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The GHG Balance of Biofuels Taking into Account Land Use Change

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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 bioenergy feedstock production. We investigate how the inclusion of the carbon effect of LUC into the carbon accounting framework, as scheduled by the European Commission, impacts on land use choices for an expanding biofuel feedstock production. We first illustrate the change in the carbon balances of various biofuels, using methodology and data from the IPCC Guidelines for National Greenhouse Gas Inventories. It becomes apparent that the conversion of natural land, apart from grassy savannahs, impedes meeting the EU’s 35% minimum emissions reduction target for biofuels. We show that the current accounting method mainly promotes biofuel feedstock production on former cropland, thus increasing 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 the current regulation provides little incentive to use such land. The exclusive consideration of LUC for bioenergy production minimizes direct LUC at the expense of increasing indirect LUC.

Keywords: land use change emissions, bioenergy, European policy,

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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 with non-fossil renewable sources. The European Union for example seeks to achieve a minimum target of 10% renewables in the transport sector by 2020. The contribution of bioenergy to the saving of greenhouse gas (GHG) emissions has recently been criticized because – according to previous practice – the inclusion of the carbon balance of land use change (LUC) has not been included in the GHG balances of bioenergy production. This approach has ignored the fact that, in the process of production, not only does the flow of GHGs in the production process need to be accounted for, but also the change in the stock of carbon contained in the land converted for feedstock production. This is of particular importance if land that has not been used before or has been subject to other uses such as forestry or as pasture comes into use for bioenergy production.

This practice often 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 GHG 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 show a correlation 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 keep climate change impacts within limits with which societies will be able to cope, greenhouse gas emissions need to decrease substantially. This cannot be achieved without reducing emissions from the land use sector (UN-REDD 2009).

With the Renewable Energy Directive 2003 (RES-D), the European Comission (EC) put forward sustainability regulations in order to avoid undesirable LUC for the expansion of the bioenergy feedstock production area. The implications of this regulation framework for the dynamics of agricultural expansion, and therefore for the emissions caused by LUC, have so far not been analysed. Several studies have been conducted, aiming to quantify the overall LUC impact and related emissions of various biofuel expansion scenarios, such as Searchinger et al. (2008), Fargione et al. (2008), Melillo et al. (2009), Valin et al. (2009) e.g., but they do not account for the sustainability regulations set up in Europe or other world regions. Therefore they somehow model an “uncontrolled” expansion of the biofuel feedstock production which is precisely what the sustainability regulations aim to avoid. Other studies such as Hennenberg et al. (2009) or Fritsche and Wiegmann (2008) directly address the sustainability criteria in the RES-D, but mainly focus on public consulting for a better implementation of the RES-D into national law and into practice. Due to the fact that the EC’s “Guidelines for the Calculation of Land Carbon Stocks” (EC Guidelines), a communication related to the sustainability critiria implemented by the RES-D, were only published recently, to our knowledge no other study exists that considers these additional regulations.

In this study we analyse the sustainability regulations set by the EC to account for LUC in the bioenergy production in detail. Our investigation focusses on how the regulation will effect land use decisions for the production of different biofuel feedstocks in different regions of the world. This is done with the intention of evaluating whether the sustainability criteria can effectively prevent emissions from LUC and the destruction of natural habits used for bioenergy feedstock production.

The paper is structured as follows. In section 2 we first discuss the current political framework, in particular, we analyse the Renewable Energy Directive of the EC. In section 3 we present the LUC emission calculation method on the basis of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines) and EC Guideline and draw first conclusions on how this method impacts on LUC choices for an expanding biofuel feedstock production. In a next step in section 4.1 and 4.2, we calculate concrete examples for LUC emissions and derive the consequences for the European biofuel policy and the various biofuel options. To evaluate the examples in terms of efficiency we compare the examples by their abatement cost in section 4.3. Furthermore, in section 4.4, we discuss the particular case of the conversion of degraded land for biofuel feedstock production in order to appraise the effect of the RES-D regulations upon the competition between food and fuel. Section 5 concludes and gives 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 extended its efforts to increase the use of bioenergy within the Community, mainly with the goal of lowering its dependency on imported oil and reducing GHG emissions in order to tackle global warming. Biofuels receive particular attention within the European bioenergy policy due to the fact that, overall, one third of the European emissions are produced by traffic. Furthermore, in the transportation sector fossil fuels mainly need to be imported from outside the EU, whereas alternative energy sources such as 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 EC 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 meantime a discussion arose about the sustainability of global biofuel production. Particularly reports about high deforestation rates in the Amazon and in Southeast Asia, two regions with a large expansion of bioenergy production, aggravated concerns about the risks of biodiversity loss and food and water shortages arising from increasing biofuel production (Goldemberg and Guardabassi 2010; Rathmann et al. 2010). In the same way the overall GHG reduction potential of biofuels was questioned when LUC emissions for biofuel production were taken into account (Fargione et al. 2008; Searchinger et.al 2008).

In January 2008 the EC 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 environmentally harmful biofuels. Together with the so called “climate and energy package” it sets a minimum GHG reduction target of 20% (relative to 1990) and a share of 20% of renewable energy in the Community´s total energy consumption by 2020.

2.2. Sustainability requirements in the RES-D

The RES-D contain sustainability requirements that mainly tackle the problem of increased bioenergy production potentially causing by the RES-D so called “undesirable” 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. However, since the carbon stock of different land types depends on various factors, the RES-D trys to avoid 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 and
- via a minimum emissions reduction target.

Concerning the first channel, it is widely agreed that some land types are always carbon rich, such as wetlands, peatlands and continuously forested areas with a canopy cover higher than 30% and therefore, in the same way as high-biodiverse land, are generally excluded from the suitable land type options for the bioenergy feedstock production.(RES-D Art.17(4)). This also applies to forests 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.17(4)). These rules form part of the second channel:

For the feedstock production on every field, the emissions savings of the final biofuel or other bioliquid need to be at least 35%, considering the emissions caused in the whole value chain including LUC emissions (RES-D Art 17(2))[1]. This implies that biofuel crops produced on land with a high carbon content before the conversion are less likely to achieve this target.

According to the RES-D, the method and data used for the calculation of emissions from LUC should be based on the IPCC Guidelines and should be easy to use in practice (RES-D Annex V C(10)). With the EC Guidelines the European Comission recently published a draft on guidelines for the calculation of land carbon stocks for the purpose of Annex V of the RES-D. We will discuss this method further in section 3.

In general, the EC intents to promote the cultivation of crops on degraded land for bioenergy crop production. In other words, the conversion of degraded land into cropland is explicitly defined as a “desirable” LUC. The RES-D attributes a bonus of 29 gCO_2eq/MJ in the computation of the carbon balance, if evidence is provided that the land is significantly salinated or eroded with a low organic matter content or heavily contaminated and thus unsuitable for the cultivation of food and feed production.(RES-D Annex V C(9)).

