excluded cropland to cropland from the LUC definition so far.

The total LUC carbon balance

After having quantified the LUC emission values of biomass, dead organic matter and the soil the total LUC carbon balance of the produced biofuel can be computed. To complete the calculation, the emission values of biomass, dead organic matter and soil emission are summed up and allocated over

20 years in equal parts. By multiplying these emissions per hectare with the energy productivity per hectare of the bioenergy crop, the LUC emissions per mega joule biofuel are computed (RES-D Annex VII C(7)).

Consequently, a biofuel crop with a higher energy productivity will have less LUC emissions per mega joule than a less productive biofuel option from the same field. Consequently, albeit the fact that they are planted on the same field, it might be perfectly possible that a more productive biofuel option combined with favorable management techniques lies within the required 35% emission savings but a less productive one might not. Therefore it is not enough to combine different biofuel options with a general default value for different LUCs but rather differentiate these default values by different crops.

Summing up the calculation method based on the IPCC Guidelines gives rise to the following outcomes:

- the carbon content of an area rises with the density of the vegetation
- different crops and management systems give rise to different LUC emissions
- Factors that decrease the carbon content are: intensive use of tillage and the plantation of annual crops
- Factors that increase or stabilize the carbon content are: the use of perrenial crops and a reduction of tillage
- the conversion of degraded land to cropland increases the soil carbon content
- the higher the energy productivity of a biofuel feedstock the lower are the LUC emissions allocated to each biofuel unit.

To further analyse the likely consequences of an accounting of LUC in the sustainability regulations for biofuels, in the next section we present - based on the calculation method and database analysed in this section - a range of examples representing the main crops and the most important growing regions for biofuel feedstocks.

4. Including LUC emissions into the carbon balance of biofuels

To avoid the promotion of environmentally harmful biofuels, the European Commission included the LUC regulation into the current directive. Yet a concrete assessment of the role of LUC emissions is still lacking even though the Commission was obliged to present such an assessment by the end of 2009 (RES-D Annex VII C(8)). We will demonstrate in this section the likely results and consequences of the inclusion of LUC into the carbon accounting framework. We use the current rules set by the European Commission to show how the carbon balance of different biofuel options change if LUC emissions are computed according to the scientific results as they are set out in the IPCC

Guidelines. The main questions to be answered by such an assessment are: Which land categories in which world regions are feasible for a biofuel production to meet the sustainability criteria and does the accounting for LUC emissions become a knock-out criterion for the sustainability of some bioenergy crops?

4.1. GHG calculations for the main biofuel crops

In order to illustrate how GHG balancing can be computed we present a range of examples representing the main crops and the most important growing regions for biofuel feedstocks. The method can be applied to all types of LUC in the same way as it is done for the examples presented here. Annex I contains the precise definition and categorization of the examples and Annex II the respective equations. First we calculate the pure land-use change emission for different previous land uses and biofuel crops. In a second part we combine the LUC emissions with the total production emission assessment of the RES-D and analyze the results with respect to the minimum emission saving target of 35% compared to fossil fuels.

Land use change emissions

The two graphs show the emissions caused by LUC for the plantation of bioethanol (figure 1) and biodiesel feedstocks (figure 2) in different geographical zones. We included an allocation factor for the main co-products according to their heating value based on EU-JRC Data (IES 2008) and divided them in twenty equal parts to account for the time path of LUC emissions. Positive values always indicate a net carbon loss from land use change, negative values stand for an additional carbon sequestration in the soil. The amount of 83,8 gCO2/MJ emissions from fossil fuels can serve as a general orientation here.

As expected, the emissions caused by clearing forest for crop production are very high. In tropical rainforests in Brazil and Malaysia/Indonesia, emissions are extremely high because of the amount of biomass that is destroyed. The same is true for savannahs with mainly woody vegetation. In the latter category, though, the importance of the soil carbon stock, management techniques and energy productivity of the crop can already be seen. The latter aspects become more important for those land use types that contain little or no aboveground biomass such as grassland and cropland.

The conversion of normal grassland with the subsequent plantation of sugarcane causes a small amount of carbon sequestration due to the perennial growth of sugarcane and a high energy productivity per hectare. In contrast, the conversion of the same grassland for the plantation of soy for biodiesel production causes already prohibitively high emissions of 87 gCO^2/MJ (in comparison to 83gCO^2/MJ for fossil fuels). This is the case because of lower energy productivity per hectare from soy and the annual replantation of the crop which results in a lower carbon content in the soil.

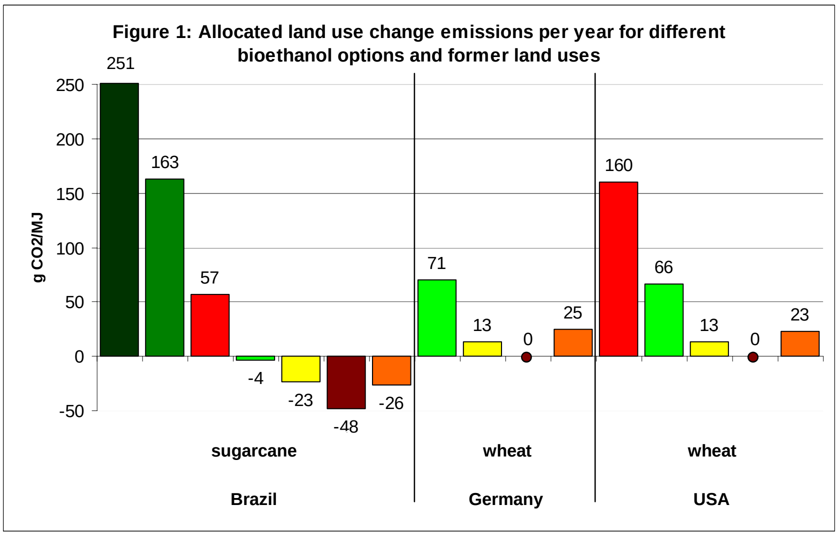
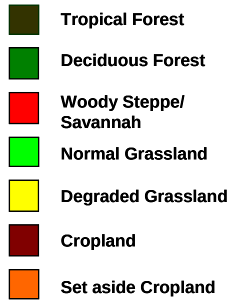


Figure 1: Allocated land use change emissions per year for different bioethanol options and former land uses



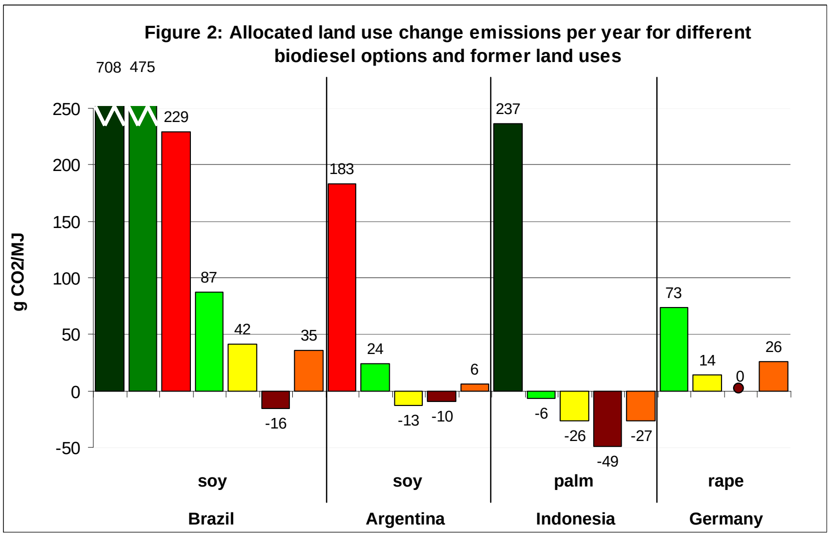


Figure 2: Allocated land use change emissions per year for different biodiesel options and former land uses

The use of existing cropland leads to zero land use emissions or even to a sequestration of carbon in the soil. The latter is possible with a change from an annual to a perennial crop, like sugarcane and palm oil, or with a change from full tillage to no tillage, as assumed here for soy production.

