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EU Biofuel Policies in Practice – A Carbon Map for the Brazilian Cerrado

by Mareike Söder

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Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

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EU Biofuel Policies in Practice – A Carbon Map for the Brazilian Cerrado*

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Abstract:

It is still difficult for biofuel producers to prove the contribution of their biofuels to reducing carbon emissions because the production of biofuel feedstocks can cause land use change (LUC), which in turn causes carbon emissions. A carbon map can serve as a basis to prove such contribution. I show how to calculate a carbon map according to the sustainability requirements for biofuel production adopted by the European Commission (EU-RED) for the Brazilian Cerrado. Based on the carbon map and the carbon balance of the production process I derive maps showing the possible emission savings that would be generated by biofuels based on soy and sugarcane if an area were to be converted to produce feedstock for this biofuel options. I evaluate these maps according to the criterion contained in the EU-RED of 35% minimum emission savings for each biofuel option compared to its fossil alternative. In addition, to avoid indirect LUC effects of the EU-RED that might offset any contribution of biofuels to reducing carbon emissions. I argue that all agricultural production should be subject to a carbon assessment. In this effort, the calculated carbon maps can be the basis for a climate friendly land use planning that is binding for all agricultural production in the Cerrado.

Keywords: biofuels, carbon emissions, Renewable Energy directive, carbon map, land use change, Brazil

JEL classification: Q42, Q58, Q56, Q16

Mareike Lange
Kiel Institute for the World Economy
24100 Kiel, Germany
Telephone: +49(0)431-8814-461
E-mail: Mareike.lange @ifw-kiel.de

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1. Introduction

Brazil is the second largest producer of fuel ethanol in the World and therefore a key producer for the European Commission´s (EC) strategy to replace fossil fuels by biofuels in the transport sector. On the one hand, this promotion of biofuels has been widely criticized. Due to an increase in biomass demand for feedstocks for biofuel production and a continuously high demand for feedstocks in the food and feed sector, the demand for agricultural land is expected to increase globally and particularly in Brazil (Erb et al. 2009, Hertel et al. 2008, Haberl et al. 2011). Meeting this demand causes emissions from LUC that contribute approximately 9% to global emissions (Global Carbon Project 2011). Thus, it is questionable whether using biofuels can reduce emissions as long as there are any emissions from LUC.

On the other hand, biofuels are considered to be especially important for reducing the dependency of the transport sector on fossil fuel and for decarbonizing the fuel it uses. Through its biofuel sustainability regulation (EU-RED), the EC seeks to achieve a minimum target of 10% renewables in the transport sector by 2020 (EU-RED 2009). The EU-RED was supplemented by a regulation stipulating a mandatory reduction of 6% in the emission intensity of fuels used in transport (European Union 2009) to emphasize the aim to reduce greenhouse gas emissions (emissions). According to the national renewable energy action plans biofuels will account for 90% of the mandated target of 10% renewables in the transport sector (EC 2011).

To ensure that biofuels contribute to a reduction in emissions and that biofuels are sustainably produced, the EU-RED contains a sustainability regulation in order to avoid undesirable LUCs caused by expanding biofuel feedstock production. These undesirable LUCs can be divided into direct land use change (DLUC) and indirect land use change (ILUC). DLUC is the conversion of land that has not been cultivated before, into land used to produce a particular biofuel feedstock. ILUC is an external effect of the promotion of biofuels. This effect is caused by changes in prices for agricultural products on the world market, particularly food and feed products in the form of grains and oils. The cropland used to produce food and feed is reduced globally when the cropland is used to produce biofuel feedstock instead. Consequently, the supply of food and feed products on world markets is reduced, which drives up their prices, which in turn creates an incentive to convert new land to produce food and feed.

Regarding DLUC, the EU-RED stipulates that, in order to be counted towards the 10% target imposed on the mineral oil industry, biofuel feedstocks may not be produced on land with high carbon stocks such as continuous forests or peatlands, or on land with high biodiversity.

In addition, in order to assure that biofuels reduce emissions even when they cause emissions from DLUC, the EU-RED stipulates a mandatory minimum emission saving threshold. To account for possible emissions from DLUC and emissions from production and transportation until the final use of the biofuel, it has to be proved that each biofuel will provide emission savings of at least 35% compared to the fossil fuel alternatives

The EC implemented the EU-RED by adapting 13 certification schemes [1]aimed at verifying compliance with the sustainability criteria set out in the EU-RED, including those regarding DLUC. Within the certification process it is possible to account for possible emissions from DLUC as they can be directly linked to a particular biofuel production, and can thus be allocated to the specific emission balance of the biofuel at hand.

In practice, the main problem for producers to verify compliance with the sustainability criteria is to account for possible emission from DLUC because the land use at the beginning of 2008 must be known. This is because 2008 is the reference year to calculate emissions from DLUC. Thus, for an individual accounting of emissions from DLUC, the producer needs a land cover and carbon map of 2008 of the cultivation area used to produce the feedstock to be potentially certified. A carbon map displays the carbon stocks stored in the biomass and soil of different land covers. Such maps are often not available, particularly in remote areas. This increases the cost of the certification process for the individual producer as the land cover and carbon stock of 2008 would need to be determined in an individual assessment. This can be an exclusionary burden for small producers.

A carbon map according to the EU-RED criteria for production regions could overcome this problem. The use of maps that determine carbon stored in natural vegetation has already become the common tool for countries preparing for the UNFCCC (United Nations Framework Convention on Climate Change) REDD+ (Reduced Emissions from Deforestation and Degradation) mechanism that aims to pay developing countries to halt their deforestation (Gibbs et al. 2007) Such maps could be used to determine a baseline for the payments and to monitor deforestation over time. Two examples of global above ground carbon maps can be found in Saatchi et al. 2011 and Baccini et al. 2012. Due to their different purposes, maps produced for REDD+ cannot be used here as they focus only on determining carbon in forests. Large areas for biofuel feedstock production are located in regions of natural grassland and shrubland such as the Cerrado in Brazil, the Chaco in Argentina or the Llanos in Colombia. In addition, these maps aim at determining forest carbon dynamics, do not necessarily start at the baseline year 2008 for biofuels and do not necessarily have a spatial resolution of 30 meters as required by the EC.

In this paper I calculate a carbon map for the Cerrado in Brazil that is in line with the EU-RED requirements and show how it could be used to control compliance with the EU-RED criteria. Based on this results, I discuss how far the generated carbon maps can help reduce emissions from land use change in general. This is in line with the claim of researchers that land use change emissions cannot be controlled for biofuels alone but need to be controlled for all agricultural production in order to

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[1] ISCC, Bonsucro EU, RTRS EU RED, RSB EU RED, 2BSvs, RBSA, Greenenergy, Ensus, Red Tractor, SQC, Red Cert, NTA 8080, RSPO RED, Biograce GHG calculation tool

avoid ILUC effects. Thus, the problem of ILUC regulation is only a problem of an incomplete emission accounting of land use practices when only biofuel production is subject to such accounting, while food, feed and bioenergy production other than biofuel production are omitted (see also Lange 2011, Lange and Delzeit 2012).

The necessity for reducing land use change is especially urgent for the study region Cerrado. The Cerrado in the Central West of Brazil has become the fastest developing agricultural region in Brazil. In its southeast the Cerrado is the expansion area for the continuously increasing sugar cane production and in its northeast and central large areas were converted for soy bean production. With these two important biofuel feedstocks, the Brazilian Cerrado can be a key area for the European Biofuel market. At the same time, the Cerrado is the most diverse tropical savannah in the World, particularly with a mammal and bird fauna. In addition, even though not achieving the carbon stocks as contained in tropical forests, savannahs such as the Cerrado play an important role as carbon sinks.

Grasslands and savannas like the Cerrado– with their below-ground carbon storage, seasonal burning, regrowth and treegrass dynamics – are major players in the global carbon cycle. Although carbon stocks, productivities and turnover times are subject to considerable uncertainty, grassland soil carbon stocks amount to 10-30% of world soil carbon and the annual carbon sink is estimated of being around 0.5±2 giga tonne carbon per annum (Scurlock and Hall 1998).

The rest of the paper is structured as follows: I begin by briefly presenting the method and data requirements to calculate land use change emissions in the EU-RED context which draws on the method in the IPCC 2006. Next, I present the database for my calculation of the carbon mapping and then present the resulting carbon maps. I then evaluate the carbon maps with the EU-RED criteria for biofuels Finally, I discuss the usefulness of the generated carbon maps for reducing emissions from land use change in the Cerrado and draw conclusions.

2. EU-RED sustainability requirements and land use change calculation

To first understand which criteria a carbon map for the EU-RED needs to fulfil, in this section I shortly discuss the entire range of sustainability requirements for EU-RED beyond carbon. These sustainability requirements mainly tackle the problem of possible DLUC to produce feedstocks for biofuel production. Under this framework, which is shown systematically in figure 1, biofuels and bioloquids shall not be made from raw material obtained from land with high biodiversity value (primary forest and other wood land; areas designated for nature protection or protection of rare, threatened, endangered ecosystem or species; and highly biodiverse grasslands), lands with high carbon stocks (wetlands, continuously forested areas with a canopy cover higher than 30%[2], and land spanning more than one hectare with trees higher than five meters and canopy cover of between 10%

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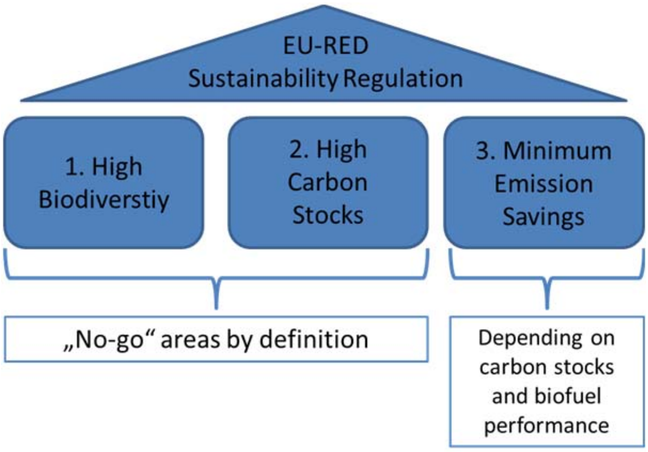
[2] This corresponds to the upper level of canopy cover of the forest definition in UNFCCC (2001)

and 30%, unless evidence is provided that the carbon stock before and after conversion saves greenhouse gas emission at least at 35% (EU-RED Art.17(3,4)).