The required sustainability criteria need to be met by both imported bioliquids and bioliquids produced within the Community in order to count towards the national targets of renewable energy, and thus to be eligible for financial support for the consumption of biofuels and other bioliquids (RES-D Art. 17 (1)). Consequently, compliance with the sustainability criteria should be verified for each biofuel producer (RES-D (76)). In the next section we present and analyse the sustainability requirements for LUC emissions in detail.

3. LUC emissions calculation

The contribution of biofuels to climate change mitigation can only be assessed if an exact calculation of the GHG emission balance and hence of the LUC emissions from feedstock production, is done. In this section we show how LUC emissions should be calculated from a theoretical point of view. However, as the theoretical approach is difficult to implement in practice we proceed by assessing the calculation requirements for LUC emissions in the RES-D and show how LUC emissions can be calculated in detail based on the EC Guidelines.

3.1. Calculating LUC emissions exactly: the theoretical approach

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 biomass above and below ground before the conversion;
- the volume of 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 upon the soil carbon content, especially when perennial crops are used;
- The influence of local circumstances upon 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. In other words, for a precise calculation of the carbon gain or loss due to LUC, an analysis of the entire individual carbon dynamics of the respective area needs to be performed in a sophisticated biological model.

However, it is neither feasible nor economical to invest such effort in each LUC that occurs for an expansion of bioenergy production, as its costs would exceed all possible gains. In the following we present the approach of the EC 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 timeframe of 20 years after the conversion. The actual land use in January 2008 serves as the benchmark (RES-D Art. 17). This is due to the fact that some emissions occur during the conversion process itself and others over a long period of time after the conversion. To simplify the calculation, the LUC emissions are to be summed up and allocated in twenty equal parts to each year (RES-D Annex V C(7)). This approach is in line with the method proposed by the IPCC Guidelines, upon which the EC Guideline’s method and data are mainly based. 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 outline the calculation method and provided data for LUC emissions in the EC Guidelines by, firstly, analyzing the database and, secondly, by presenting the various calculation steps necessary for deriving the complete LUC carbon balance of biofuels. This detailed exposition is important because we can already draw conclusions from the calculation method itself on the land use incentives provided by the regulatory framework.[2]

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

The calculation procedure set out in the IPCC Guidelines was, to a certain extend, modified by the EC. Additionally, some, but not all gaps in the data were filled, as clarified in the following section.

3.3.1. The database

The IPCC Guidelines contain inventory lists for the carbon content of several biomass categories, soil types and soil management systems. Some of these categories differentiate between climate zones and/or regions.[3]

The EC Guidelines primarily use the categorization of default values in the IPCC Guidelines. The EC, however, did add the following values: forest with a canopy cover between 10%-30%, scrubland, shifting cultivation and perennial crops. These additions were necessary in order to account for all possible cases of LUC. However, one problem still remains: it is difficult to make a clear distinction between different natural grassland and forest categories. This distinction is vital for transitions areas ranging from grassland to forest, such as the Brazilian cerrado in the Amazon region. In the case where the IPCC Guidelines contained data ranges, the EC Guidelines chose single values. In the following we will simply refer to the EC Guidelines as the source for the calculation procedure and data, bearing in mind, though, that it is based on the IPCC Guidelines.

3.3.2. The calculation procedure

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

- 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 processes of these two parameters differ, both methods will be explained in depth in the following sections. All parameters required for the calculation process can be taken from the inventory tables in the EC Guidelines.

Biomass and dead organic matter (DOM) (Eq. 1)

For biomass and DOM, the IPCC approach implicitly assumes that the entire biomass and dead organic matter are destroyed when converting the land to cropland. Therefore, carbon stocks in biomass after conversion are assumed to be zero (IPCC 2006 p.5.26). Consequently, the total carbon content in biomass (B^{before}) and dead organic matter (C_{DOM}) before LUC represents the first fraction of emissions caused by LUC ($C_{Biomass+DOM}$). Therefore, it is logical to say that the emissions from LUC rise with the density and the extent of the vegetation.

Eq. 1 Change in biomass carbon content

$$C_{Biomass+DOM}\left[\frac{tC}{ha}\right]=B_{before}\left[\frac{tC}{ha}\right]+C_{DOM}\left[\frac{tC}{ha}\right]$$

For annual crops

$$C_{Biomass+DOM}\left[\frac{tC}{ha}\right]=B_{before}\left[\frac{tC}{ha}\right]-B_{20years}\left[\frac{tC}{ha}\right]+C_{DOM}\left[\frac{tC}{ha}\right]$$

For perrennial crops

The EC excludes all perennial crops from the emission calculation rule for biomass carbon that the entire living and dead biomass carbon stock is destroyed in the conversion process. In the case of biofuels, this mainly refers to sugarcane and palm oil. The EC assumes that due to the perennial growth of these plants, carbon is accumulated in the sugarcane plant or palm oil tree. Thus, the carbon stock in the biomass after the conversion ($B_{20years}$) is not zero but positive, the amount depending on the crop. However, this assumptions might lead to an underestimation of the LUC emissions for perrennial crop plantations when considering that the LUC emission values represent averages over 20 years. As sugarcane plants are harvested in their entirety after a few years the carbon stored in the biomass is released into the atmosphere. The same is true for palm oil plants when they are replaced exactly after 20 years.

To choose the right value, the respective area needs to be classified according to existing land categories. The classification is crucial for the emissions from LUC allocated to this area, hence it should be done carefully. The components defining the various categories are outlined next.[4]

The first component of land categories is the climate zone.[5] The next component - the categorization of the different biomass types - is much more sophisticated. The biomass types listed in the EC Guidelines are cropland, grassland and forest. ‘Cropland’ is divided into annual cropland and perennial cropland, listing specific values for sugarcane and oil palm trees. ‘Forest’ is divided into natural forest - seperated into forest with a canopy cover between 10%-30% and over 30% - and forest plantations.[6]

Natural savannah-like vegetation still seems to be a difficult component to define, despite the EC augmenting the relevant data bases. There is a special value provided for miscanthus grassland which primarily applies to subtropical grassland regions in Europe and North America. Furthermore, there is a value for ‘scrubland’, which is defined as a vegetation composed largely of wood plants less than five meter high that do not have the clear physiognomic features of trees. These values are close to those of the subcategory ‘subtropical steppe’ in the forest category of canopy cover over 30%. In the forest category for a canopy cover between 10%-30% there is also a subcategory ‘subtropical steppe’, with much smaller carbon stock values. The augmentation of the default values for biomass types in the transition areas between pure grassland and forest was necessary in order to better account for gradual differences in biomass densities. However, in practice, a clearer definition of and differentiation between the different subcategories and geographic ranges of the typical natural grassland types existing throughout the world would make it easier to choose an appropiate value.