It is important to notice the large difference between normal grassland and degraded grassland. Except for the conversion of grassland for sugarcane or palm oil plantation, the conversion of normal grassland, including grassy savannahs, leads to high emissions whereas the emission from the conversion of degraded grassland are much smaller or even negative. This becomes even more important when the degraded land bonus from the EU RES-D is included, which has not been done here but is included when deriving the final GHG balance. The differences found for these two at first sight closely related categories show clearly that a more precise and differentiated definition of different grassland categories and their geographically explicit identification on a global scale is pressing.

The full carbon balance

We now combine the LUC emissions with the calculation of the total process emissions caused by the production of the biofuel based on the calculation procedure in the RES-D. In order to do so we sum up LUC emissions with the typical total production pathway emission values in the RES-D. We include again an allocation factors for co-products and subtract a bonus of 29 gCO2/MJ for the use of degraded grassland (RES-D Annex VII C (1) and (7)).

The resulting emission values need to be evaluated with respect to the minimal emission saving target of 35% in comparison with fossil fuels. By doing this, the main result of this assessment illustrated in figure 3 for bioethanol and 4 for biodiesel can be seen immediately:

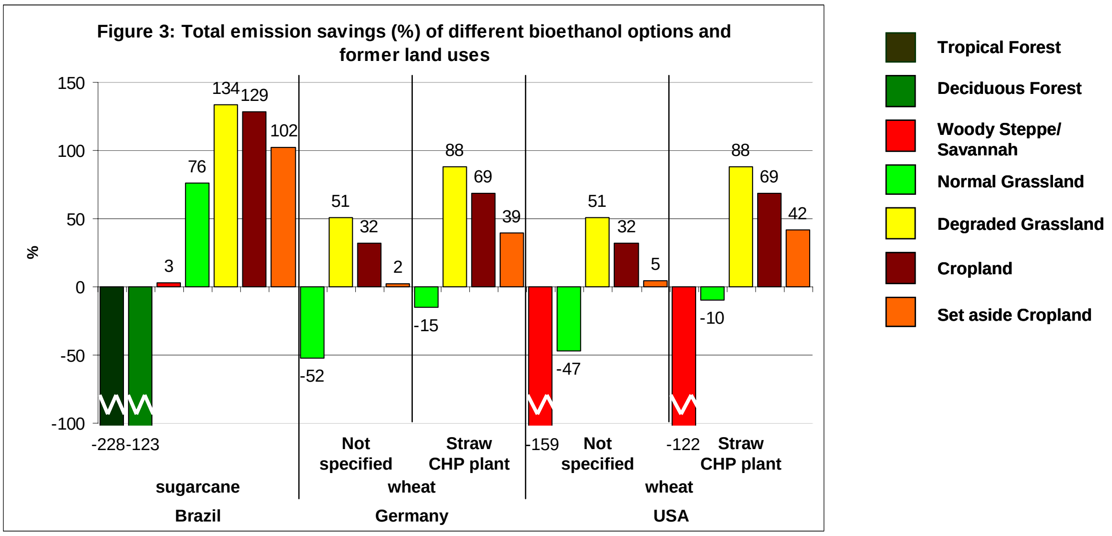


Figure 3: Total emission savings (%) of different bioethanol options and former land uses

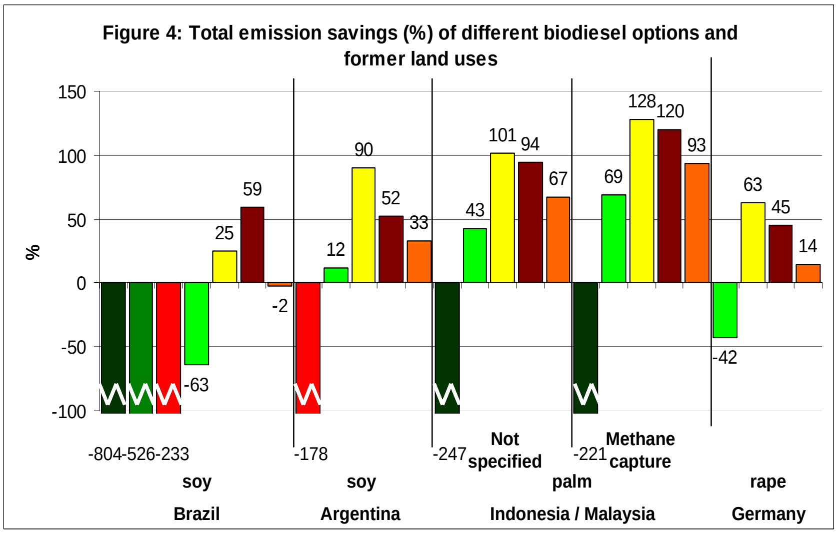


Figure 4: Total emission savings (%) of different biodiesel options and former land uses

- The conversion of natural land for the bioenergy production never meets the 35% target and in most cases even leads to much higher emissions than the use of fossil fuels. The only exception are 76% emission savings when Brazilian grassland is converted for the sugarcane bioethanol production.
- Except for the soy biodiesel production in Brazil, the conversion of degraded grassland for the bioenergy crop production leads to high emission savings meeting the 35% reduction target.[2]

[2] All calculations for degraded land were done assuming the same productivity as for non degraded land. In practice this is not neccessarily the case. The energy productivity per hectare might be much lower on degraded

- Cropland is always a suitable option except for the use of old inefficient plants for the wheat bioethanol production as process emissions are to high to meet the 35% reduction target.
- Set aside cropland[3] is a suitable option for the bioethanol production made from Brazilian sugarcane and German and American wheat in efficient plants. The same is only true for the biodiesel production in the case of palmoil[4].

4.2. Consequences for the regulation framework and land use dynamics

The examples presented in the previous section highlight a number of conclusions that can be drawn from the current regulatory framework. They also suggest some adjustment in the regulation in order to make the carbon accounting more target oriented and to improve the incentives for a climate friendly production of biofuels. We draw the following conclusions:

- The presented accounting method for LUC emissions create incentives to use areas with little or no vegetation cover such as cropland and grassland as well as to use crops with a high energy productivity per hectare and to improve management techniques.
- The variation in the carbon balances underline the need to assess LUC emissions individually for each field and farm. Overall default values for example for a region or a country will not be suitable to cope with the highly differing LUC emissions from different land uses and crop types not even considering the already mentioned incentive problems. Brazil is the best example that a single biofuel option from one country can have very different carbon balances because of the previous land use of the crop area.
- To keep monitoring cost within a reasonable scope it is advisable to augment the default value list in the RES-D by LUC emission default values, differentiating them at least by world region, vegetation type, crop and management system. Neglecting e.g. previous land use could lead to a high over- or underestimation of the emissions of a particular biofuel. This aspect is also important for the practical applicability of a certification scheme. Biofuel producers are probably more interested in using differentiated default values as the derivation of farm specific values for LUC emissions might be very costly. Thus the default values should be as differentiated as possible so as to not exclude sustainable biofuel options and to avoid undesirable LUCs.
- The selection of high conservation value areas as no-go areas for the bioenergy crop production is not necessary in most cases since practically all potential high conservation value areas do not meet

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land because of less fertile soils. Hence the actual emission savings of biofueloptions produced on former degraded land could be much lower in reality. For further discussion see section 4.3.