For all other production areas, accounting for possible emissions from DLUC and production and transportation emission, it has to be proved that the resulting biofuel will provide emission savings of at least 35% compared to the fossil fuel alternatives (EU-RED Art 17(2))(third column of Figure 1) .This implies that biofuel crops produced on land with high carbon content before the land use change are less likely to achieve this target as well as biofuels with low energy yields per hectare and high process emissions. This minimum emission saving threshold will be increased to 50% in 2017 and 60% in 2018 for new installations for biofuel production (EU-RED 2009).

These sustainability requirements need to be met by both imported bioliquids and bioliquids produced within the European Union in order to count towards the national targets of renewable energy.

Figure 1. Framework of the EU-RED sustainability regulation



This paper focuses on the third column of the sustainability criteria which includes all areas which are not already excluded by definition from being suitable for biofuel production. However, as far as possible, areas falling under column 1 and 2 are included into the final maps in order to get the full picture. Thus, the major challenge of this paper is to provide a good measure of potential DLUC emissions that would occur if an area where to be converted for biofuel feedstock production. This measurement is based on the carbon map. According to the EU-RED, the method and data used for the calculation of emissions from DLUC should be based on the IPCC Guidelines for National Greenhouse Gas Inventories – Volume 4 (IPCC 2006) and should be easy to use in practice (EU-RED Annex V C(10)). With the “Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories” Carré et al. 2010 published guidelines for the calculation of land carbon stocks for the purpose of Annex V of the EU-RED.

3. Carbon Mapping according to the EU-RED for the Cerrado

In this section I demonstrate the method of the EU-RED for calculating carbon emissions from land use change as presented in Carré et al. 2010. I only go into the details of Carré et al. 2010 where it is relevant for our purpose. After each major calculation step I present the data I used for the carbon mapping in the Cerrado.

For the calculation of a carbon stock (CS_{il}) per unit area i associated with a particular land use l, the carbon stock stored in the soil $(SOCact_{il})$ and the carbon stock stored in biomass $(Cbio_{il})$ need to be summarized and multiplied with the hectares per unit area (A_i). [3]

$$CS_{il} = (SOCact_{il} + Cbio_{il}) \times A_i \qquad (1)$$

a. Biomass Carbon

I. Method

For the calculation of carbon stock stored in biomass $(Cbio_{il})$ it is assumed that it can be subdivided into carbon stock stored in above ground biomass (C_{AGB}), below ground biomass (C_{BGB}) and dead organic matter (C_{DOM})[4]. The carbon stock stored in below ground biomass is normally calculated by applying a constant ratio factor (R) to the carbon stock stored in above ground biomass.

$$Cbio_{il} = C_{AGB} + C_{BGB} + C_{DOM} \qquad (2)$$

$$C_{BGB} = C_{AGB} \times R \qquad (3)$$

II. Data

Different methods are available for the calculation of the carbon stock stored in biomass. The very basic method for a producer is to produce ground based inventory data of the land cover classes present on their land. The carbon values could be determined by field surveys on the diameter at breast height which along with information on tree height can be converted to estimates of forest carbon stocks using allometric relationships (Wertz-Kanounnikoff 2008). Data on the allometric relationship can be based on data from sample sites or forest inventories (Wertz-Kanounnikoff 2008). However, this method seems like a disproportional burden particularly for small producers. In addition, to determine land use change emissions, the land cover in 2008 is the reference land cover. If there have been land cover changes in between, it might be difficult to retrace the land cover in 2008.

The most commonly used method to derive an above and below ground biomass carbon map is to use land cover maps based on a classification of the spectral signature derived from satellite images and to combine them with carbon values that represent the biome-average carbon value. This method

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[3] Normally one uses one hectare as the unit area. However, it could be every other area like the area of a pixel if the analysis is made on the basis of a raster data set.

[4] In line with the EU-Red we use a value of 0 for C_DOM, except in the case of forest land – excluding forest plantations – having more than 30% canopy cover.

corresponds with the Tier 1 method of the IPCC. The EC adopts this method presenting carbon values for the purpose of calculating emissions from LUC in Carré *et al.* 2010. Other data sources is the scientific literature on carbon values generated on sample sites. A major drawback of this method is that the biome average analyzed in the scientific literature does not necessarily adequately represent biome or region and may overestimate the carbon stored in premature stands (Gibbs et al. 2007, Wertz-Kanounnikoff 2008, Goetz et al. 2009)

There has been a fast development of techniques to determine above ground biomass carbon in particular for tropical forests via satellite or aircraft based remote sensing techniques based on active signals such as Synthetic Aperture Radar technologies (SAR) and or Light Detection and Ranging (LIDAR) (Engelhart et al. 2011). The signal of SAR penetrates through clouds and returns the ground terrain as well as the level of the top of the canopy cover which in turn gives the basis for deriving the height of the biomass cover. Thus, SAR provides a 2 dimensional image of the ground. If slightly different angles are used, this 2D image can be converted into a 3D image. The knowledge about typical biomass heights of different land covers can then be used to derive a land cover map (Mette et al 2003, Kellndorfer et al, 2004, Shimada et al 2005). Recent applications to tropical forest can be found e.g. in Gama et al. 2010, Engelhart et al. 2011, Kuplich et al. 2005, Michard et al. 2009, Pandey et al. 2010 or Santos et al. 2006

Instead of using radar signals, the Light Detection and Ranging (LIDAR) method uses pulses of laser light and analyses the signal return time (Engelhart et al. 2011). This method cannot penetrate through clouds but allows estimating the height and density of the biomass cover resulting in a detailed 3D image (Patenaude et al 2004). The biomass density and height is linked to biomasses and thus the 3D image can be converted into above ground carbon estimates applying allometric height–carbon relationships (Hese et al 2005). Recent application for tropical forest can be found e.g. in Saatchi et al 2011, Duncanson et al. 2010 or Zao et al. 2009.

The purpose of this paper is not to evaluate the different methods but to demonstrate the use of the available data and maps for the sustainability regulation of the EU-RED[5] in the study region. Therefore, I use a detailed land-cover map with the biome average carbon value approach.(Figure 1). The land cover map was generated by WWF Brazil based on several geographic datasets available for the Cerrado. The first of the two most important sources for this mapping process was the governmental project PROBIO from the Environmental Ministry MMA– (Project for the Conservation and Sustainable Use of the Brazilian Biologic Diversity). The second fundamental data source used by WWF Brazil to update the map to 2008 was the governmental Project for the Satellite-based Monitoring of the Brazilian Biomes Deforestation (PMDBBS) executed by the Brazilian Institute for the Environment (IBAMA). A detailed description of the mapping process can be found in the related

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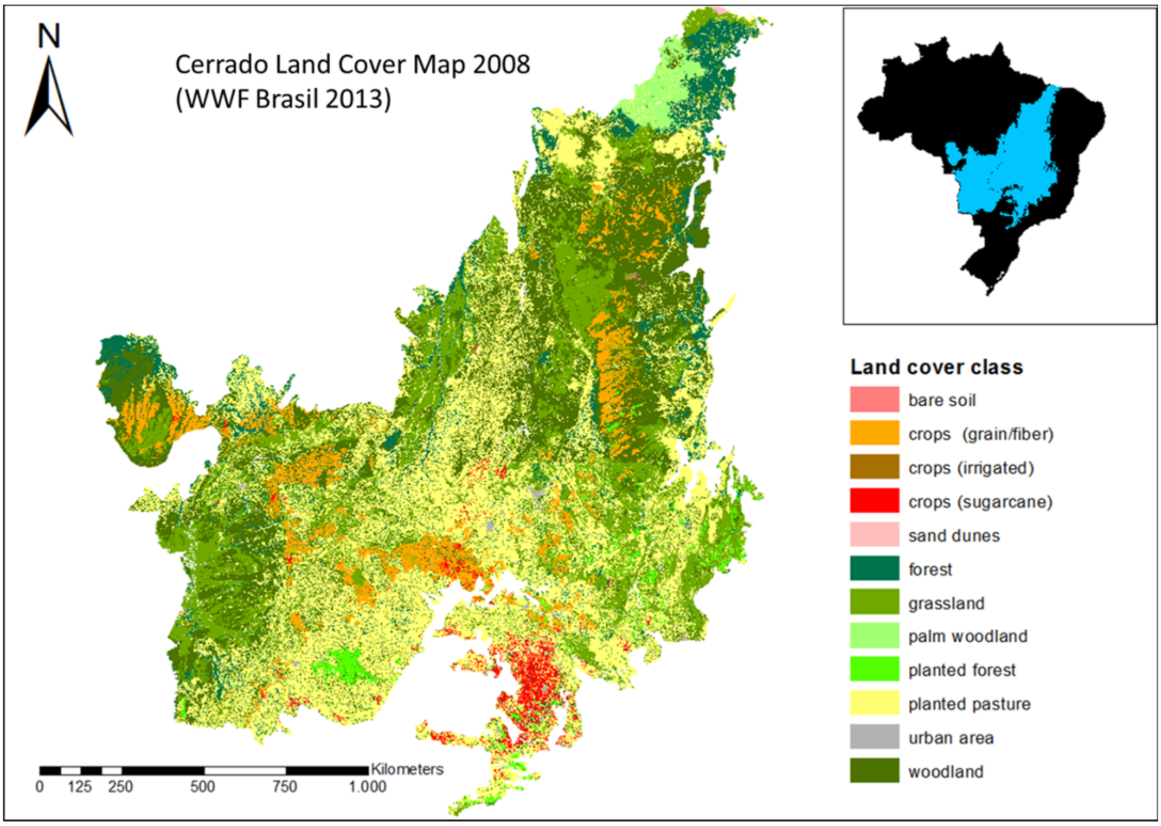
[5] A comparison of different methods can be found in Goetz et al. 2009 or Wertz-Kanounnikoff 2008

report on the Cerrado land cover mapping for the Sulu Project conducted by WWF Brazil (WWF Brazil 2013)