Soil

Changes in soil carbon content are calculated differently because the carbon in the soil can not be fully distroyed like in biomass, since it is subject to other carbon dynamics (IPCC 2006 Eq. 2.25). The procedure we present, as well as all our exemplary calculations in section 4, refers to mineral soils only. This is due to the fact that organic soils predominantly exist in wetlands and peatlands and hence are not considered suitable for bioenergy crop production by the RES-D.

The EC Guidelines, based on FAO soil classifications, contain default values of the original or natural carbon content of different global soil categories. Natural soil carbon content (C_{native}) increases or decreases depending upon different land uses (F_{LU}), management techniques (F_{MG}) or nutrition input (F_I). To what extent these factors impact upon the soil carbon content ($C_{soil\ before/crop}$) differs from climate zone to climate zone. A reduction in tillage and use of degraded land increases the natural carbon content of the soil, the plantation of perennial crops stabilizes it. Annual crop cultivation with full tillage lowers the soil´s carbon content.

By accounting for these factors, soil carbon content is calculated twofold (Eq. 2): once for former land use ($C_{soil\ before}$), and once for bioenergy crop production (C^{soil} ^{crop}). The difference between the two values (Eq. 3) provides the soil emissions from LUC ($C^{soil\ emission}$).

Eq. 2. Soil Carbon Content

$$C_{soil\,before/crop}\left[\frac{tC}{ha}\right] = C_{native}\left[\frac{tC}{ha}\right] * F_{LU} * F_{MG} * F_{I}$$

Eq. 3. Change in Soil Carbon Content

$$C_{soilemission}\left[\frac{tC}{ha}\right] = C_{soilbefore}\left[\frac{tC}{ha}\right] - C_{soilafter}\left[\frac{tC}{ha}\right]$$

The EC added two additional values for shifting cultivation that were not included in the IPCC Guidelines. The first value accounts for mature fallow, where the vegetation has recovered and reached a mature or near mature state. The second value accounts for shortened fallow, where the forest vegetation recovery is not attained prior to re-clearing (EC-Guidelines). The presence of shifting cultivation reduces the soil’s natural carbon content. There is no specific value for the biomass of shifting cultivation. Thus, it must be classified in the forest category according to existing canopy cover.

The implementation of such values for the soil carbon of shifting cultivation areas is a useful addition to certifiers, as this kind of agriculture is quite common in transition areas of tropical rain forests. Shifting cultivation areas are often declared as degraded land, and their influence on soil carbon content is similar to the influence of degradation. However, according to the RES-D definition, they are not degraded areas and hence will not gain an additional emission saving bonus.[7]

The total LUC carbon balance

After quantifying the LUC emission values of biomass and soil, the total LUC carbon balance of the produced biofuel can be computed (Eq. 4). To further develop

Eq. 4. Total LUC emission per MJ biofuel

$$C_{LUC}\left[\frac{gCO_2}{MJ}\right] = \left(\frac{\left(C_{Biomasse\ DOM} + C_{soilemission}\right)}{20}\left[\frac{tC}{ha}\right] * 3{,}664\right) * \frac{1.000.000}{P\left[\frac{MJ}{ha}\right]}$$

the calculation, the emission values of biomass ($C_{biomass+DOM}$) and soil emission ($C_{soil\ emission}$) are added together and allocated in equal parts over 20 years. By multiplying these emissions per hectare with the energy productivity per hectare of the bioenergy crop (P), the LUC emissions per mega joule biofuel (C_{LUC}) are computed (RES-D Annex V 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. In turn, it is perfectly possible that a more productive biofuel option combined with favourable management techniques lies within the required 35% emission savings, but a less productive one might not, despite being cultivated in the same field.

To complete the calculation of the LUC emissions, the EC allows for an allocation of the resulting LUC emission to each biofuel or its intermediate products and possible by-products (Eq. 5). The allocation factor (A) should be calculated on the basis of the energy content, that is the lower heating value. Furthermore, in the case of degraded grassland being converted for the biofuel feedstock production, the granted additional emission saving bonus (D^{Bonus}) needs to be subtracted from the LUC

Eq. 5. Total allocated LUC emissions per MJ biofuel

$$C_{LUCallocated}\left[\frac{gCO_2}{MJ}\right] = C_{LUC}\left[\frac{gCO_2}{MJ}\right] * A - D_{Bonus}\left[\frac{gCO_2}{MJ}\right]$$

emissions.

In summary, the calculation method proposed by the EC 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 decreasing the carbon content are: intensive use of tillage and the cultivation of annual crops;
- factors increasing or stabilizing the carbon content are: the use of perennial crops and a reduction of tillage;
- the conversion of degraded grassland or shifting cultivation forest to cropland increases the soil carbon content;
- the higher the energy productivity of a biofuel feedstock, the lower the LUC emissions allocated to each biofuel unit.

It is important to further analyse the likely consequences of an accounting of LUC emission in the sustainability regulations for biofuels. For this reason, in the next section, we present a range of examples representing the main crops and the most important growing regions for biofuel feedstocks using the above mentioned calculation method and database.

4. Including LUC emissions in the carbon balance of biofuels

To avoid the promotion of environmentally harmful biofuels, the EC integrated the LUC regulation into the current Directive. In this section, we will demonstrate the likely results and consequences of this inclusion of LUC into the carbon accounting framework. We use the current rules set by the EC to show how the carbon balance of different biofuel options changes when LUC emissions are computed according to the scientific results set out in the IPCC Guidelines. The main questions driving such an assessment forward are: Which land categories in which world regions are feasible for biofuel production in accordance with the EC’s sustainability criteria? Does the accounting for LUC emissions in the carbon balance become a knock-out criterion for the feasability of some bioenergy crops?

4.1. GHG calculations for the main biofuel crops

A range of examples representing the main crops and the most important growing regions for biofuel feedstocks help illustrating how the current EC rules effect their carbon balances . The method presented above can be applied to all types of LUC, as done for the examples presented here. Annex I contains the precise definition and categorization of the examples. To start with, we calculate the pure LUC 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 cultivation of bioethanol (figure 1) and biodiesel feedstocks (figure 2). According to the calculation method above, 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 into twenty equal parts, accounting for the time path of LUC emissions. Positive values always indicate a net carbon loss from LUC, negative values stand for an additional carbon accumulation in the soil. The amount of 83.8 gCO_2/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 (248gCO_2/MJ for sugarcane and 616gCO_2/MJ for soy) and Malaysia/Indonesia (182gCO_2/MJ) in particular, emissions are extremely high because of the amount of biomass that is destroyed. The same is true for deciduous forests and scrubland with predominantly woody vegetation.