[3] Set aside land is defined by the IPCC Guidelines as temporary set aside of annually cropland or other idle cropland that has been revegetated with perennial grasses (IPCC Guidelines p. 5.17)

[4] The differentiation between „not specified“ and „methane capture“ for the palm oil production in Figure 4 aswell as the differentiation between „not specified“ and „straw CHP plant“ in Figure 3 results from different values used for the production process emissions. This differentiation is equivalent to the default value categories for production process emissions in the RES-D.

the emission saving target. This could ease the work of certifiers when natural land in general is excluded from the areas suitable for the production of bioenergy crops. An exception in this context is the positive emission saving of 76% for sugarcane production on former grassland in Brazil, as the definition of grassland includes managed pasture as well as grassy savannahs such as grassy *cerrado*, which is known to contain rich biodiversity. There are vital commercial interests in Brazil to convert the *cerrado*, which is to a large extent already used for extensive cattle grazing, as this vegetation type is dominant in Central Brazil, the main agricultural expansion area. Thus, especially for grasslands first the precise definition and then additionally the identification of global bio-diverse hotspots is absolutely necessary.

- The results underline the hypothesis that crop production for bioenergy is likely to take place on already arable land. In many world regions the main potential expansion area for the crop production is grassland. The current uncertain classification for different vegetation densities on grassland create a potential risk of not being certified when converting grassland to cropland. This might result in a tendency not to use the expansion areas for the biofuel crop production. Hence, the current certification requirements would increase the competition between food and biofuel production. In other words, the RES-D will avoid direct LUC for bioenergy production at the cost of promoting indirect LUC. In section 6 we will further discuss the subject of indirect LUC.

One could argue that the results based on the IPCC data are questionable due to some data augmentation necessities and the employment of a standardized calculation method that does not account for every individual characteristics of an area. We have already identified the need to augment existing data sets and to define different land use types more precisely, especially those of grassland and degraded land. However, the results, especially for areas with a dense vegetation cover are clear and it is unlikely that more precise assessments will change the overall results. Quite to the contrary, by including values for biomass growth rates, dead organic matter and erosion, aspects that are not included in the present calculation, emissions from LUC would rise.

4.3. The special case of degraded land

The large differences in the GHG-balances between the two categories normal grassland and degraded grassland presented above indicate that there is a need to differentiate the two categories into more subcategories to account for gradual differences between the two land use types. Apart from growing biofuel feedstocks on normal and set aside croplands, degraded grassland is the only option for Argentinean soy, German wheat and rape and US wheat if they were to achieve the minimum reduction target of the RES-D. Therefore, there is a need to define these degraded grassland areas more precisely and then identify these areas on a global scale.

Studies that try to compute the global potential for bioenergy production often refer to the degraded land areas that could be brought back into productive use. Such assessments indeed provide a figure –

albeit currently still with a high margin of uncertainty – for the overall bioenergy potential. Estimates by Houghton (1993) (cited in Field et al. 2007) are based on areas of tropical land formerly forested but not currently used for agriculture, settlements or other purposes. They estimate a global area of 500 Mha of degraded land. Field et al. (2007) estimate abandoned agricultural land to be 385-472 Mha based on an analysis of historical land use data.

The favorable carbon balance of degraded land and the avoidance of competition with the food production when degraded land is recultivated for biofuel production offer a good opportunity for producing bioenergy without significant side effects. The question then is as to whether the European biofuel policy sets effective incentives to use such degraded areas. In this section we will first cover in detail the definitions for this particular land use type as given by the IPCC Guidelines and the RES-D. We then ask whether the regulatory framework of the RES-D indeed fosters the expansion of bioenergy mainly into degraded land.

The IPCC Guidelines provide three levels of grassland: *Normal grassland, moderately degraded grassland* and *severely degraded grassland*. Moderately degraded grassland represents *overgrazed or moderately degraded grassland, with somewhat reduced productivity* (relative to the native or nominally managed grassland) and *receiving no management inputs*. Severely degraded grassland implies *major long-term loss of productivity and vegetation cover,* due to *severe mechanical damage to the vegetation and/or severe soil erosion* (IPCC 2006 Table 6.2). As the IPCC Guidelines do not contain the category of "degraded cropland" and set aside cropland is not necessarily degraded but set aside because of other economic or regulatory reasons, it seems practical to include degraded cropland into the degraded grassland category of the IPCC Guidelines tables as degraded cropland might be set aside and have some grass vegetation.

The RES-D provides a relatively precise definition of degraded lands (see page 6) as it offers the emission bonus for the use of degraded land for bioenergy production. It is important to notice that this definition does not distinguish between grassland and cropland and seems more restrictive than the IPCC Guidelines definition as degraded land needs to be *severely degraded* or *heavily contaminated*. For the practical implementation it would be necessary to verify whether the data and studies used in the IPCC Guidelines actually match the requirements for degraded land as set out in the RES-D and can thus be applied for calculating LUC for degraded land according to the RES-D.

The production of biofuel feedstocks on degraded land constitutes an important aspect of the RES-D. It is the only option where the competition between food and fuel is less pronounced. The extent to which degraded land will actually be used for such activities depends on the incentives given to farmers in their decision about allocating their land to either food or biofuel feedstock production. This decision is primarily determined by the market prices of the different crops which the farmer can plant. The conflict between food and energy crops remains as long as the price signals do not favor decisions to bring degraded land into production. In other words, the political incentives need to be set in such a way that the bioenergy crop production on degraded land is more profitable than on cropland.

Important determinants that influence the profitability of bringing degraded land into use are the following:

In terms of production:

- investment cost for the restoration of the degraded land for agricultural production
- most likely lower yields per hectare than on non degraded cropland

In terms of incentives:

- The calculation procedure for LUC from degraded land according to the the IPCC and the emission bonus for degraded land that is granted by the RES-D lead to computed (but not actual) emission savings for the final biofuel that are in most cases higher than those on cropland.[5] With this policy Member States can achieve their emission reduction targets with a smaller amount of emission savings from biofuels than the true carbon balance. Therefore these biofuels from degraded land should gain a premium at the market according to their emission savings.

In most countries biofuel production takes place only with supportive measures such as subsidies, blending requirements or tax incentives. The question as to whether incentives for using degraded land for production feedstocks for biofuels depend on the profitability of such an activity.

Currently the bonus of 29gCO2/MJ acts as an indirect subsidy for production on degraded land. We made an exploratory calculation of the incentives of this bonus system. For these calculations we assume that the CO2-prices of the ETS represent the premium for emission savings.