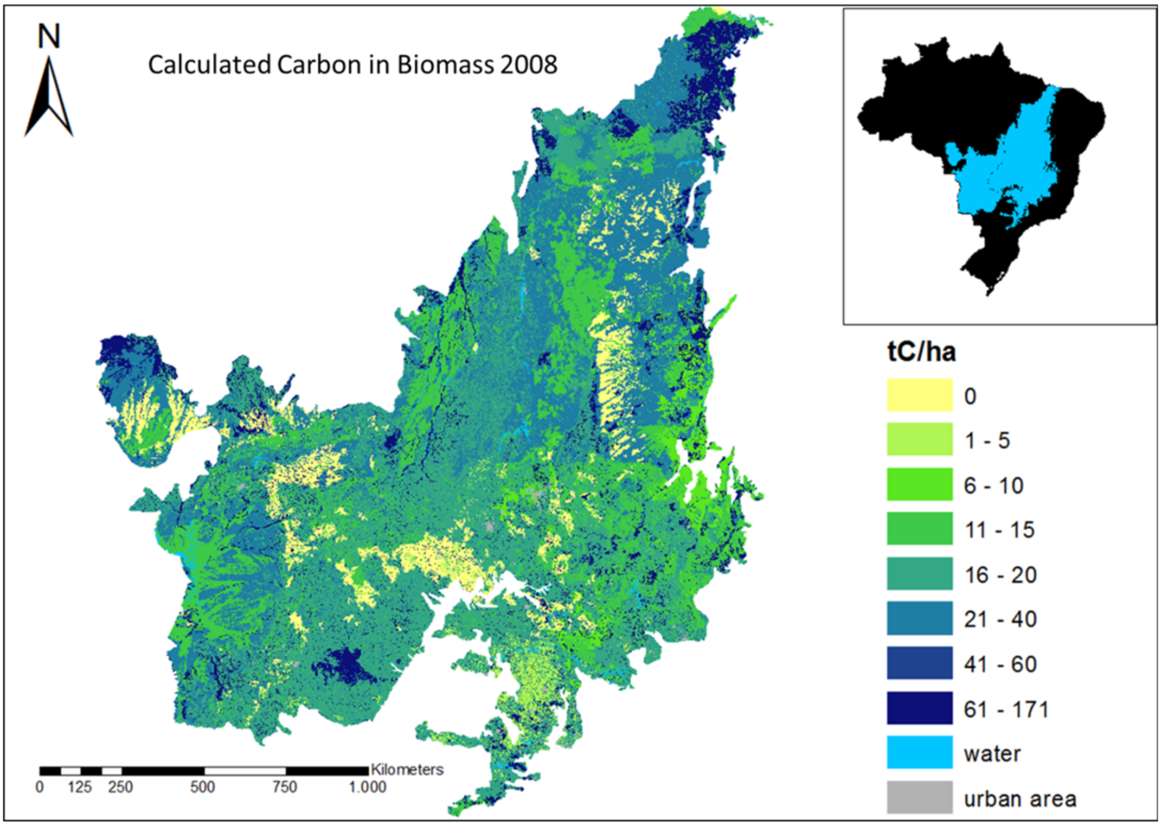
Figure 1



The use of this land cover map is appropriate here as a classification of land cover provides sufficient information to calculate GHG emission savings as required by the EU-RED. This differs from REDD+ projects which require explicit determination of the carbon stored in the biomass of forest to determine a baseline for the payments for ecosystem service mechanism. Lidar and Radar are better equipped to provide the necessary information on changes in carbon stocks within forest, the relevant land cover class for REDD+. Therefore, there is also a cost benefit in the choice of the method as Landsat and others optical sensors are cheaper than LIDAR or SAR technology. Last but not least, the impact of a derived carbon map strongly depends on the acceptance of policy makers and producers in the country. The land cover map from WWF Brazil uses only officially recognized sources which is important to feed in results into the political process. The land cover map is shown in Figure 1.

To convert the land cover map into a map that displays the carbon stock stored in above and below ground biomass, the values for carbon stock stored in above and below ground biomass associated values from previous research for carbon storage in above and below ground biomass were interpolated into each land cover class. All values could have been taken from Carré et al. 2010 or the IPCC 2006, however, these carbon values do not always correspond one to one to the land cover classes in the map. Furthermore, Carré et al. 2010 or the IPCC (2006) values are, if at all, only specified for South America in general and not specific for the Cerrado. Specific values were used for below ground biomass where they were available. The exact values used in the calculation and the respective sources are listed in the data tables of ANNEX 1. For some of the carbon values taken from Carré et al. 2010 or the IPCC 2006, the climate zone of the area must be known. For this purpose, I used the climate zone map provided by the Joint Research Centre (EC-JRC 2010).

Figure 2



The resulting map on carbon stocks stored in total biomass is shown in Figure 2. One can clearly determine the difference between the large carbon stocks in the remaining natural forest areas and the very low carbon stocks in the already cleared and used areas of the Cerrado.

b. Soil Carbon

I. Method

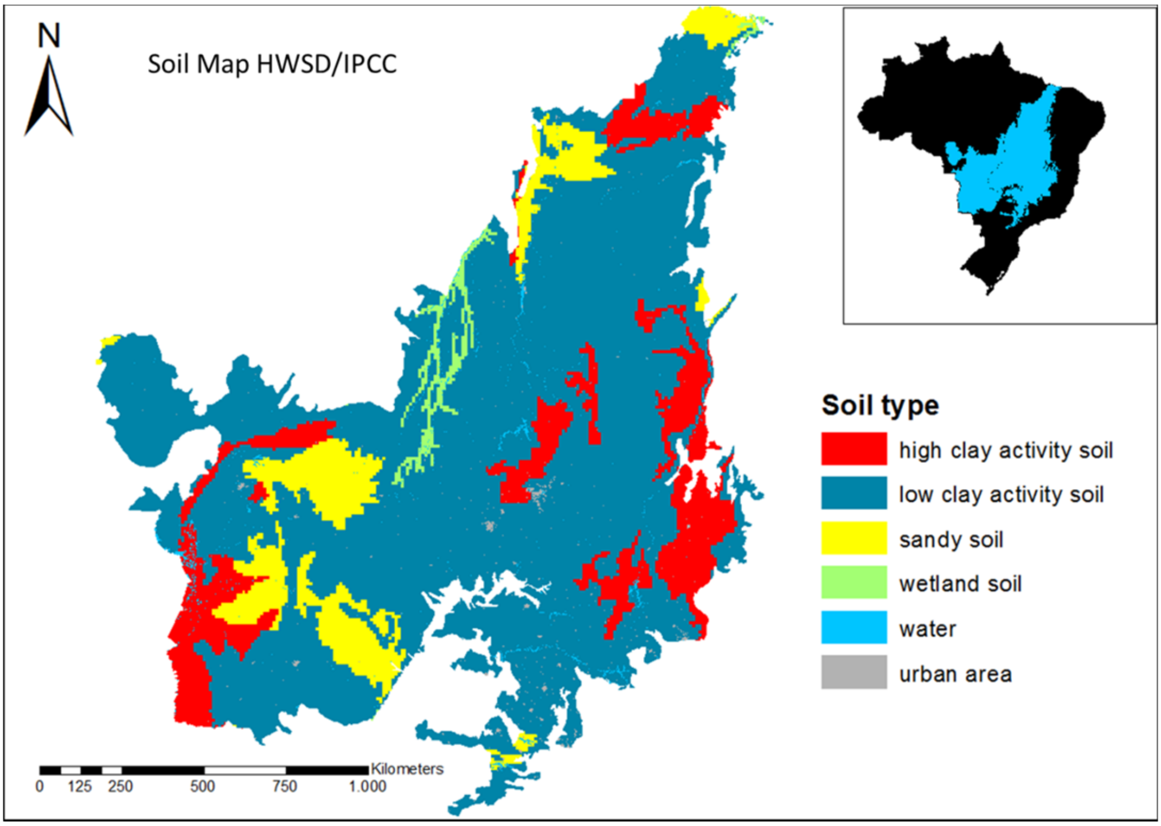
Carbon stored in the soil concerns the stock of carbon in the soil that is not part of the living biomass, which means all carbon apart from living roots. For the calculation of the carbon stock stored in the soil, information of the land cover map needs to be combined with a soil map. This is because the carbon stock stored in the soil under natural vegetation is changed once the land is used for agricultural production. Soil maps are commonly provided by national institutions as they cannot be derived directly from remote sensing methods. Here, I only consider the Tier 1 approach of the IPCC 2006 which models soil carbon stocks influenced by climate, soil type, land use, management practices and inputs. The method is based on the assumption that the actual carbon stock stored in the soil ($SOCact_{il}$) is the product of the carbon stock under natural land cover ($SOCref_i$) and the influence of land use (Flu_l), management (Fmg_l) and input factors (Fi_l), which can increase or decrease the carbon content under natural land cover.[6] Thus, the working steps to be done for the calculation of a soil carbon map is to first choose a suitable soil map, second, allocate the carbon values for soil under natural land cover to the soil categories in the map and, third, define and allocate the influence factors from the IPCC 2006 based on the land cover map (see equation 4).

$$SOCact_{il}\left(\frac{tC}{ha}\right) = SOCref_i\left(\frac{tC}{ha}\right) \times Flu_l \times Fmg_l \times Fi_l \qquad (4)$$

II. Data

The EC provides a soil map based on the FAO harmonized world soil database (HWSD) generated by IIASA (FAO/IIASA/ISRIC/ISSCAS/JRC, (2012). (see figure 3)

Figure 3



As a first step I generate a map of soil carbon as if the whole area where under natural land cover by combining the SOCref carbon values with the HWSD soil map. The SOCref carbon values corresponding to the soil map categories are taken from the EU Guidelines which draw on the data in IPCC 2006.