Figure 1. Land Use Change Emissions per year for various bioethanol options and former land uses

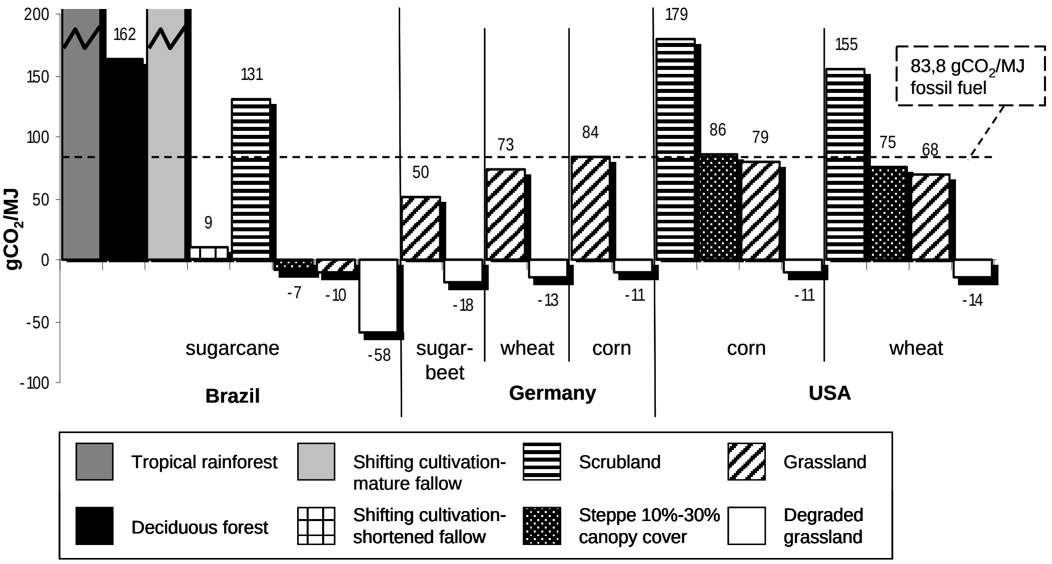
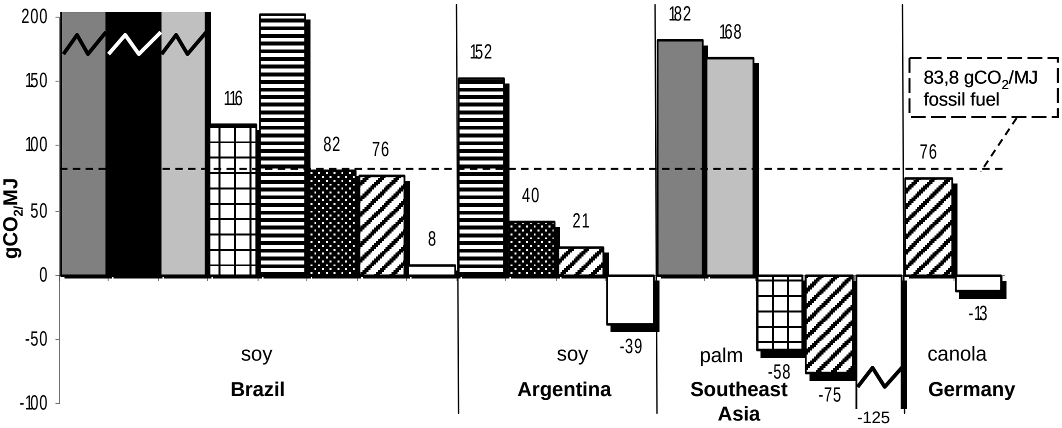


Figure 2. Land Use Change Emissions per year for various biodiesel options and former land uses



The soil carbon stock and energy productivity is more important for those land use types that contain little aboveground biomass such as steppe with a canopy cover < 30% or normal grassland[8]. This can be seen for example in Brasil, where the conversion of steppe with a canopy cover of 10%-30%, that is grassy cerrado, with the subsequent cultivation of sugarcane causes a small amount of carbon accumulation (-7 gCO_2/MJ) due to the perennial growth of sugarcane, and a high energy productivity per hectare. In contrast, the conversion of the same area for the cultivation of soy for biodiesel production already causes nearly prohibitively high emissions of 82.1 gCO_2/MJ (in comparison to 83.8 gCO_2/MJ for fossil fuels). This is due to soy's lower energy productivity per hectare and the annual replantation of the crop which results in a lower carbon content in the soil and no carbon accumulation in the crop biomass. The same is true for US corn and wheat production which show similar values as soy production in Brazil for the conversion of different grassland types.

Values for shifting cultivation differ substantially for shortened or mature fallow areas converted for sugarcane production in Brazil and palmoil production in Southeast Asia. This is mainly driven by the assumption of differences in biomass density for the regrowing forest. As the LUC emission values for shortened fallow shifting cultivation, unlike those for mature fallow, still do not surpass the emission of fossil fuels, there will be an incentive for farmers to allocate their shifting cultivation areas to this category. As the transition between the two categories will be gradual in practice, the European definition should be more precise. Also, potential certifiers need to be trained in practice to be able to distinguish between the two categories.

It is important to notice the vast difference between normal grassland and degraded grassland. Apart from the conversion of grassland to sugarcane or palm oil cultivation, the conversion of normal grassland, including grassy savannahs, leads to relatively high emissions. In contrast, the emissions resulting from the conversion of degraded grassland are much smaller, often even negative. This can be seen even clearer from all German and American biofuel options where the conversion of degraded land always leads to an accumulation of carbon in the soil whereas the conversion of normal grassland already causes relatively high emissions (e.g. 76gCO_2/MJ for rape). The differences between these two, at first sight closely related, categories clearly show that a more precise and differentiated definition of various grassland categories and their geographically explicit identification on a global scale is urgently needed.

The full carbon balance

To derive the full carbon balance (C_{Total}), we now combine the LUC emissions ($C_{LUCallocated}$) with the calculation of the total process emissions caused by the production of the biofuel based on the calculation procedure in the RES-D (Eq.6). In order to do so, we add the LUC emissions to the typical total production pathway emission values that can be directly taken from the RES-D (C_{WtW}) (RES-D Annex V C (1) and (7)).

Eq. 6. Total allocated emissions per MJ biofuel

$$C_{Total}\left[\frac{gCO_2}{MJ}\right] = C_{LUCallocated}\left[\frac{gCO_2}{MJ}\right] + C_{WtW}\left[\frac{gCO_2}{MJ}\right]$$

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 are illustrated in figure 3 for bioethanol and 4 for biodiesel becomes immediately apparent:

- The conversion of natural land for bioenergy production almost never meets the 35% target and in most cases even leads to much higher emissions than the use of fossil fuels.