First we assume for degraded land a productivity of 80%[6] of the original productivity on normal cropland. Figure 5 then shows the subsidies per hectare degraded land for different biofuel crops under different carbon prices. If there were a complete connection of the petroleum industry to the ETS market the current subsidy would be about 13€ /tCO2. As this connection currently does not exist it is likely that the premium paid for higher emission savings is above the current carbon price. Since the

[5] In our exemplary calculations in some cases the emissions of the conversion of degraded land exceeds those of the conversion of cropland. This is because degraded land in the IPCC Guidelines is defined as degraded grassland with a grassy vegetation cover. This biomass is destroit when the degraded land is converted into cropland and the stored carbon in the biomass is released to the atmosphere. Regarding the soil carbon content the conversion of degraded land to cropland leads to an accumulation of carbon in the soil whereas the conversion of cropland to cropland leads to none or very little accumulation of soil carbon. Depending on the amount of emissions caused by the destruction of the grassy biomass on degraded land in relation to the accumulation of carbon in the soil, the emission savings of the conversion of degraded land are higher or lower than those of cropland.

[6] To test for the actual amount of the subsidy per hectar one should derive realistic productivity levels of degraded areas in practice.

bonus is granted per mega joule fuel the more productive biofuel crops such as sugarcane and palmoil receive a higher subsidy per hectare. The subsidies vary strongly for the different crops grown.

For Figure 6 we assume a constant carbon price of 20€/tCO2 and compute the subsidies per hectare degraded land for different biofuel crops under different productivity levels. The degraded land bonus implies that a strongly degraded land – i.e. land with a low productivity compared to the productivity on normal cropland – gets a lower subsidy per hectare than a less degraded land. This does not seem to be a suitable framework to foster the use of degraded land. On the contrary, the higher the level of degradation the higher are investment cost for restoring the area and the lower is the expected productivity.

Figure 5: Subsidies per hectare degraded land for different biofuel crops under different carbon prices

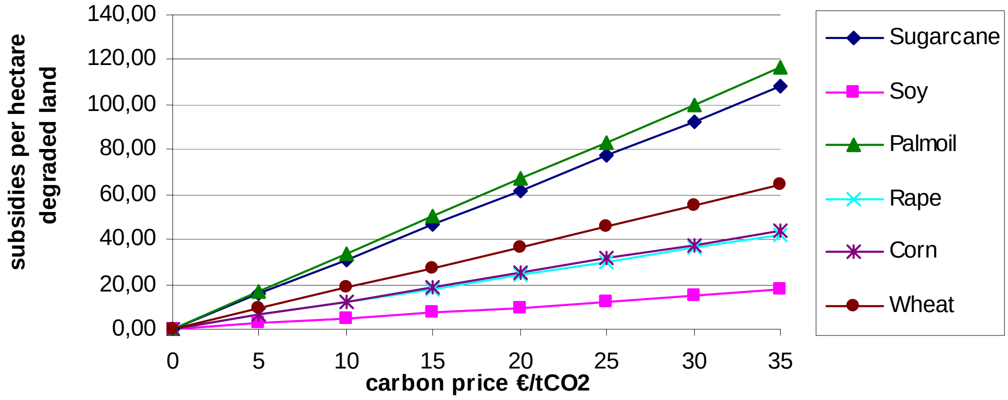
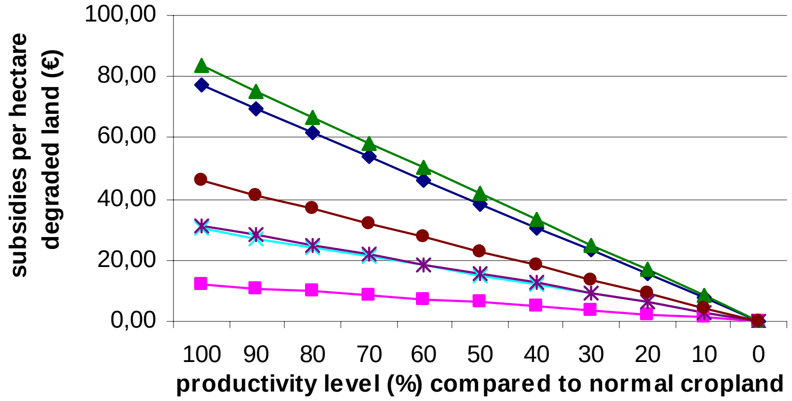


Figure 6: Subsidies per hectare degraded land for different productivity levels under a constant carbon price of 20€/tCO2



Thus, under the current regulatory structure it is more likely that the subsidy creates incentives for using areas with little degradation and high productive crops especially sugarcane and palm. Otherwise the bonus will not be high enough to exceed the loss from investment costs and lower productivity. But it is questionable whether a degree of degradation of say 10% fits into the definition of “highly salinated” and “highly contaminated” of the RES-D. Consequently, the RES-D definition is likely to create only limited incentives for using such land since the bonus becomes very small for higher levels of degradation. A better alternative for the calculation of the granted bonus would be to increase subsidies with the level of degradation of an area and to gain it directly per hectare.

5. Accounting for indirect LUC (ILUC) – A convincing approach?

As shown in the analysis of direct LUC emissions, the RES-D sets incentive to use land with little or no vegetation cover for the bioenergy feedstock production. Hence, there will be a tendency to use land that is or has been in agricultural use instead of natural land. Consequently, the bioenergy feedstock will compete directly with the food production for the already available cropland. For the case that the bioenergy feedstock production replaces food production on an area, and the food production will somewhere else in the world lead to a conversion of so far unused land – e.g. forests – to crop land, this LUC could be declared to be the ILUC effect of the bioenergy feedstock production. This ILUC also causes emissions from LUC. Consequently, the ILUC emissions caused directly by the food production would be defined as an externality of the bioenergy production.

The impact of including direct LUC into the carbon balance of biofuels has been demonstrated above. Though one could argue about the calculation methods or the default values, the conceptual framework and causalities are clear. Some claim that just as emissions from direct LUC are added to the carbon balance of biofuels, the emissions from indirect LUC should be added as well. If one assumes that ILUC is the main LUC effect of an expanding bioenergy feedstock production – and our results support such a hypothesis - the carbon balance of biofuels would be mainly driven by emissions from ILUC. Hence it would be important to include ILUC emissions to derive a realistic carbon balance of a biofuel production. In practice, however, the accounting for indirect LUC emissions faces several difficulties concerning their quantification and causality that we believe are impossible to solve. This is especially due to the following mutually interacting effects driving ILUC:

First of all there will be a price effect: The global externality of ILUC results from international markets for agricultural products. The mechanism driving this is the reaction of world market prices to an increased scarcity in the supply of food products. This food supply scarcity is the result of a replacement of a food production by a bioenergy feedstock production from LUC as decribed above. Higher prices for food products on the world agriculture markets set incentives to bring into use land for food production that has previously not been in use. As higher prices for food products are reflected on the world market, this LUC can take place anywhere in the world were it is profitable. Hence the location of the ILUC effect is globally independent from the location of the bioenergy feedstock production.