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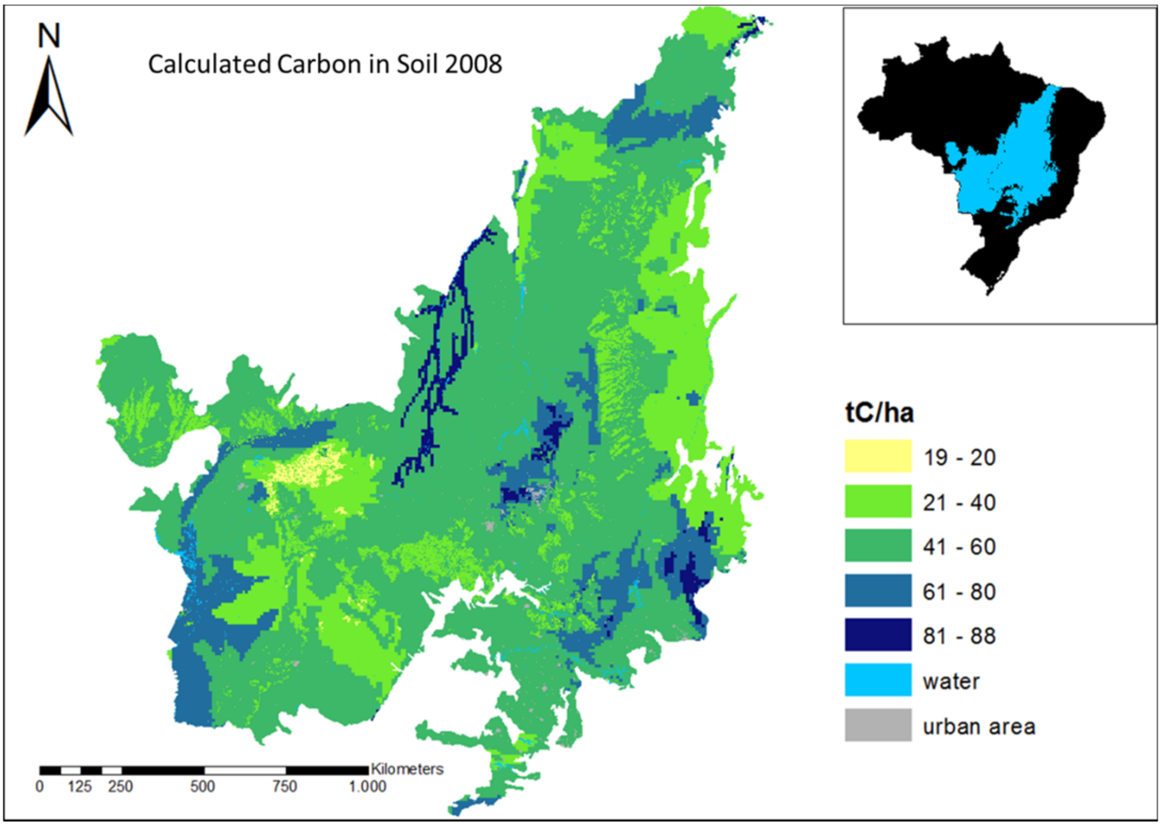
[6] The EU Background Guide gives more details and data about land cover classes not explicitly covered by the IPCC 2006 e.g. savannahs and degraded land.

As a second step, to determine the actual carbon stock stored in the soil, the carbon stock under natural land cover must be adjusted with the soil use factors that correspond to the current (2008) land use. For natural land cover these factors are a constant value of 1. Thus, the soil carbon under natural vegetation remains the same after this calculation step. For all other land use with non-natural land cover, these factors indicate how much the land use type, the management practice and the inputs change the carbon stock stored in the soil compared to a natural land cover (see equation 4).

Figure 4

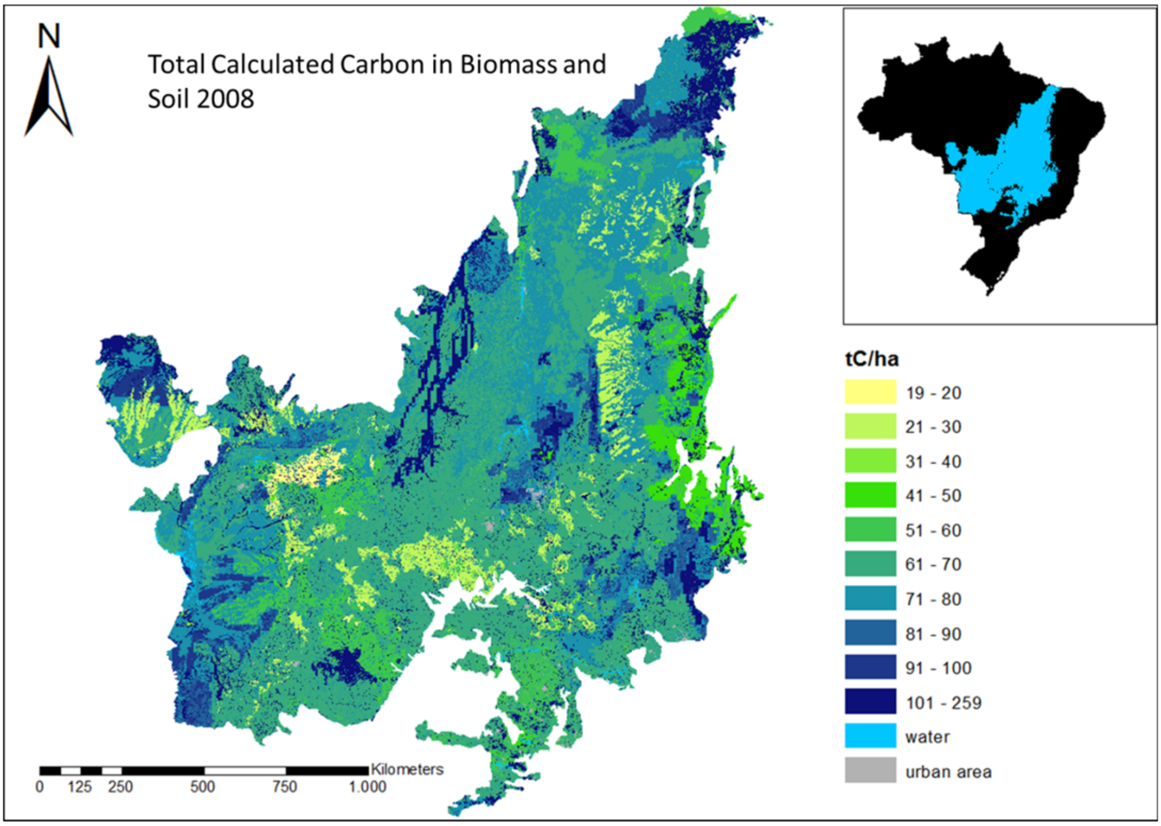


The categories for the land use type factor are annual cropland, perennial cropland, pasture or forest plantations. The categories for the management factor mainly account for the tillage regime and the input factor account for the amount of fertilizer/manure applied to the production. In order to determine which of these factors apply, I use the land cover map. I do this by defining for each land cover category the land use factor, the typical management regime applied for a particular land use in the region and the corresponding typical input. The corresponding values for the factors are exclusively taken from the EU/RED and the IPCC 2006. Thus, to determine the actual carbon stock stored in the soil ($SOCact_{il}$) I multiply the SOCref calculated in the first step with these soil factors according to equation 4. The resulting soil carbon map (actual soil carbon stocks SOCact) is shown in figure 4.

c. Total Carbon Map

I calculate the final carbon map by overlaying and summarizing the map for carbon stocks stored in total above and below ground biomass and the map about actual carbon stocks stored in the soil. The result is a carbon map which indicates the high and low carbon stock areas in a region. Figure 5 shows this map for the Cerrado. Results mainly mirror the results of the carbon maps of only the biomass cover at a higher level as there are no major peatland soils. This results in very high carbon stocks in the forest areas and low carbon stocks in the areas already used for agricultural production.

Figure 5



4. Sustainable production areas under the EU-RED emission saving requirements

This section evaluates the carbon maps with respect to the sustainability regulation concerning carbon emissions of sugarcane and soy based biofuel production in the EU-RED. For the practical implementation of the EU-RED, a further step of calculation is necessary. To prove the compliance with the 35% emission saving threshold, the emission savings for each spatial unit that would occur if converted into cropland to produced biofuel feedstock needs to be calculated. Thus, I calculate the emission savings of each spatial unit if this unit were converted into a sugarcane or soy field for biofuel production. Emission savings represent average annual savings for a production period of 20 years.[7]

a. Calculation Steps

For the calculation, first, the emission caused by the land use change (LUC_i) needs to be calculated by taking the difference of the carbon stocks stored in the land use at t0 ($CS_{i_{before}}$) (which is 2008 for the current regulation) and the carbon stocks stored in the land use at t1 (which is the after the land use change). For our purpose, t1 represents the carbon stock stored in sugarcane or soy ($CS_{i\_biofuel\_feedstock}$). The carbon stock of sugar cane is assumed to be positive because it is a perennial crop which is not harvested every year. Soy requires an annual and wholesale removal of all biomass and thus $CS_{i\_biofuel\_feedstock}$ is zero for soy.

$$LUC_i = CS_{i_{before}} \; - \; CS_{i_{biofuel_{feedstock}}} \qquad (5)$$

I derive ($CS_{i\_biofuel\_feedstock}$) by repeating all calculations steps under the assumption that all areas are under soy or sugarcane production.