Figure 3. Total emission savings (%) per year of various bioethanol options and former land uses

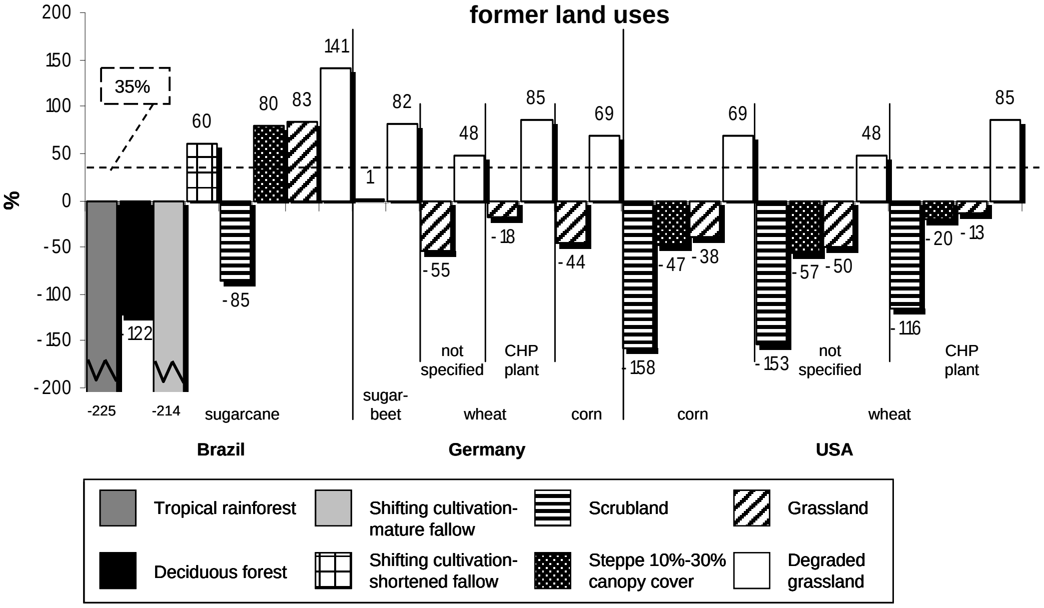
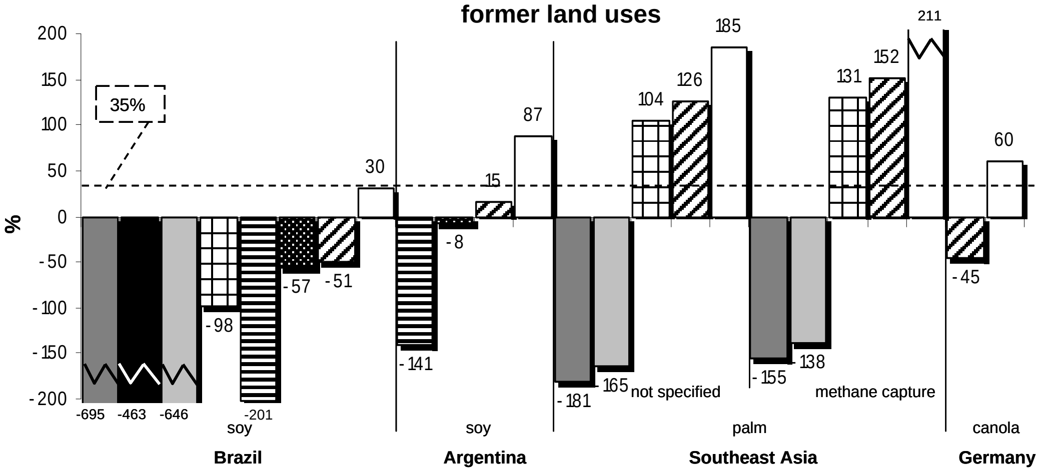


Figure 4. Total emission savings (%) per year of various biodiesel options and former land uses



- The only exceptions are Brazil, with 80% emission savings when grassy steppe or 60% when shortened fallow forest is converted for the sugarcane bioethanol production and Southeast Asia with 131% emission savings[9] when shortened fallow forest is converted for palm biodiesel production[10].

- Except for soy biodiesel production in Brazil, the conversion of degraded grassland for bioenergy crop production leads to high emission savings, which meet the 35% reduction target.[11] Moreover, for all German, American and Argentinean biofuel options considered in these examples, degraded grasslands provide the only option of expansion into non-agricultural land in order to meet the sustainability requirements of the EC.

4.2. Consequences for the regulatory framework and for the choice of a particular LUC

Based on the examples presented in the previous section we draw a number of conclusions from the current regulatory framework. We also suggest adjustments to the regulations, in order to make the carbon accounting more target-oriented and to improve the incentives for climate friendly production of biofuels. We draw the following conclusions:

- The accounting method for LUC emissions as prescribed by the EC Guidelines creates incentives to use areas with little or no vegetation cover, such as cropland and grassland, as well as using crops with a high energy productivity per hectare and improved management techniques.
- The variation in the carbon balances emphasize the need for assessing LUC emissions individually for each field and farm. Overall default values, eg. for example for a region or country, whould not identify the highly differing LUC emissions from different land uses and crop types. Brazil is a key example of a country where one single biofuel option has a vast range of carbon balances due to the variety of previous land uses of the crop area.
- The classification of high conservation value areas as so called “no-go areas” for bioenergy crop production is not necessary in all cases, since practically all potential high conservation value areas do not meet the emission saving target. It could ease the work of certifiers if natural land in general was excluded from the areas considered suitable for the production of bioenergy crops.

- An exception in this context is the positive emission saving of 80% for sugarcane production on former steppe with a canopy cover <30% in Brazil. There are vital strong commercial interests in Brazil to convert the *cerrado,* which, to a large extent, is already used for extensive cattle grazing. This is due to the fact that this vegetation type is dominant throughout Central Brazil and represents the main agricultural expansion area. Thus, especially for natural grasslands and savannah-like vegetation in Central Brazil, the differentiation between steppe and scrubland needs to be specified and enhanced by specific default values which consider the different vegetation types specific to Central Brazil. Furthermore, for this region, the identification of bio-diverse hotspots and high conservation value areas is extremly important.
- The results support the hypothesis that crop production for bioenergy which meets the RES-D targets is likely to take place on land already in crop production. In many regions of the world the main potential expansion area for crop production is degraded grassland. The current vague classification of various grasslands creates the potential risk of not being certified when converting grassland to cropland. This might result in a tendency to not use the expansion areas for biofuel crop production. Hence, the current certification requirements would increase the competition between food and biofuel production. In other words, the RES-D avoids direct LUC for bioenergy production at the cost of promoting indirect LUC.

One can argue that the results based on the IPCC data are questionable due to data augmentation requirements and the employment of a standardized calculation method that does not account for every individual characteristic of an area. We already identified the need to augment existing data sets and to define different land use types more precisely. However, the results, particularly for areas with a dense vegetation cover, are clear and it is unlikely that more precise assessments will change the overall results.