However, it is not at all clear whether indeed a substitution of food production will take place. There might be some effect of interregional reallocation: Depending on the demand elasticity of the respective food product, higher prices may cause the demand for food to fall in the region in which the expansion takes place. It may also be met by deliveries from other regions or countries. This can be due to a comparative advantage in bioenergy versus food production of a country relative to other countries as it may be the case with sugar cane, a crop best suited for bioenergy use. Therefore, the assumption that the replacement of one hectare food production by a biofuel crop leads exactly to one hectare new cropland for the food production elsewhere has no scientific basis.

Furthermore, given a sustained high demand, displaced products will be reallocated between the producing countries which are subject to different land use regulations. Different accounting methods for LUC in different world regions will set different incentives for the conversion of unused land to cropland. Besides the effects of global commodity markets, local effects such as biophysical characteristics, local infrastructure and access to the market as well as time dependent influences such as crop rotation requirements also play an important role (Gnansounou et al. 2008).

Consequently, if one wanted to actually account for the external effects of biofuel promotion with respect to ILUC this large number of simultaneous market reactions needs to be taken into account. To include ILUC into the carbon balance of a particular biofuel produced in a particular place the emissions related to ILUC world wide would need to be quantified. Suppose this were possible through a detailed large scale model of agricultural markets and land use decisions, then - once the global ILUC effect is quantified - it would need to be allocated to the particular producer for whom the carbon balance including ILUC is to be computed.

In Europe the regulation concerning ILUC is still under discussion. The RES-D requires that:

The Commission shall, by 31 December 2010, submit a report to the European Parliament and to the Council reviewing the impact of indirect LUC on greenhouse gas emissions and addressing ways to minimize that impact. The report shall, if appropriate, be accompanied, by a proposal, based on the best available scientific evidence, containing a concrete methodology for emissions from carbon stock changes caused by indirect LUCs, ensuring compliance with this Directive, in particular Article 17(2). Such a proposal shall include the necessary safeguards to provide certainty for investment undertaken before that methodology is applied… The European Parliament and the Council shall endeavor to decide, by 31 December 2012, on any such proposal submitted by the Commission (Renewable Energy Directive, Article 19(6)).

In the following we present some examples of approaches to quantify the global ILUC effect that are currently promoted. Afterwards we discuss proposals to convert the global ILUC effect into a single factor that can be included into the carbon balance of each biofuel. In the last section we present an outlook how a global carbon assessment of the whole agriculture sector could eliminate the ILUC problem.

5.1. Quantifying the ILUC effect

A number of recent publications in prestigious journals have raised the issue of ILUC (Searchinger et al. (2008), Melillo et al. (2009), Valin et al. (2009) e.g.). Due to the fact that the recent biofuel expansion continues to be a very small driver relative to global LUC, the biofuel impact is likely to be swamped by other causes (Liska & Perrin 2009). Therefore it is widely agreed that an empirical verification is not possible based on current data and empirical methods. Hence the available literature uses partial and/or general equilibrium model frameworks to quantify the LUC effect of different biofuel expansions via scenario modeling. The respective emissions of the calculated ILUC are computed by using average carbon stocks, the IPCC Guidelines or coupled terrestrial biogeochemistry models (see Melillo et al. 2009 for example).

As a detailed analysis of all available approaches to quantify the global ILUC effect of an expanding biofuel crop production would be beyond the scope of this paper we present some explanatory examples for different modeling approaches in the following.[7]

A controversially discussed and thus well-known publication concerning ILUC effects of bioenergy activities is the paper by Searchinger et al. (2008). Based on a partial equilibrium land use model, the authors quantify that an increase of US corn-based ethanol production of 56 billion liters, requiring 12.8 million ha of U.S. cropland for extra corn cultivation, would cause indirect LUC of 10.8 million ha mainly in Brazil, China, India and the US. According to them this would double greenhouse gas emissions over 30 years and increase greenhouse gases for 167 years before starting to mitigate GHG emissions by using corn ethanol as a transport fuel.

The main critique concerning the Searchinger approach refers to the strong assumptions made in the modeling framework that only poorly address the complex dynamics required to reflect the global land use system in a realistic way (Liska & Perrin 2009). For one thing he assumes that the US ethanol target is only achieved by exclusively planting corn on already existing cropland in the US; hence with every unit corn planted for the biofuel target a crop displacement would occur by definition. This seems to be a very strong assumption as other crops which are available for achieving the target such as imports from other countries like Brazil or the direct conversion of other land to cropland inside the US are therefore not included. Other criticism focuses on the partial equilibrium model that represents global land use dynamics in a generalized way without accounting for regional land use characteristics and regulations (Methews & Tan 2009). Other similar modeling approaches use combinations of different partial equilibrium models as done for the Renewable Fuel Standard (RFS) of the U.S. EPA basically applying the FASOM model for the US forest and agriculture market and the FABRI for markets outside of the US including other models and data to calculate the land use change emissions (Fehrenbach et al. 2009).

[7] see Fehrenbach et al. (2009) as a starting point for a detailed analysis of different approaches

A similar, more recent approach by Melillo et al. (2009) calculates, by linking economic and terrestrial biogeochemistry models, the direct and indirect effects of possible LUCs from an expanded global cellulosic bioenergy program on greenhouse gas emissions over the 21st century (Melillo et al. 2009). They predict that indirect LUC from cellulosic bioenergy will be responsible for up to twice as much carbon loss than direct LUC. The displacement dynamics of wood products imply that modeling cellulosic bioenergy from wood (a second-generation biofuel), indirect LUC will always result in forest clearing for other wood products causing high emissions. Potentially other land types such as degraded land or grassland causing much less emissions when converted for crop production that would be a perfectly suitable option for all bioenergy field crops, does not play a role in this modeling framework. Therefore, Melillo et al.'s (2009) results lack relevance for today's bioenergy sector that mainly consists of field crops.

An overview about the modeling approaches of incorporating LUC into a CGE framework can be found in Kretschmer and Peterson (2009). A recent example of such a CGE model that also tries to incorporate the environmental aspects of LUC is the paper by Valin et al. (2009). They apply the trade policy model MIRAGE based on the GTAP 7 database including LUC at the level of Agro-Ecological Zones (AEZ). Land substitution among managed land types is governed by nested constant elasticity of transformation functions and a land supply module for the total amount of managed land available is based on historic managed land expansion rates. The incorporation of different land characteristics in the form of different AEZs allows to some extent to account for substitution constraints between different crops because of differing local conditions. Furthermore, the AEZs are used as a database to calculate LUC emissions from different land types relying on the IPCC Guidelines' method and data. Land dynamics are partly endogenous as the distribution of all managed land, including cropland, managed forest and grassland, across the different land uses is determined by market forces. Hence, expansion of bioenergy production and a corresponding need to expand cropland can cause indirect LUC emissions by converting from one type of managed land to another. The conversion of unmanaged land to managed land, on the other hand, i.e. LUC that affects natural forest and grassland is exogenously given and follows historically observed conversion patterns and thus cannot be influenced by an expanding bioenergy activity.

Valin et al. (2009) calculate a scenario for a US domestic mandate of 30 billion gallons of ethanol and a 10% biofuel mandate in Europe accounting only for effects from the ethanol production. By accounting for all emission savings due to the use of fuel from renewable sources on the one hand and by considering emissions from indirect deforestation and cultivation of new land on the other hand, they find that it takes 12 years from 2020 onward to actually start saving emissions with the production of ethanol. That is to say a "payback time" for the ethanol production of 12 years due to emissions from indirect land use change. Other similar model approaches can be found for example for the Californian Low Carbon Fuel Standard (LCFS) also based on the GTAP model.