Figure 6 shows the result of this calculation step for sugarcane production in the Cerrado. Figure 7 shows the same for soy production respectfully. Thus figure 6 and 7 show the potential LUC emissions in ton carbon per hectare if converted into sugarcane or soy production. Areas colored in blue would generate zero LUC emissions or even a gain in carbon storage when converted into sugarcane or soy production. All other areas result in carbon emissions. Thus, the conversion of these areas into a sugar cane (soy) field would generate a carbon debt. Figure 6 and 7 show that both crops would generate zero or negative LUC emissions on areas already used for crop production. The conversion of all other areas for crop production results in a carbon debt which is particularly high in forested areas. However, the debt resulting from conversion into soy production is higher than from conversion into sugarcane production.

Figure 6

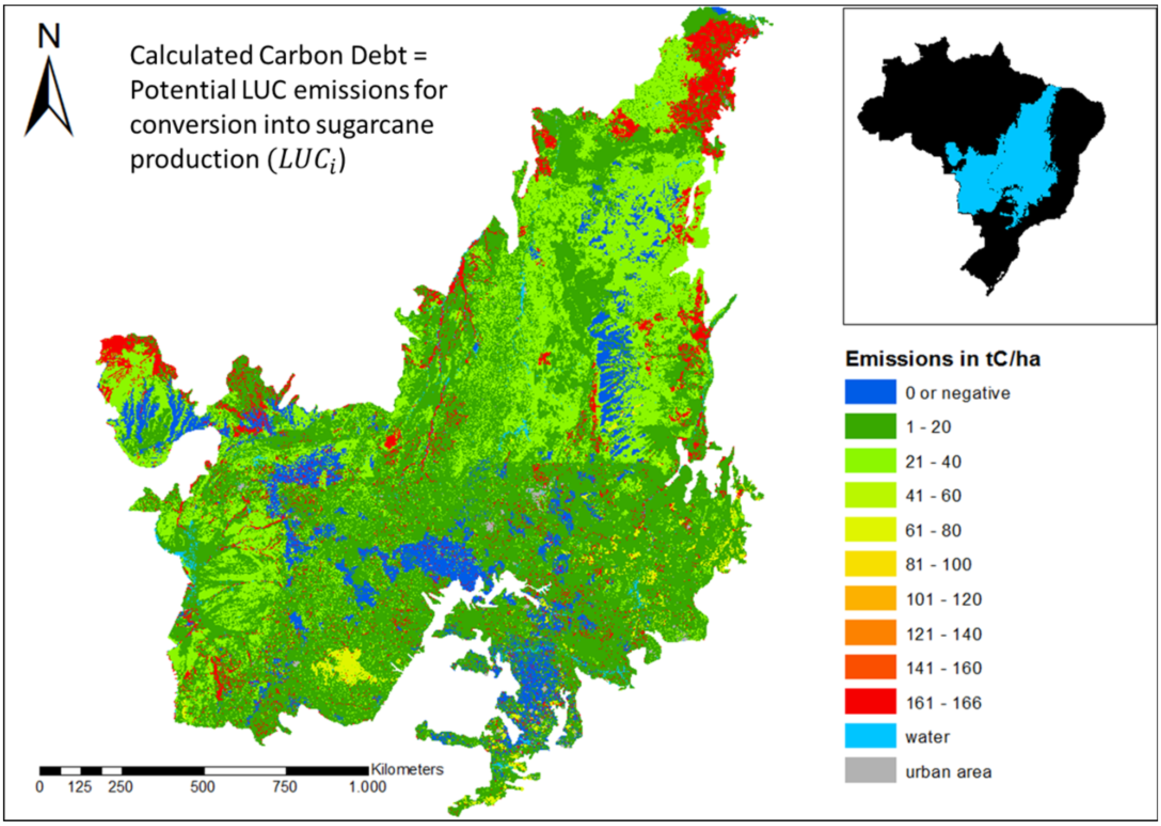
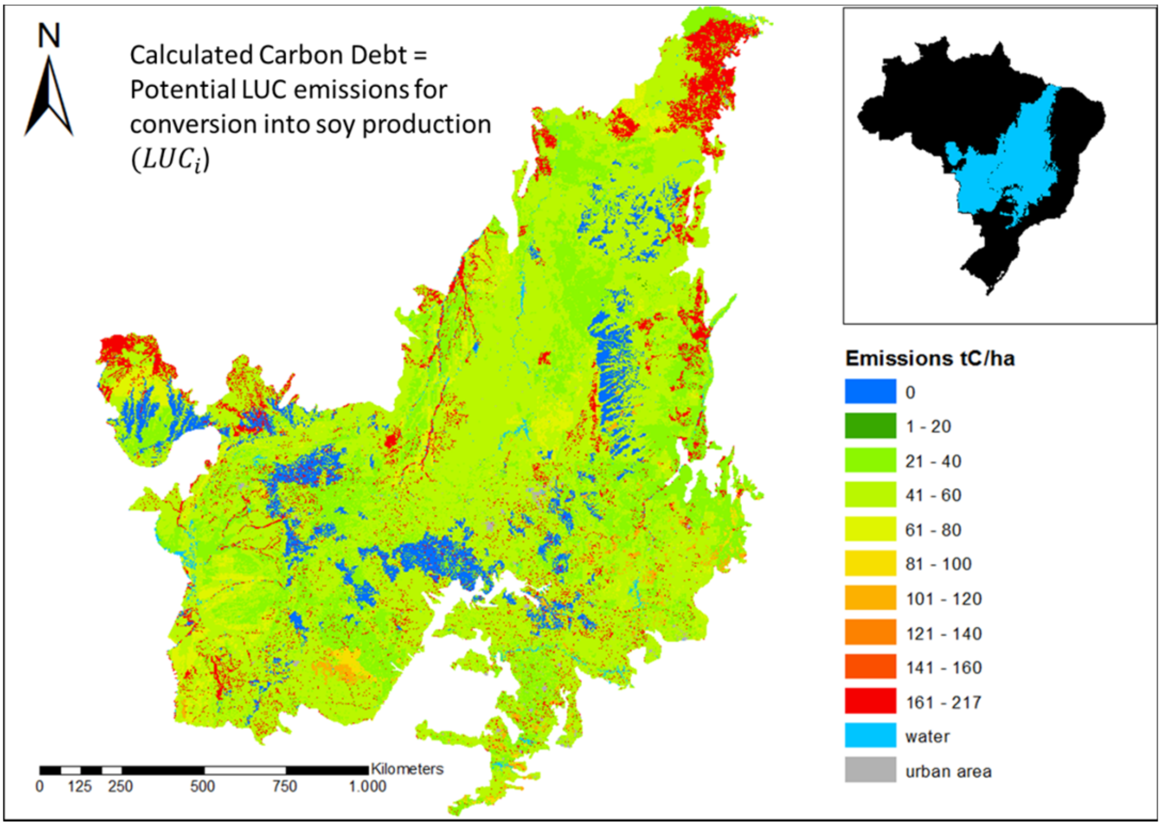


Figure 7



Second, I convert the total emissions caused by the land use change (LUC_i) into emissions per year on the basis of a 20 year period and convert carbon stocks into carbon dioxide stocks by multiplying the former by the factor 3.664 (IPCC 2006). Third, I convert the LUC emissions per hectare into LUC emissions of the final biofuel unit (LUC_{mj_i}). Thus, I divide the LUC emissions per hectare with the energy yield per hectare of the biofuel feedstock (P_i).[8] Consequently, the resulting LUC emissions per mega joule (MJ) biofuel (LUC_{mj_i}) are specific for each biofuel due to the specific energy yield per hectare. Higher energy yields result in fewer emissions per MJ biofuel.[9]

$$LUC_{mj_i}\frac{CO_2}{MJ} = LUC_i\frac{C}{ha} * 3.664 * \frac{1}{20} * \frac{1000000}{P_i\frac{MJ}{ha}} * AL_i \qquad (6)$$

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. The allocation factor (AL) should be calculated on the basis of the energy content, that is, the lower heating value. This means that for example from the soy bean, only the oil is used for biodiesel production. The remaining soy cake is mainly used as animal feed. Consequently both the soy cake and the soy oil are evaluated with their lower heating values. Then, land use and production pathway emissions are allocated to the emissions caused by the soy biodiesel in the same proportion as the proportion of the soy oil on the total lower heating value of the harvested soy bean. Equation 6 summarizes these calculation steps.

Table 1. Assumptions on Production Process and Yield

	$P_i\frac{MJ}{ha}$	Source	AL_i	Source	WTW_i gCO$_{2eq}$/MJ	Source
Sugar cane ethanol	134 363	FNR (2012)	1	IES 2008	24	EU-RED
Soy bean biodiesel	20 896	FNR (2012)	0.32	IES 2008	58	EU-RED

As a last step, I calculate emission savings (ES_i). Emission savings mean savings generated due to the use of biofuel feedstock compared to the alternative use of fossil fuels. The term “emission savings” used by the EU-RED is slightly misleading as it does not indicate that every biofuel saves emissions. Emission savings could be also negative if the production and use of the biofuel causes higher emissions than the fossil fuel alternative. With respect to land use change emissions, one can generally say that high land use change emissions due to high carbon stocks before the land use change result in low or negative emission savings. To calculate the emissions savings one has to add to the land use

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[8] I only assume one yield per crop here as yields are relatively harmonized across the production areas in contrast to large differences in productivity e.g. in palm production in Indonesia.

[9] I assume no production on degraded land and thus ignore a possible emission bonus granted by the EU-RED for emission savings.

change emissions LUC_{mj_i} the emissions caused in the production process (WTW_i). These emissions include all emissions from well-to-wheel (WTW), meaning all emissions from the production of the feedstock until the transportation of the biofuel to the gas station. The total resulting emissions are then compared to 83.8gCO2/MJ emissions the fossil fuel alternative and emission savings are derived in %. These calculation steps are summarized in equation 7.