4.3. Abatement Costs

It is common practice, when comparing different options of renewable energy, to evaluate them according to their abatement cost. In the case of renewable energies, this refers to the marginal cost of the energy option to abate one unit of GHG emissions. This concept captures not only the emission mitigation potential of a renewable energy option, but also its economic performance. The aim of using the marginal abatement cost as a criterion to evaluate different renewable energy sources is to assess the efficiency of a climate policy. Emissions should be reduced at the lowest cost possible. This concept can also be applied to biofuels. By only choosing biofuel options with the lowest abatement cost, the mitigation goal of the European Commission could be achieved efficiently: that is, at lowest cost.

Figure 5. Abatement cost of various biofuel options when accounting for LUC emissions

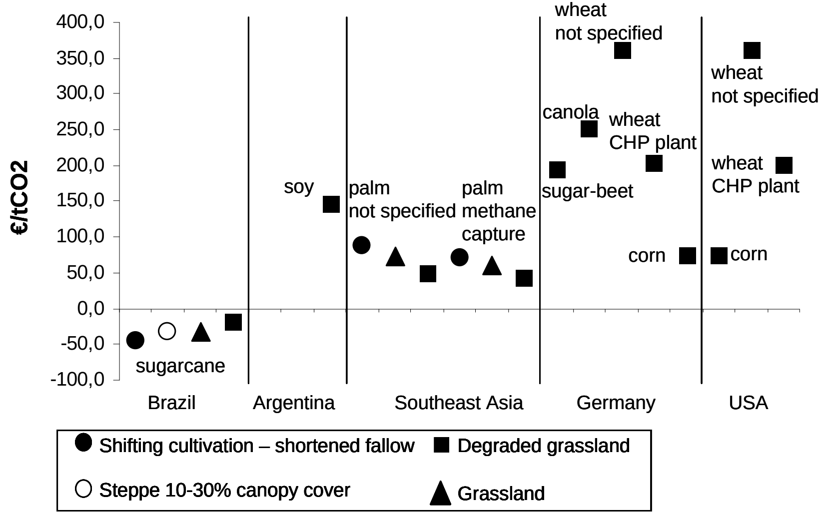


Figure 5 shows the abatement cost for the LUC emission examples used in Figures 1.-4. by dividing the production cost difference of the respective fossil fuel and biofuel by the emission savings of the biofuel. The cost for production and fossil fuels are based on FNR[12] 2007 data. Fuel costs were converted from US Dollars into Euros at the average US Dollar exchange rate of 2007. Naturally, we only used the examples that realize emission savings and skipped those with higher total emission than the respective fossil fuel.

The examples in figure 5 clearly show that biofuel options that are already highly productive in terms of a higher energy yield per hectare and, consequently, lower emissions per energy unit, also have advantages when it comes to cost per energy unit. This can be seen for example from negative abatement cost for sugarcane. Nevertheless, for some feedstocks, the differences in performance were lessened due to differences in production cost. Corn ethanol from degraded grassland, for example, costing 75€/tCO_2, comes close to the abatement cost of palm oil biodiesel from degraded grassland with 49€/tCO_2, despite this palm oil biodiesel option having with 0,155 tCO_2/GJ 3 times the emission saving of corn with 0,058 tCO_2/GJ (see figure 4). This is due to a difference in the underlying 2007 production cost of 19€/GJ for palm oil biodiesel and 16€/GJ for corn ethanol.

The only crop that achieves negative abatement cost is sugarcane because its production costs are lower than those of fossil gasoline. The problem with the concept of abatement cost is the fact that it results in a scaling problem when it comes to negative values. The negative values need to be interpreted as cost savings by using the biofuel instead of the fossil fuel with respect to the total emission savings. Thus, with rising emission savings, the cost savings per unit of emissions saved decreases. This scaling problem was not touched upon by other studies (e.g. Kopmann et al. 2009), as they only considered one negative value for sugarcane. When differentiating between them by different LUCs, an option with lower emission savings will have more negative abatement costs than an option with higher emission savings. This mathematical problem cannot be solved without losing the entire meaning of the calculation of abatement cost. Therefore, we maintained the resulting negative values for sugarcane but did this keeping in mind that the scaling should be the other way around. Nevertheless, it becomes clear that sugarcane ethanol is by far the lowest cost biofuel option in terms of greenhouse gas savings and degraded grassland is the efficient option amongst the range of LUCs.

Amongst biodiesel, palm oil is the efficient option. However, when assuming a carbon price of 15-20 € per tonne CO_2 in the ETS, even the cheapest biodiesel option is still not competitive enough in comparison with other emission mitigation options. In the future, though, this may change if production costs decline.

Consequently, to realize an efficient climate policy, ethanol from sugarcane from converted grassland or degraded grassland should be the first option from amongst the biofuels available. The fact that the abatement cost of all other biofuel options by far supass the current ETS prices indicates that there are much cheaper options for abating carbon dioxide emissions than biofuels. Therefore, regarding an efficient greenhouse gas mitigation strategy, policies should concentrate on alternative mitigation options, unless the productivity rates of biofuel feedstocks increase substantionally. [13]

4.4. The particular case of degraded land

Considering that 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., 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. He calculates a global area of 500 Mha of degraded land. Field et al. (2007) estimate that abandoned agricultural land accounts for 385-472 Mha based on an analysis of historical land use data.

When degraded land is recultivated for biofuel production, the favourable carbon balance of degraded land and the avoidance of competition with food production offer the opportunity of producing bioenergy without significant side effects. As the granted bonus for the use of degraded land is indeed the only instrument in the European biofuel policy to reduce such competition, the question is whether it sets effective incentives to use degraded areas. In this section we investigate whether the regulatory framework of the RES-D[14] indeed fosters the expansion of bioenergy, predominantly into degraded land.

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 available to the farmer. The conflict between food and energy crops remains as long as the price signals do not favour 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 production cost differences and political incentives:

Production cost differences depend on:

- investment cost for the restoration of degraded land for agricultural production
- differences in yields per hectare on degraded cropland relative to non-degraded land.