Though several modeling approaches abound, current economic modeling of ILUC in the context of biofuels still entails assumptions at every stage which are not well established at the moment. These concern the effect of biofuel demand on world agricultural commodity prices, the response of crop yields and consumption patterns to these price increases, and the response of land conversion to the price increases in specific ecological regions of the world (Liska & Perrin 2009). Even though a much more complex representation of LUC has been developed in the last years, the modeling of global land use dynamics and the change in these dynamics due to an expanding biofuel production as well as the related carbon cycle in a realistic way are still in its infancy. However, even if we were able to create such a "perfect" model one day this model would still only represent the ILUC effects of bioenergy as a global effect. It would not provide information about the causality between a particular biofuel activity and global ILUC.

5.2. Downscaling the global ILUC effect – a causal linkage?

After calculating the global effect of an expanding biofuel feedstock production, this global effect needs to be downscaled to an individual bioenergy production pathway. This is necessary to account for it in the biofuel carbon balance. In the following we discuss current proposals to downscale the global ILUC effect. We argue that it is impossible to create a fair ILUC factor for each biofuel production that maintains the incentives for farmers to achieve large carbon saving.

The only practical downscaling option that is proposed so far consists of the (sometimes weighted by productivity) allocation of an average carbon loss to all bioenergy activities. Searchinger et al. (2008) and Melillo et al. (2009) simply allocate the emission caused by ILUC to the assumed total bioenergy production and hence create an equal amount of ILUC emissions per MJ biofuel produced adding these ILUC emissions to the carbon balance of each biofuel unit.

Another way of calculating and allocating indirect LUC emissions is suggested by Fritsche (2009). The idea behind the construction of the ILUC factor is that all countries that export agricultural products on the world market are influenced by global land use dynamics. For the construction of the ILUC factor he calculates - based on IPCC data and method - the mean of potential LUC emissions from the land fraction in each region used for agricultural exports for the case a LUC would occur. The resulting value represents the LUC emission potential. Dividing this by 20 years and accounting for the use of set aside land and productivity improvements Fritsche (2009) derives a value of average ILUC emissions per hectare for the whole bioenergy sector (Fehrenbach 2009). This results in different ILUC values for different crops when the ILUC factor is converted from ILUC emissions per hectare to ILUC emissions per mega joule with the energy productivity of each respective crop. As this has a similar effect as the degraded land factor, i.e. more productive crops as sugarcane and palm will produce less ILUC emissions per MJ biofuel, Fritsche (2009) aims to include an additional risk factor for biofuel feedstocks that are produced in regions with high conversion rates of land with high carbon stocks. This is based on the assumption that in South East Asia and Brazil - the main growing area for these highly productive crops - ILUC effects are higher than in Europe because land conversion rates are higher and the converted land – especially tropical rainforests and savannahs - releases more carbon in the conversion process. He concludes that these high conversion rates are a direct ILUC effect of the local expansion of biofuel crops and thus their ILUC factor should be higher than those for biofuel crops in Europe for example.

Evaluating these approaches one has to ask if they live up to the promises of the sustainability regulations which aim at promoting those biofuel options with the highest emission savings and to avoid undesirable LUC. To begin with, the proposed approaches are in contrast to the complexity of global land use dynamics and the calculation methods seem rather arbitrary. They also may conflict with basic legal principles of liability. However, the main critique concerns tha fact that all allocation approaches do not provide incentives for farmers to implement carbon saving technologies such as lowering the tillage level or yield improvements. A carbon load that is artificially added to all bioenergy activities will simply result in a shift of the net carbon balance for a whole region or even the whole world but not in a change of the competitive advantage of a producer that can produce with a better net carbon balance.

If such a “correction” is made on a country wide basis it runs the risk of being seen as a trade barrier instead of an incentive instrument for promoting those biofuel activities with the highest GHG savings. Especially if high values such as the Searchinger (2008) result of 104 gCO2/MJ are added as an ILUC factor to the carbon balance of corn ethanol. Compared to 83,8 gCO2/MJ for fossil fuels, the ILUC factor alone without any production emissions is already prohibitively high. The result of such a factor would be the total abandonment of the biofuel feedstock production in some regions.

The only approach to create a fair ILUC factor in the sense that it does not destroy individual carbon saving incentives is to identify the ILUC effect of every individual bioenergy activity. But the global ILUC effect of bioenergy activities cannot be translated to a single farm or even a region. As described above, the adjustment processes and the replacement of areas devoted to food production as well as the expansion of cultivated land areas is governed by complex global processes. Global demand and supply conditions as well as the regional support policies in the agricultural sector simultaneously determine land use decisions. As a consequence, the ILUC of bioenergy production does not take place within the local community nor on a national level but is spread throughout the globe. Therefore, a local carbon balance including ILUC can not be computed. Establishing a causal relationship between one particular bioenergy activity and its ILUC effect is impossible.

Nevertheless, on a global scale it is very likely that a further expansion of bioenergy production will either indirectly or directly lead to LUC. This is simply necessary in order to meet the increased demand for biomass. It could be argued that the additional biomass for bioenergy uses is grown on degraded land. But as analyzed in section 4.3., under the current setting, if production incentives are more in favor of bioenergy relative to food production, the expansion of these activities is more likely to take place on fertile land and not on marginal land. In this case there is a good chance - and all modeling approaches so far support this - that globally a negative GHG balance will be the result of an expansion of bioenergy production.

An intermediate step to avoid such negative effect of ILUC on the global GHG balance is to create incentives for bioenergy production to expand predominantly into degraded land or land that is not used for crop production and has a small carbon stock such as set aside land. The degraded land bonus granted by the European Commission should be transformed to serve as such an incentive by being sufficiently high and increasing with the level of degradation. Another tool to reduce the ILUC risk is to encourage yield improvements without using carbon-intensive fertilizer essentially as the bioenergy targets could then be met by using less agricultural area. As was already seen in the calculation for direct LUC, the energy productivity per hectare plays an important role in the LUC emission balance of biofuels creating incentives to use crops with a higher energy productivity per hectare and therefore to reduce the ILUC risk. For this purpose, raising the default emission saving target for biofuels as it is planned by the European Commission for 2015 represents a suitable tool. Additionally, the European Commission should promote less fuel consuming cars as this would lower the total amount of biofuels needed to achieve the 10% target and advance research activities to increase the energy productivity per hectare of the available bioenergy crops.

Summing up, the whole ILUC debate has its critical point in the method of attributing the global ILUC effect to the local production. Though the global amount of emission from ILUC might at some point be quantifiable with a complex global land use modeling framework, we do not think that it can be downscaled for every individual bioenergy activity due to the complexity of global land use dynamics. The ILUC problem should rather be tackled by creating incentives to plant bioenergy crops on degraded land and to improve the energy productivity per hectare.

Nevertheless, as long as biofuels of the first generation are dominant ILUC will remain an unresolved problem in the calculation of GHG balances of biofuels. In the last section we present a complete world wide GHG balancing of all agricultural production activities that would create a level playing field and a market solution for the competition between food and fuel. Knowing that the following setting is realistic only within a medium or long term process, we do believe that it is the only way to efficiently come closer to reducing the ILUC problem and other problems that are related to the exclusive sustainability requirements for the biofuel production.