As the energy yield per hectare ($P_i \frac{MJ}{ha}$), the emission caused in the production process (WTW_i) or the fraction of the biomass that is allocated to the biofuel production are specific for each biofuel option (AL_i), emission savings are also specific for each biofuel option(see Table1 for the values used for equation 6 and 7 in the carbon maps). I use the default values for production emission (WTW_i) from the EU-RED for different biofuel production pathways and take average values for energy yields from FNR (2012). I consider an allocation factor (AL_i) for the main co-products according to their heating value[10] based on EU-JRC Data (IES 2008).

$$ES_i\% = \frac{100}{83.8} * \left[83.8 - \left(LUC_{mj_i} + WTW_i\right)\right] \qquad (7)$$

b. Results

I calculate the emission savings of sugar cane based ethanol and for soy based biodiesel.

In terms of the minimum emission saving threshold, it is allowed to use and convert land when the final biofuel option does not cause less than 35% emission savings. Thus, according to the EU-RED, all areas that result in 35% or more emission savings would be potentially eligible for certification with respect to carbon emissions when converted for biofuel production. However, I do not consider biodiversity or other sustainability criteria here and consequently do not call these areas “go-areas”. As the minimum emission savings threshold is about to rise to 50% for new installations from 2017[11] on, and to 60% in 2018 for installations built after 2017, I also indicate these thresholds in the maps. Figure 7 and 8 show the emission saving maps for the Cerrado and sugarcane and soy production. All green areas are sustainable production areas under the minimum emission saving criterion. Based on the total carbon map derived above, it is only logical that areas with high carbon stocks are less likely to achieve the 35% minimum emission saving threshold than areas with low carbon stocks.

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[10] The lower heating value is used as an indicator for the heating energy contained in a fossil fuel or organic material. The EC decided to use this value as a unit to base on the allocation of emission on different co-products.

[11] The threshold might be increased already in 2014.

Figure 8

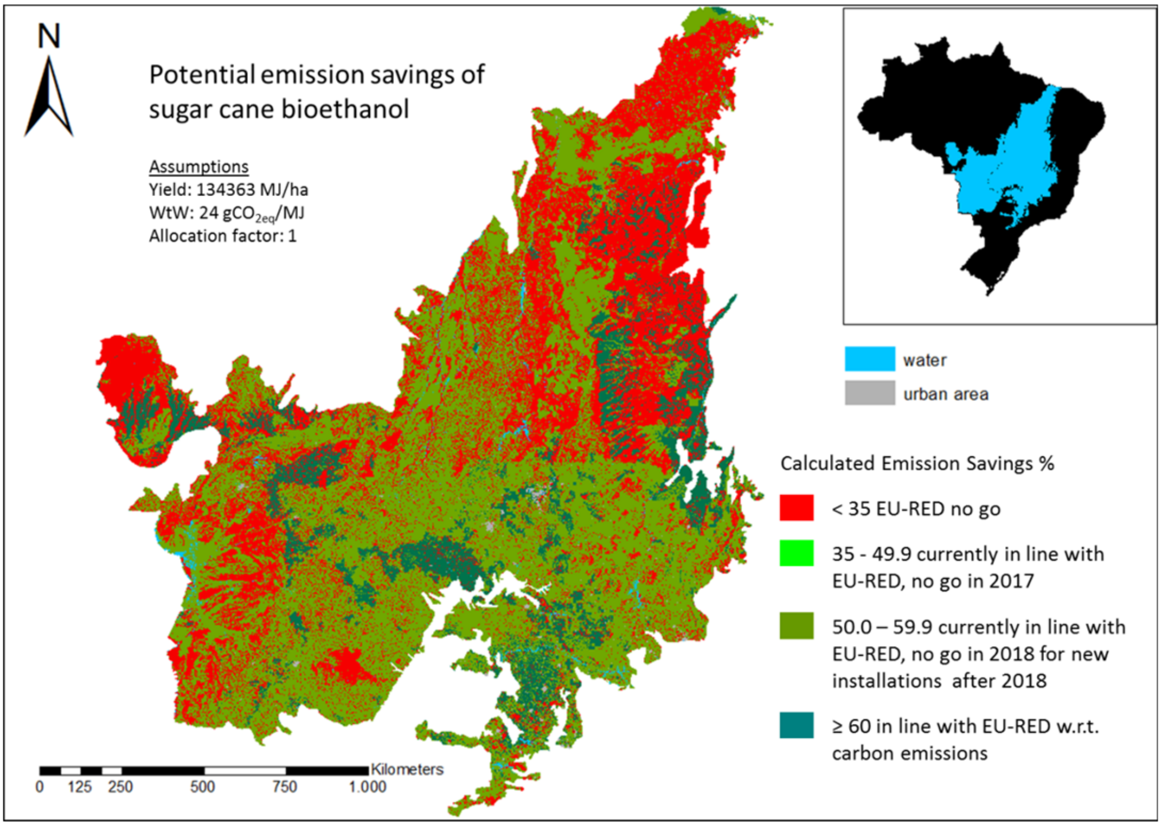
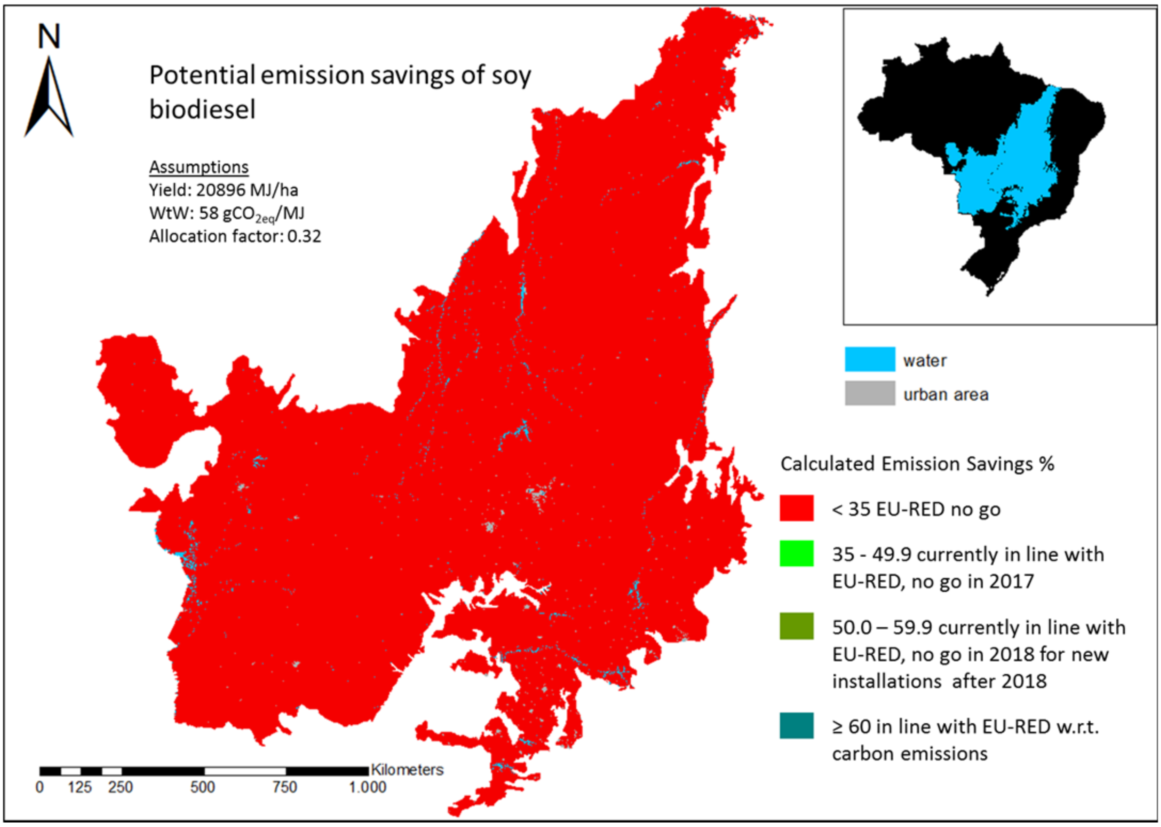


Figure 8 shows the results on potential emission savings from sugarcane bioethanol production. Sugar cane has a much higher energy yield per ha compared to soy and is a perennial crop. Therefore much more areas are possibly available for sugar cane production with respect to EU-RED carbon criteria. This also applies for the natural areas of low biomass cover such as campo limpo and campo sujo contained in the grassland category. The remaining forest and woodland areas are under no assumption in line with the EU-RED sustainability criteria when converted into sugar cane production. These areas are colored in red. The planned increases in the minimum emission saving threshold are indicated with the different shades of green. Only an increase in the required emission savings of more than 60% would substantially reduce the available area if productivity would remain at the assumed level.

The low energy yield per hectare of soy results in the fact that practically no area is potentially available for soy biodiesel production according to EU-RED (Figure 9). Even the areas already used for crop production would not be available for exporting to the European biofuel market. Naturally, areas without LUC, like areas with sugar cane (or soy production) already installed in 2008, have no LUC emissions. Here, results in Figure 8 and 9 are purely driven by the process and transport emissions. Results are therefore also driven by the EU-RED default value for production emission (WTW) for soy biodiesel which is prohibitively high. Producer would need to prove that their WTW emissions are substantially lower than the default values assumed in the EU-RED. As a robustness check I calculated emissions savings of soy by using the typical WTW emissions from soy biodiesel production in the EU-RED rather than the default values. Results (not shown in this report) differ only from those based on the default values (Figure 9) that production on already existing cropland is countable under the 35% emission saving criterion.

Figure 9



5. Implications of results on DLUC and ILUC

The analysis in the previous section shows the areas suitable for sugar cane and soy production with respect to the EU-RED minimum emission saving threshold including potential emissions from DLUC. The results do not yet indicate whether the overall expansion of sugar cane or soy production for the production of biofuels for the European Union are more likely to cause DLUC emissions or ILUC emissions. This can be assessed by asking whether most of the biofuel feedstocks are produced on already existing cropland, which increases the DLUC risk, or on former natural areas converted for the biofuel feedstock production, which would cause DLUC.