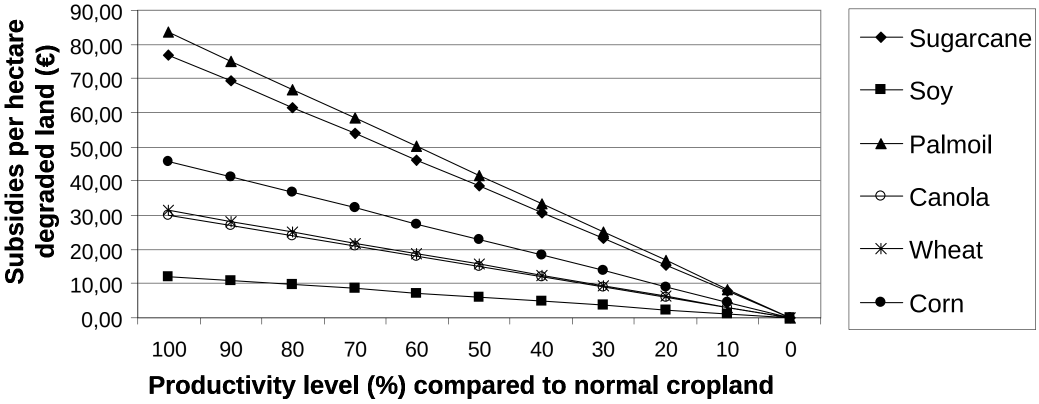
Political incentives depend on:

the incentives given by the emission bonus for LUC on degraded land that is granted by the RES-D. This procedure leads to computed (but not actual) emission savings for the final biofuel, which, in most cases, are higher than those on cropland. 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 can gain a premium in the market depending on the amount of emission savings.

Currently the bonus of $29gCO_2/MJ$ acts as an indirect subsidy for production on degraded land. We made an exploratory calculation of the incentives this bonus system creates. For these calculations we assumed that the CO^2-prices of the ETS represent the premium for emission savings.

In Figure 6 we assumed a constant carbon price of $20€/tCO_2$ and computed the subsidies per hectare of degraded land for different biofuel crops at various productivity levels. Since the bonus is granted per mega joule fuel, more productive biofuel crops such as sugarcane and palmoil, receive a higher subsidy per hectare. The subsidies vary strongly for the different crops cultivated.

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



This setting of the degraded land bonus further implies that a strongly degraded land – i.e. land with low productivity compared to the productivity on normal cropland – receives a lower subsidy per hectare than less degraded land. This does not seem to be a suitable framework for fostering the use of degraded land. On the contrary, the higher the level of degradation, the higher are investment costs for restoring the area and the lower is the expected productivity.

Lets consider the example of rape biodiesel to get an idea of the monetary impact of the subsidy. We assume that the producer realizes a price at the market for the rape biodiesel that is equal to the production cost on normal cropland. Based on 2007 FNR data, for rape biodiesel this means a price of 24 €/GJ or 1248 €/ha with an underlying productivity of 52 GJ/ha. We ignore possible investment cost and keep the assumption of a carbon price of 20 €/tCO_2. It turns out that already with a productivity level of 97% of the degraded land, the subsidy of 29.56 €/ha for this productivity level is not sufficiently high anymore to compensate for the decrease in rent compared to normally productive cropland which declines to 1210.56 €/ha under these assumptions. Doing the same for Braszilien sugarcane, this productivity threshold is achieved at a productivity level of 93% compared to normally productive cropland.

Thus, under the current regulatory structure it is more likely that the subsidy creates incentives for using areas with very little degradation and highly productive crops, particularly sugarcane and palm. Otherwise the bonus is not high enough to exceed the loss from investment costs and lower productivity. However, it is highly questionable whether a degree of degradation, of say 2-7%, 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 distribute it directly per hectare.

5. Conclusions

We analyzed the EC´s current sustainability regulations for biofuels with respect to LUC. The RES-D aims to control direct LUC by entirely excluding peatland, natural forest and other high bio-diverse land from the conversion to bioenergy crop production. Furthermore, to monitor the emission saving target of 35% when compared to fossil fuels, the emissions from direct LUC for bioenergy crop cultivation need to be added to the process emissions of the biofuel option. For the calculation of emissions from LUC, the EC recently published a Communication with guidelines for a standardized calculation method based on 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.

We illustrated the proposed procedures and highlighted the consequences of including LUC into the carbon accounting framework. We found that the conversion of natural land for bioenergy production almost 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, 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. The identification of high biodiversity hotspots is necessary only for grassy savannahs, especially in Brazil as it is classified as natural land with a small vegetation cover but often a high level of biodiversity. The precise identification and distinction between different types of natural savannah-like vegetation is of particular interest to the Brazilian sugarcane production, as the high energy productivity of sugarcane results in emission savings when converting grassy savannah.

In addition, we found that the current arrangement of the RES-D predominatly promotes crop production for bioenergy on land already in crop production. 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 EC 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 showed that - apart from growing biofuel feedstocks on normal and designated croplands - degraded grassland is the only option for Argentinean soy, German wheat and rape, and US wheat in order to achieve the minimum reduction target of the RES-D. Nevertheless, we critically examined whether it is profitable, even with the degraded land bonus, to use such degraded land for commercial bioenergy use since degraded land is most likely to be less productive than normal cropland and requires investment costs 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. We showed how under the current arrangement the subsidy per hectare 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 arrangement should be changed into 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 bioenergy crop production.

Our results illustrate that the accounting for LUC in sustainability requirements for bioenergy production creates incentives to use cropland for bioenergy production and – as a consequence - to convert natural land or pasture for other agricultural uses such as food production. In other words, the current regulatory system taking LUCs into account minimizes direct LUC at the cost of increasing indirect LUC. At the same time, we have so far not come across a convincing proposal to implement indirect LUC into the LUC assessment of biofuels because of the underlying complex global land use dynamics. Instead, we propose subjecting all agricultural activities to a carbon accounting system. Hence, the burden of LUC would always be imposed upon the activity replacing the previous type of land use. Thus, all LUC would, by definition, be direct LUC. Unfortunately, the implementation of a global system of GHG accounting for all agricultural products still seems a long way off. However, in the meantime, the risk of ILUC through biofuels can be reduced by promoting high energy productive crops and biofuel feedstock production on degraded land.

Finally, it needs to be pointed out that the LUC as well as the ILUC problems of biofuel production need to be considered in the context of an increasing scarcity of the globally available land area with several competing uses. Especially the rising world population with an increasingly milk and meat intensive - and thus land intensive - diet will likely require an expansion of agricultural areas at the expense of other land uses. Erb et al. (2009) show that the bioenergy potential, the development of agricultural production technologies and the shift to a more vegetarian diet are closely interrelated with respect to their demand for fertile land. Thus, the land use change following an increasing biofuel feedstock production would be smaller the less area were needed for food and feed production which in turn depend on diets and the advance in agricultural productivity. Consequently the degree by which the European regulations aggravate the competition between food and fuel by promoting biofuels mainly from agricultural areas depends in the long term strongly on the development of global diets and investments in agricultural technologies.

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Notes

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[1] This threshold shall rise to 50% in 2017 and to 60% in 2018 for installations whose production will start from 2017 onwards (RES-D Art 17(2)).

[2] We concentrate our analysis on the data presented as default values in the EC Guidelines as this is the channel used to calculate LUC emissions without an individual carbon cycle assessment. The RES-D provides the option of relying totally or partly on individual calculations instead of using default values. However, we think that this will not be a common scenario due to the cost resulting from such an assessment.