5.3. Towards a global carbon assessment for the agricultural sector

Both NGOs and the bioenergy sector criticize that the regulations of computing carbon balances are applied exclusively to bioenergy crop production but not to crop production for food. Indeed, one would expect the current regulations to create incentives that a crop that passes the sustainability regulations of the RES-D will be devoted to bioenergy production and the other crop output not sustainably produced, mainly because of LUC, will go to other uses such as food and industrial use. This regulation would not reduce the global emission balance from LUC. It raises the competition between food and fuel production on the areas that are already cropland. As a consequence land conversions for the food production will be the main drivers of the global LUC emission balance. Only if large amounts of all agricultural products were subject to certification requirements, this policy instrument could display its desired impact: a reduction of global LUC emissions.

Consequently, indirect LUC cannot be controlled efficiently for biofuel activities alone. Efficiency is here understood as the quality of an accounting system to ascribe the causal effects of the chain of LUCs to the biofuel activity. As argued above, this is in principle impossible and can only in a few cases be established with some accuracy. This problem could only be overcome if all agricultural activities are brought into the GHG accounting system. In this case every land use change becomes by definition a direct LUC. And this LUC may increase or decrease the stock of carbon on the area under consideration; hence the LUC would incur a carbon debt in the case of a loss and a carbon gain in the case of an accumulation of carbon through the new land use practice.

This means the problem of indirect LUC is in fact only a problem of an incomplete carbon accounting of land use practices where only biofuel activities are subject to such an accounting but not food production or other bioenergy uses. If, in contrast, all land use practices from forestry, to animal grazing, and to food, fodder and bioenergy production were subject to a carbon accounting system the burden of LUC would always be imposed on the activity that has replaced the previous type of land use. All considerations about accounting for indirect LUC would be meaningless.

A market oriented approach to implement such a complete carbon accounting would be the following: An operator could be given the option to compensate the debt incurred through LUC by buying the equivalent amount of carbon certificates from a carbon market. Once he has served this debt he could operate on the basis of the current carbon flow balance and get accounted for the GHG savings from the standard GHG balance. Such an approach of compensation payments would also solve potentially more complex cases where over time several changes in the land use practices take place. Suppose there is first a change from forest to food production and then to the production of biofuel feedstocks. In the case where the debt is allocated to the next activity the loss in carbon would not be attributed to bioenergy because there was food production – to which carbon balances are currently not applied – before the area is used for biofuel feedstock. In this case the new bioenergy activity would need to compensate for the loss in carbon if the conversion from forest has taken place before a reference year that would have to be determined. This would avoid the need to assess the whole chain of LUCs which would be very difficult to control. In fact, as long as only biofuel activities are subject to carbon balances a chain of LUCs will essentially prohibit an entirely correct attribution of carbon stock changes on the biofuel activity but the compensation system would at least approximate it.

Summing up, the solution to the accounting for ILUC can not be an ad hoc attribution of LUCs that are taking place all over the world due to the expansion of bioenergy production. ILUC can only be efficiently taken care of if all land use activities will in the next years become subject to a GHG accounting. If every agricultural activity is charged by its climate impact, it creates a level playing field between food and fuel production. The result would be a compatible incentive system to reduce emissions from the global agricultural production including LUC.

6. Conclusions

We analyzed the current sustainability regulations for biofuels of the European Commission with respect to LUC. The RES-D aims at controlling for direct LUC by the complete exclusion of peatland, natural forest and other high bio-diverse land from the conversion for bioenergy crop production. Furthermore, to control for the emission saving target of 35% when compared to fossil fuels, the emissions from direct LUC for a bioenergy crop cultivation need to be added to the process emissions of the biofuel option,. According to the RES-D this should be done based on the method and data of the IPCC Guidelines for National Greenhouse Gas Inventories as a detailed individual accounting of the carbon cycle for each production area is not practical.

In general, it seems possible to include direct LUC emissions into a sustainability certification framework for biofuels, as required from the European Commission. It would be practical though, to create default values for different LUCs similar to the default values that have been established for the production process in order to reduce certification costs. However, such default values need to be well disaggregated in order to reflect the different land conditions. Overall default values for example for one world region will not be suitable to cope with the highly differing LUC emissions from different land uses and crop types and would destroy incentives for the farmer to reduce emissions from LUC. However, to keep monitoring cost within a reasonable scope it is advisable to augment the default value list for the production process in the RES-D by default values for land use change, differentiating them by world region, vegetation type, crop grown and management system.

For this purpose the data in the IPCC Guidelines are the most extensive source available. However, to use this source for the construction of default values for the RES-D, the available data need to be further differentiated for different vegetation types and world regions to account better for gradual differences. This is especially the case for grassy and woody savannahs and different types of managed grasslands. Moreover, the IPCC Guidelines often present large spreads for the different parameters thus making further research necessary to reduce this spread. To include the aspect of LUC into already existing sustainability certification systems such as the ISCC-Project, a clear body of rules and regulations concerning LUC from the European Commission is pressing.

The basic concept for the emissions calculation from LUC is to quantify the carbon content of a certain area before the conversion and 20 years after the conversion process. The difference of both values gives the emissions caused by the LUC.

We illustrate the proposed procedures and highlight the consequences from including LUC into the carbon accounting framework. We find that the conversion of natural land for the bioenergy production never meets the minimum emissions reduction target of 35% and in most cases even leads to much higher emissions than the use of fossil fuels. Consequently, the concerns about the protection of high conservation value areas would automatically be resolved since the integration of LUC emissions would already prohibit the use of such areas. Only for grassy savannahs, as it is natural land with a small vegetation cover but often a high biodiversity, there is probably a need to identify global biodiversity hotspots.

In addition, we find that the current setting of the RES-D mainly promotes crop production for bioenergy on already arable land. Hence, the current certification requirements would increase the competition between food and biofuel production. To avoid such a competition effect between food and fuel production the European Commission aims at promoting the expansion of bioenergy production on degraded land by granting an emission bonus for biofuel crops planted on such land. Our results support such a policy. Our examples show that - apart from growing biofuel feedstocks on normal and set aside croplands - degraded grassland is the only option for Argentinean soy, German wheat and rape and US wheat to achieve the minimum reduction target of the RES-D. Nevertheless we scrutinize whether it is profitable even with the degraded land bonus to use such degraded land for commercial bioenergy since degraded land is most likely less productive than normal cropland and requires investment cost for the restoration of the area.

By assuming that a market premium is paid for a biofuel option with higher emission savings the degraded land bonus serves as an indirect subsidy for the use of degraded land. We show that under the current setting the subsidy per hectare for the use of degraded land falls with the level of degradation. Therefore it is likely that only limited incentives for using such land are created since the bonus becomes very small for higher levels of degradation. The current setting should be modified to an incentive system that increases with the level of degradation and is high enough to make the use of degraded land more profitable than the use of cropland for the bioenergy crop production.