Therefore in this section I show how much area for expansion still does exist which is not yet used for crop production, but still achieves the minimum emission saving threshold. Thus, this would be area where an expansion would cause DLUC emissions but still produce sufficient emission savings to be eligible under the EU-RED criteria. This can be calculated by subtracting the area already used for crop production from the area suitable under EU-RED calculated in section 4. This analysis only makes sense for sugarcane as all soy biodiesel does not achieve the 35% emission saving threshold. Again, this analysis only includes carbon emissions and does not include other sustainability issues like biodiversity. The data availability only allows to exclude protected areas and indigenous land from being suitable expansion areas. A more sophisticated inclusion of other sustainability issues might further reduce the available expansion area.

This is the basis for the analysis of ILUC implications of the EU-biofuel mandate. Because, if ethanol for the EU biofuel mandate is produced on already existing cropland areas, and the demand for ethanol or sugar from other sectors remains stable or increases, agricultural production will expand into natural areas due to increasing prices. This expansion of other agricultural production or sugarcane not for the EU-biofuel market is possible because no binding sustainable criteria exist for these productions.[12] Without further policy measures, this ILUC mechanism can only be avoided if there are expansion areas in the Cerrado which are both in line with the EU-RED sustainability criteria and not yet used for crop production.

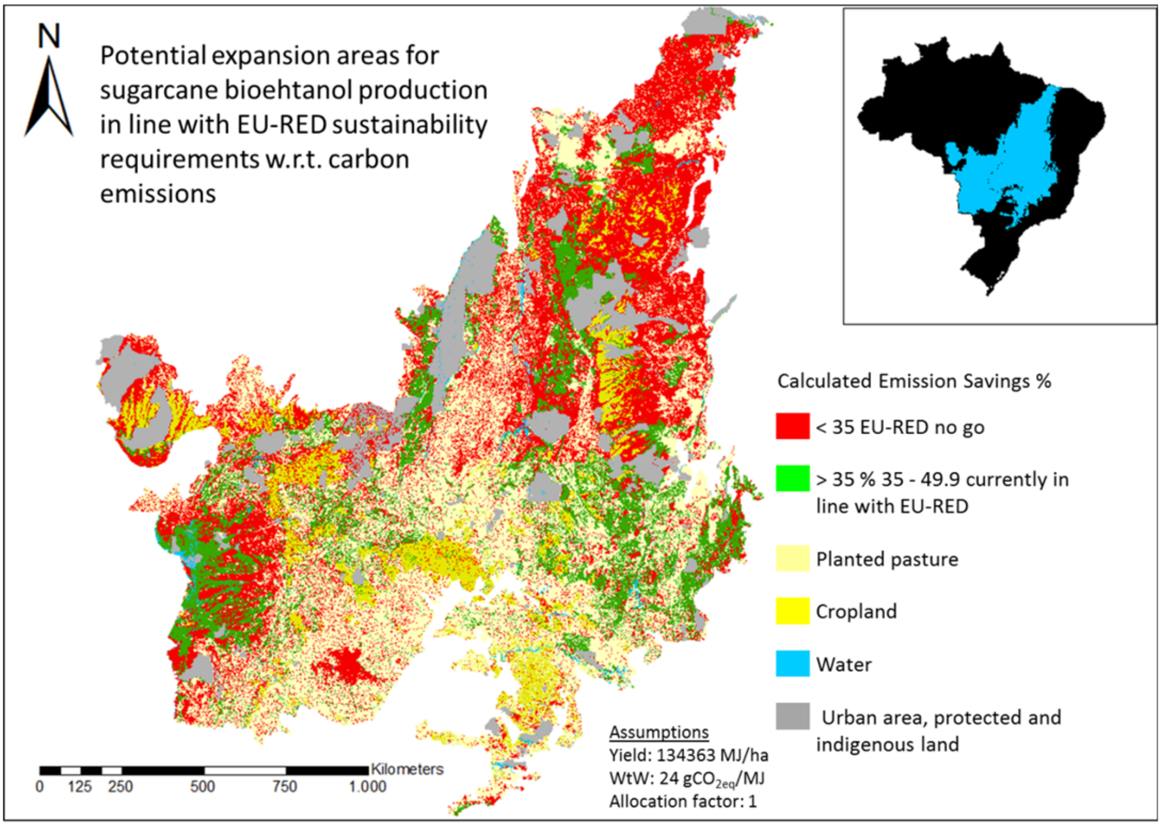
With respect to carbon, these areas can be determined with the previously explained analysis. I exclude all areas already used for crop production. I mark the areas used already for planted pasture in yellow as I come back to this expansion option later on in this section. Both these areas I determine with the land cover map of Figure 2. In addition, all areas designated by a competent authority for the protection of nature or indigenous culture and rights can be defined as “no-go areas” by definition of the EU-RED.

For the evaluation of results shown in Figure 10 one has to keep in mind that this map does not include biodiversity factors and areas needed for other infrastructure, settlements etc. They further do not account for the suitability or productivity of the land for production which might further decrease suitable areas.

It becomes evident that there are not many areas left for expansion into unused areas. The in figure 10 these are the light green areas, which are under natural vegetation and with respect to carbon, would achieve the EU-RED sustainability requirements. Most of the other potential expansion area, which does not cause two little emission savings (red area) or is urban land, protected area or already used for crop production (grey area) is planted pasture (yellow areas). Thus, these areas are presumably used for cattle grazing.

Thus, as the expansion areas for sugarcane causing DLUC are not too large, ILUC can become a problem when most of the sugar cane for the European biofuel market is produced on already existing agricultural land. Soy biodiesel production would even cause only ILUC emissions. This is because, based on the results in figure 9, soy biodiesel does not achieve the 35% minimum emission saving threshold when causing any DLUC. Therefore, only production on already existing cropland is an option for soy biodiesel if WTW emissions are sufficiently low.

FIGURE 10



The effect of ILUC exist under two assumptions: first, the replacement of other agricultural production by biofuel feedstocks results in a price price increase of (some) agricultural products on the world market, and second other agricultural production does not underlie any sustainability requirements.

The first and easiest way of reducing the price effect of an increased biofuel production is to reduce biofuel production. This is one of the strategies in a new proposal of the European Commission on how to reduce ILUC. The contribution of the transport sector to emission savings is then artificially[13] achieved by multi-counting the reduction of emissions produced by electric cars or second generation biofuels.

A way of maintaining the production of biofuels and reducing their price effect is to increase productivity on the biofuel feedstock production sides compared to the former production. Based on experience of certification systems this is well possible when the certification process and the implementation of all criteria on the production sides serve as an extension service. This is for example the case when changes in the production process are made throughout the certification process in order to fulfill the sustainability requirements and be able to receive a certificate. As a “side effect” these changes in the production process, like for example a proper management of fertilizer applications, might increase productivity.

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[13] Artificially means in this context that a produced unit of second generation biofuels and their emission savings compared to fossil fuels is counted e.g. twice, even though it generated these emission savings only once.

The same mechanism holds if the price effect on the production replaced by the biofuel production results in intensification on the remaining area rather than in an expansion into new areas. This can be observed in particular with respect to cattle production. Agricultural land in the Cerrado mostly expands into extensively used cattle areas. At the same time one can observe an intensification process in the cattle sector, meaning a higher amount of cattle per pasture areas (Martha et al. 2012). This intensification process might not offset all possible price incentives for land expansion (ILUC) but possible reduces it.

Besides efforts to reduce the price effect or the land expansion vs. intensification elasticity, leakage effects exist because other production does not underlie any sustainability regulation. A sustainable expansion path without ILUC or leakage effects can only be achieved if all production is subject to sustainability criteria. Such sustainability criteria can be implemented in the importing countries like those implemented by EU-RED for biofuels. Another way of achieving a sustainability regulation for all production is the implementation of a sustainable land use planning, based on carbon maps, that defines areas for expansion and protection binding for all agricultural production. Low carbon stock areas could be priority areas for agricultural expansion whereas high carbon stock areas should remain untouched for a climate friendly expansion policy.

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Appendix 1 Data used in calculation steps

Table 1. Sources for biomass carbon

Land Cover Class	Above Ground Biomass Carbon (Mg C/ha)	Below Ground Biomass Carbon (Mg C/ha)	Source
Campo Limpo	2.75	8.15	De Castro and Kaufmann (1998)
	3.55		Kaufmann et al. (1994)
	1.2		Barbosa and Fearnside (2005)
	1.8	7.6	Castro (1996)
	0.67		Barbosa and Fearnside (2005)
Campo Sujo	4.65	15.05	De Castro and Kaufmann (1998)
	3.65		Kaufmann et al. (1994)
	1.2		Barbosa and Fearnside (2005)
	1.7		Barbosa and Fearnside (2005)
	2.7	15.1	Castro (1996)
Campo Cerrado	4.3		Kaufmann et al. (1994)
Cerrado Denso	12.45	26.45	De Castro and Kaufmann (1998)
	11	25.5	Castro (1996)
Cerrado Sensu Stricto	5.2		Barbosa and Fearnside (2005)
	4.4		Barbosa and Fearnside (2005)
	11.35	15.18	Lilienfein et al. (2001)
	18.4	20.55	Abdala et al. (1998)
	9.6	23	Castro (1996)
Parkland Cerrado	3.4		Barbosa and Fearnside (2005)
	2.5		Barbosa and Fearnside (2005)
Forest	125		Asner 2010

Grassland = average of Campo Limpo, Campo Sujo, Campo Cerrado and Parkland Cerrado
Woodland (and palm woodland) = average of Cerrado Denso and Cerrado Sensu Stricto