[3] 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. The categorization in the inventory tables mainly follows the categorization used in the studies that the IPCC Guidelines 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.

[4] There are no default values for DOM (C^{DOM}) in the EC Guidelines. As it is usually of low significance for the whole carbon loss from LUC, it only has to be accounted for in continuously forested areas (EC Guidelines).

[5] The IPCC Guidelines contain a world climate map (IPCC 2006 Annex 3A.5) from which the climate zone in question can be derived.

[6] Information on typical natural forest biomass types in different world regions can be taken from a FAO world biomass map in the IPCC Guidelines (IPCC 2006 map 4.1). However, the categories used for the map are not fully consistent with the inventory table categories and, hence, can only serve as a general orientation.

[7] The EC excluded the “conversion” from cropland to cropland for annual crops from the LUC definition. This is reasonable with respect to the administrative burden of certification requirements but it will not account for the various impacts of tillage levels and manure inputs which can substantially change soil carbon contents. The EC provides the possibility of accounting for these

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effects if the producer can prove that there was an substantial impact on the soil carbon content due to a change in the above mentioned factors. This will obviously only be used for improvements in the carbon balance. Thus, in some cases the emission saving potential of the produced biofuel will be overestimated. An example of this is the change from a low tillage level to a high tillage level with a reduction of the manure input.

[8] normal grassland includes natural grassland with no trees and managed pasture land

[9] As mentioned before, this very high emission saving results, to some extent, from the assumption that palm oil cultivation accumulates carbon in the palm biomass.

[10] The distinction between „not specified“ and „methane capture“ for the palm oil production in Figure 4 as well as the distinction between „not specified“ and „straw CHP plant“ in Figure 3 result 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.

[11] 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 land because of less fertile soils. Hence, the actual emission savings of biofuel options produced on former degraded land could be much lower in reality. For further discussion see section 4.4.

[12] Fachagentur für Nachhaltige Rohstoffe: Agency for Renewable Resources of the German Federal Ministry of Food, Agriculture and Consumer Protection

[13] This might be the case if second generation biofuel that are more productive and less land intensive would become commercially available.

[14] The RES-D provides a relatively precise definition of degraded lands 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 when calculating LUC for degraded land according to the RES-D.

Appendix A

The following tables represent the assumptions underlying the examples in figure 1-4. They are based on the categorization in the EC Guidelines for land use categories and the RES-D for the production pathway emissions. For the categorization of the climate region and the soil type, the IPCC climate map and the FAO world soil map were used respectively. The examples were chosen so that they represent a typical production area in the regions. We deliver these tables in order to make clear that results might differ when other assumptions are made in categorizing a land area. This mainly refers to the assumptions made for the soil carbon factors concerning tillage practice and manure input.

Bioethanol options: Assumptions for Examples in Figure 1. and 3.

country	**crop**	**vegetation category**	**climate**	**soil**	**Biomass: land use before**	**Biomass: cropland**	**Soil:land use before**	**Soil: cropland**	**Bonus**
Brazil	sugarcane	rainforest	tropical wet	LAC	tropical rainforest >30%	sugarcane	no management	perrennial crop/ no tillage	no
		shifting cultivation mature fallow			tropical rainforest >30%		shifting cultivation / mature fallow		no
		shifting cultivation shortened fallow			tropical rainforest 10-30%		shifting cultivation / shortened fallow		no
		deciduous forest	tropical moist		tropical moist forest		no management		no
		steppe			subtropcial steppe 10-30%		no management		no
		scrubland			tropical scrubland		no management		no
		grassland normal			grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
Germany	sugarbeet	grassland normal	cool tempered moist	HAC	grassland	zero	normal managed/natural land	annual crop / full tillage	no
		grassland degraded			grassland		severely degraded		yes
	wheat not specified	grassland normal			grassland		normal managed/natural land	annual crop / full tillage	no
		grassland degraded			grassland		severely degraded		yes
	wheat straw CHP plant	grassland normal			grassland		normal managed/natural land	annual crop / full tillage	no
		grassland degraded			grassland		severely degraded		yes
	corn	grassland normal			grassland		normal managed/natural land	annual crop / full tillage	no
		grassland degraded			grassland		severely degraded		yes
US	corn	scrubland	subtropical	HAC	subtropical scrubland	zero	no management	annual crop / full tillage	no
		steppe			subtropical steppe 10-30%		no management		no
		grassland normal	warm tempered moist		grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
	wheat not specified	scrubland	subtropical		subtropical scrubland	zero	no management	annual crop / full tillage	no
		steppe			subtropical steppe 10-30%		no management		no
		grassland normal	warm tempered moist		grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
	wheat straw CHP plant	scrubland	subtropical		subtropical scrubland	zero	no management	annual crop/ full tillage	no
		steppe			subtropical steppe 10-30%		no management		no
		grassland normal	warm tempered moist		grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes

Biodiesel options: Assumptions for Examples in Figure 2. and 4.

country	**crop**	**vegetation category**	**climate**	**soil**	**Biomass: land use before**	**Biomass: cropland**	**Soil:land use before**	**Soil: cropland**	**Bonus**
Brazil	soy	rainforest	tropical wet	LAC	tropical rainforest >30%	zero	no management	annual crop/ no tillage	no
		shifting cultivation mature fallow			tropical rainforest >30%		shifting cultivation / mature fallow		no
		shifting cultivation shortened fallow			tropical rainforest 10-30%		shifting cultivation / shortened fallow		no
		deciduous forest	tropical moist		tropical moist forest		no management		no
		steppe			subtropcial steppe 10-30%		no management		no
		scrubland			tropical scrubland		no management		no
		grassland normal			grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
Argentina	soy	scrubland	warm tempered try	HAC	subtropical scrubland	zero	no management	annual crop/ no tillage	no
		steppe			subtropical steppe 10-30%		no management		no
		grassland normal			grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
Southeast Asia	palm not specified	rainforest	tropical wet	LAC	tropical rainforest >30%	palm plantation	no managment	perrennial crop/ no tillage	no
		shifting cultivation mature fallow			tropical rainforest >30%		no managment		no
		shifting cultivation shortened fallow			tropical rainforest 10-30%		no managment		no
		grassland normal			grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
	palm methane capture	rainforest			tropical rainforest >30%	palm plantation	no managment	perrennial crop/ no tillage	no
		shifting cultivation mature fallow			tropical rainforest >30%		no managment		no
		shifting cultivation shortened fallow			tropical rainforest 10-30%		no managment		no
		grassland normal			grassland		normal managed/natural land		no
		grassland degraded			grassland		severely degraded		yes
Germany	canola	grassland normal	cool tempered moist	HAC	grassland	zero	normal managed/natural land	annual crop / full tillage	no
		grassland degraded			grassland		severely degraded		yes