Our results illustrate that the accounting of LUC for bioenergy production will creates incentives to use cropland for bioenergy production and – as a consequence - to convert natural land or pasture to other agricultural uses such as food production. In other words, the current regulatory system with LUC taking into account would minimize direct LUC at the cost of increasing indirect LUC. At the same time, we do not know of a convincing proposal to implement indirect LUC into the LUC assessment of biofuels because of complex global land use dynamics that underlie ILUC. Instead, we propose to make all agricultural activities subject to a carbon accounting system. Hence, the burden of LUC would always be imposed on the activity that has replaced the previous type of land use. Thus, all LUC would be direct LUC by definition. Since a global system of GHG accounting for all agricultural products is still far away from being implemented, in the meantime the risk of ILUC trough biofuels can by lowered by promoting high energy productive crops and the biofuel feedstock production on degraded land.

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Annex I: Assumptions for the examples in section 4

Assumptions for examples in calculation: definition according to IPCC Guidelines

BIOETHANOL

country	climate	vegetation	crop	soil	land use before	management before	land use after	management after
	tropical wet	rainforest			native forest	no management		
		deciduous forest			native forest	no management		
Brazil	tropical moist	shrubland	sugarcane	LAC	native forest	no management	perennial crop	no tillage
		grassland normal			normally managed/native	normal managed/natural land		
		grassland degraded			severely degraded grassland	severely degraded		
		cropland			long term cultivated/annual	full tillage		
		set aside cropland			set aside	no management		
		grassland normal			normally managed/native	normal managed		
Germany	cool tempered moist	grassland degraded	wheat	HAC	severely degraded grassland	severely degraded	long term cultivated/ annual	full tillage
		cropland			long term cultivated/ annual	full tillage		
		set aside cropland			set aside	no management		
		subtropical steppe			native forest	no management		
		grassland normal			normally managed/native	normal managed		
USA	warm tempered moist	grassland degraded	wheat	HAC	severely degraded grassland	severely degraded	long term cultivated/ annual	full tillage
		cropland			long term cultivated/annual	full tillage		
		set aside cropland			set aside	no management		

BIODIESEL

country	climate	vegetation	crop	soil	land use before	management before	land use after	management after
	tropical wet	rainforest			native forest	no management		
		deciduous forest			native forest	no management		
		shrubland			native forest	no management		
Brazil	tropical moist	grassland normal	soy	LAC	normally managed/native	normal managed/natural land	long term cultivated/ annual	no tillage
		grassland degraded			severely degraded grassland	severely degraded		
		cropland			long term cultivated/annual	full tillage		
		set aside cropland			set aside	no management		
		steppe			native forest	no management		
		grassland normal			normally managed/native	normal managed/natural land		
Argentina	warm tempered dry	grassland degraded	soy	HAC	severely degraded grassland	severely degraded	long term cultivated/ annual	no tillage
		cropland			long term cultivated/ annual	full tillage		
		set aside cropland			set aside	no management		
		tropical rainforest			native forest	no management		
		grassland normal			normally managed/native	normal managed/natural land		
Indonesia / Malaysia	tropical wet	grassland degraded	palm	LAC	severely degraded grassland	severely degraded	perennial crop	no tillage
		cropland			long term cultivated/ annual	full tillage		
		set aside cropland			set aside	no management		
		grassland normal			normally managed/native	normal managed		
Germany	cool tempered moist	grassland degraded	rape	HAC	severely degraded grassland	severely degraded	long term cultivated/ annual	full tillage
		cropland			long term cultivated/annual	full tillage		
		set aside cropland			set aside	no management		

ANNEX II: Equations

1. Carbon content of biomass above and below ground = loss of carbon due to LUC

$$C_{Biomass+DOM}\left(\frac{tC}{ha}\right) = \left(B_{above} + B_{above} * R_{above/below}\right)\left(\frac{tdrymass}{ha}\right) * C_{drymass}\left(\frac{tC}{tdrymass}\right) + C_{DOM}\left(\frac{tC}{ha}\right) \qquad (1)$$

B_{above}: Tonne biomass per hectare
$R_{above/below}$: Ratio above to below ground biomass
B_{below}: $B_{above} * R_{above/below}$
$C_{drymass}$: Carbon content in stored one tonne biomass drymass
C_{DOM}: Tonne carbon stored in dead organic matter per hectare

2. Carbon Content of the soil

$$C_{soil}\left(\frac{tC}{ha}\right) = C_{native}\left(\frac{tC}{ha}\right) * F_{LU} * F_{MG} * F_{I} \qquad (2)$$

C_{native}: Native mineral soil carbon content
F_{LU}: Soil carbon content change factor for land-use type
F_{MG}: Soil carbon content change factor for management system
F_{I}: Soil carbon content change factor for management system

3. Carbon loss of the soil due to LUC

$$C_{soilemission}\left(\frac{tC}{ha}\right)=C_{soilbefore}\left(\frac{tC}{ha}\right)-C_{soilafter}\left(\frac{tC}{ha}\right) \tag{3}$$

$C_{soilbefore}$: Soil carbon content before LUC
$C_{soilafter}$: Soil carbon content after LUC

4. Total LUC emission per hectare per year

$$C_{LUC}\left(\frac{tCO_2}{ha*a}\right)=\frac{\left(C_{Biomasse}+C_{DOM}+C_{Soilbefore}-C_{Soilafter}\right)}{20}\left(\frac{tC}{ha*a}\right)*3{,}664 \tag{4}$$

5. Total LUC per MJ biofuel per year

$$C_{LUC}\left(\frac{gCO_2}{MJ}\right)=C_{LUC}\left(\frac{tCO_2}{ha*a}\right)*\frac{1.000.000}{productivity\left(\frac{MJ}{ha}\right)} \tag{5}$$

productivity: Energy productivity per hectare of the biofuel crop

6. Allocationfactor for a 2 step production process and 1 Co-product in each step

$$Allocationfactor_{Step1}=\frac{Output_{\text{intermediate product}}*HV_{\text{intermediate product}}}{\left(Output_{\text{intermediate product}}*HV_{\text{intermediate product}}+Output_{\text{Co-product1}}*HV_{\text{Co-product}_1}\right)} \tag{6}$$

$$Allocationfactor_{Step2}=\frac{Output_{Biofuel}*HV_{\text{Biofuel}}}{\left(Output_{\text{Biofuel}}*HV_{\text{Biofuel}}+Output_{\text{Co-product}_2}*HV_{\text{Co-product2}}\right)} \tag{7}$$

$$Allocationfactor=Allocationfactor_{Step1}*Allocationfactor_{Step2} \tag{8}$$

Output: Output volume of the biofuel, intermediate output or co-product

7. Total allocated LUC per MJ biofuel

$$C_{LUCallocated}\left(\frac{gCO_2}{MJ}\right)=C_{LUC}\left(\frac{tCO_2}{MJ}\right)*Allocationfactor \tag{9}$$

8. Total allocated emissions per MJ biofuel

$$C_{Total}\left(\frac{gCO_2}{MJ}\right)=C_{LUCallocated}\left(\frac{tCO_2}{MJ}\right)*C_{WtW}\left(\frac{tCO_2}{MJ}\right) \tag{10}$$

C_{WtW}: well to whell emisison from the biofuel production, including agricultural prodution, production process and distribution

Note: For the C_{WtW} factor we use the typical values of the RES-D Annex VII that already include an allocation factor for co-product. Thus, we do not multiply this factor again by the allocationfactor here but it needs to be done when other data without an allocation factor are used.