Table 2: Datatable

Land Cover Class	Climate Regime	Soil Type	SOCref	Total Carbon in Biomass	Total Soil Factors	SOCact	Total Carbon	Total Carbon Sugarcane	Total Carbon Soy	Emission Savings Sugar Cane	Emission Savings Soy
			tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%
bare soil	Tropical Dry	LAC	35	0	1.00	35	35	40	20	79	-18
bare soil	Tropical Moist	HAC	65	0	1.00	65	65	70	31	79	-82
bare soil	Tropical Moist	LAC	47	0	1.00	47	47	52	23	79	-51
crops (grain/fibre)	Tropical Dry	LAC	35	0	0.58	20	20	40	20	103	31
crops (grain/fibre)	Tropical Moist	HAC	65	0	0.48	31	31	70	31	134	31
crops (grain/fibre)	Tropical Moist	LAC	47	0	0.48	23	23	52	23	119	31
crops (grain/fibre)	Tropical Moist	Sandy	39	0	0.48	19	19	44	19	112	31
crops (grain/fibre)	Tropical Montane	HAC	88	0	0.48	42	42	93	42	154	31
crops (grain/fibre)	Tropical Montane	LAC	63	0	0.48	30	30	68	30	133	31
crops (grain/fibre)	Tropical Wet	LAC	60	0	0.48	29	29	65	29	130	31
crops (grain/fibre)	Tropical Wet	Sandy	66	0	0.48	32	32	71	32	135	31
crops (irrigated)	Tropical Dry	LAC	35	0	0.58	20	20	40	20	103	31
crops (irrigated)	Tropical Moist	HAC	65	0	0.48	31	31	70	31	134	31
crops (irrigated)	Tropical Moist	LAC	47	0	0.48	23	23	52	23	119	31
crops (irrigated)	Tropical Moist	Wetland	86	0	0.48	41	41	91	41	152	31
crops (irrigated)	Tropical Montane	HAC	88	0	0.48	42	42	93	42	154	31
crops (irrigated)	Tropical Montane	LAC	63	0	0.48	30	30	68	30	133	31
crops (sugarcane)	Tropical Moist	HAC	65	5	1.00	65	70	70	31	71	-99
crops (sugarcane)	Tropical Moist	LAC	47	5	1.00	47	52	52	23	71	-68
crops (sugarcane)	Tropical Moist	Sandy	39	5	1.00	39	44	44	19	71	-54
crops (sugarcane)	Tropical Montane	HAC	88	5	1.00	88	93	93	42	71	-139
crops (sugarcane)	Tropical Montane	LAC	63	5	1.00	63	68	68	30	71	-96
dunes	Tropical Moist	Sandy	39	0	1.00	39	39	44	19	79	-37
forest	Tropical Dry	HAC	38	171	1.00	38	209	43	22	-199	-596
forest	Tropical Dry	LAC	35	171	1.00	35	206	40	20	-199	-592
forest	Tropical Dry	Sandy	31	171	1.00	31	202	36	18	-199	-586
forest	Tropical Moist	HAC	65	171	1.00	65	236	70	31	-199	-656
forest	Tropical Moist	LAC	47	171	1.00	47	218	52	23	-199	-625
forest	Tropical Moist	Sandy	39	171	1.00	39	210	44	19	-199	-611
forest	Tropical Moist	Wetland	86	171	1.00	86	257	91	41	-199	-692
forest	Tropical Montane	HAC	88	171	1.00	88	259	93	42	-199	-696
forest	Tropical Montane	LAC	63	171	1.00	63	234	68	30	-199	-652
forest	Tropical Wet	LAC	60	171	1.00	60	231	65	29	-199	-647

Land Cover Class	Climate Regime	Soil Type	SOCref	Total Carbon in Biomass	Total Soil Factors	SOCact	Total Carbon	Total Carbon Sugarcane	Total Carbon Soy	Emission Savings Sugar Cane	Emission Savings Soy
			tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%
forest	Tropical Wet	Sandy	66	171	1.00	66	237	71	32	-199	-658
forest	Tropical Wet	Wetland	86	171	1.00	86	257	91	41	-199	-692
forest	Warm Temperate Moist	LAC	63	171	1.00	63	234	68	43	-199	-608
grassland	Tropical Dry	HAC	38	14	1.00	38	52	43	22	57	-70
grassland	Tropical Dry	LAC	35	14	1.00	35	49	40	20	57	-66
grassland	Tropical Dry	Sandy	31	14	1.00	31	45	36	18	57	-60
grassland	Tropical Moist	HAC	65	14	1.00	65	79	70	31	57	-130
grassland	Tropical Moist	LAC	47	14	1.00	47	61	52	23	57	-98
grassland	Tropical Moist	Sandy	39	14	1.00	39	53	44	19	57	-84
grassland	Tropical Moist	Wetland	86	14	1.00	86	100	91	41	57	-166
grassland	Tropical Montane	HAC	88	14	1.00	88	102	93	42	57	-170
grassland	Tropical Montane	LAC	63	14	1.00	63	77	68	30	57	-126
grassland	Tropical Wet	LAC	60	14	1.00	60	74	65	29	57	-121
grassland	Tropical Wet	Sandy	66	14	1.00	66	80	71	32	57	-131
grassland	Tropical Wet	Wetland	86	14	1.00	86	100	91	41	57	-166
grassland	Warm Temperate Moist	LAC	63	14	1.00	63	77	68	43	57	-82
palm woodland	Tropical Moist	HAC	65	33	1.00	65	98	70	31	27	-191
palm woodland	Tropical Moist	LAC	47	33	1.00	47	80	52	23	27	-160
planted forest	Tropical Dry	HAC	38	79	1.00	38	117	43	22	-49	-287
planted forest	Tropical Dry	LAC	35	79	1.00	35	114	40	20	-49	-283
planted forest	Tropical Moist	HAC	65	79	1.00	65	144	70	31	-49	-347
planted forest	Tropical Moist	LAC	47	79	1.00	47	126	52	23	-49	-316
planted forest	Tropical Moist	Sandy	39	79	1.00	39	118	44	19	-49	-302
planted forest	Tropical Moist	Wetland	86	79	1.00	86	165	91	41	-49	-383
planted forest	Tropical Montane	HAC	88	79	1.00	88	167	93	42	-49	-387
planted forest	Tropical Montane	LAC	63	79	1.00	63	142	68	30	-49	-343
planted forest	Warm Temperate Moist	LAC	63	79	1.00	63	142	68	43	-49	-299
planted pasture	Tropical Dry	HAC	38	9	1.00	38	47	43	22	65	-52
planted pasture	Tropical Dry	LAC	35	9	1.00	35	44	40	20	65	-48
planted pasture	Tropical Dry	Sandy	31	9	1.00	31	40	36	18	65	-42
planted pasture	Tropical Moist	HAC	65	16	1.00	65	81	70	31	53	-136
planted pasture	Tropical Moist	LAC	47	16	1.00	47	63	52	23	53	-105
planted pasture	Tropical Moist	Sandy	39	16	1.00	39	55	44	19	53	-91
planted pasture	Tropical Moist	Wetland	86	16	1.00	86	102	91	41	53	-173
planted pasture	Tropical Montane	HAC	88	9	1.00	88	97	93	42	65	-152

Land Cover Class	Climate Regime	Soil Type	SOCref	Total Carbon in Biomass	Total Soil Factors	SOCact	Total Carbon	Total Carbon Sugarcane	Total Carbon Soy	Emission Savings Sugar Cane	Emission Savings Soy
			tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%
planted pasture	Tropical Montane	LAC	63	9	1.00	63	72	68	30	65	-108
planted pasture	Tropical Wet	HAC	44	16	1.00	44	60	49	21	53	-100
planted pasture	Tropical Wet	LAC	60	16	1.00	60	76	65	29	53	-128
planted pasture	Tropical Wet	Sandy	66	16	1.00	66	82	71	32	53	-138
planted pasture	Tropical Wet	Wetland	86	16	1.00	86	102	91	41	53	-173
planted pasture	Warm Temperate Moist	LAC	63	14	1.00	63	77	68	43	58	-80
urban area	Tropical Dry	HAC	38	0	1.00	38	38	43	22	79	-23
urban area	Tropical Dry	LAC	35	0	1.00	35	35	40	20	79	-18
urban area	Tropical Dry	Sandy	31	0	1.00	31	31	36	18	79	-13
urban area	Tropical Moist	HAC	65	0	1.00	65	65	70	31	79	-82
urban area	Tropical Moist	LAC	47	0	1.00	47	47	52	23	79	-51
urban area	Tropical Moist	Sandy	39	0	1.00	39	39	44	19	79	-37
urban area	Tropical Moist	Wetland	86	0	1.00	86	86	91	41	79	-119
urban area	Tropical Montane	HAC	88	0	1.00	88	88	93	42	79	-122
urban area	Tropical Montane	LAC	63	0	1.00	63	63	68	30	79	-79
urban area	Tropical Wet	LAC	60	0	1.00	60	60	65	29	79	-74
urban area	Tropical Wet	Wetland	86	0	1.00	86	86	91	41	79	-119
urban area	Warm Temperate Moist	LAC	63	0	1.00	63	63	68	43	79	-35
woodland	Tropical Dry	HAC	38	33	1.00	38	71	43	22	27	-131
woodland	Tropical Dry	LAC	35	33	1.00	35	68	40	20	27	-127
woodland	Tropical Dry	Sandy	31	33	1.00	31	64	36	18	27	-122
woodland	Tropical Moist	HAC	65	33	1.00	65	98	70	31	27	-191
woodland	Tropical Moist	LAC	47	33	1.00	47	80	52	23	27	-160
woodland	Tropical Moist	Sandy	39	33	1.00	39	72	44	19	27	-146
woodland	Tropical Moist	Wetland	86	33	1.00	86	119	91	41	27	-228
woodland	Tropical Montane	HAC	88	33	1.00	88	121	93	42	27	-231
woodland	Tropical Montane	LAC	63	33	1.00	63	96	68	30	27	-188
woodland	Tropical Wet	HAC	44	33	1.00	44	77	49	21	27	-155
woodland	Tropical Wet	LAC	60	33	1.00	60	93	65	29	27	-182
woodland	Tropical Wet	Sandy	66	33	1.00	66	99	71	32	27	-193
woodland	Tropical Wet	Wetland	86	33	1.00	86	119	91	41	27	-228
woodland	Warm Temperate Moist	LAC	63	33	1.00	63	96	68	43	27	-143