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EU Biofuel Policies in Practice – A Carbon Map for Kalimantan and Sumatra

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Abstract:

It is still difficult for biofuel producers to proof 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 proof 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 Kalimantan and Sumatra in Indonesia. 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 palm if an area were to be converted to produce feedstock for this biodiesel 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 sustainability assessments and that for an effective forest protection, policies need to address the manifold drivers of deforestation in the country. In this effort, my resulting carbon maps can be the basis for a sustainable land use planning with a strategy to reactivate degraded areas that is binding for all agricultural production in the country.

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

JEL classification: Q42, Q58, Q56, Q16

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1. Introduction

One of the components of the European Commission´s (EC) strategy to replace fossil energy sources by non-fossil renewable sources is to expand the production of biofuels. On the one hand, this promotion of biofuels has been widely criticised. 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 (Erb et al. 2009, Hertel et al. 2008, Haberl et al. 2011). Meeting this demand causes emissions from LUC that still 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 decarbonising 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. Accounting for possible emissions from DLUC and emissions from production and transportation till 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.

Beyond the direct accounting of possible emissions from DLUC for EU-RED, a carbon map could represent a tool for land use planning which aims at reducing emissions from land use change in general. If land use change is only allowed on areas with low carbon content, emissions from land use change would be reduced compared to a situation where land use change is allowed independent of the carbon stock stored in the expansion area. 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 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, but food, feed and bioenergy production other than biofuel production are not (see also Lange 2011, Lange and Delzeit 2012). A land use planning based on a carbon map for all agricultural production could thus be a tool used for an overall reduction of land use change emissions. Including all agricultural production in such land use planning by defining priority areas for expansion would account at the same time for the need of countries to further develop their agricultural sector and meet increasing global demand for agricultural production.

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

[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

above ground carbon maps can be found in Saatchi et al. 2011 and Baccini et al. 2012. Due to their different purpose, maps produced for REDD+ cannot be used here as they focus only on determining carbon in forests. In addition, they 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 show how a carbon map that is in line with the EU-RED requirements could be calculated for Kalimantan and Sumatra in Indonesia and how it could be further used to control compliance with the EU-RED criteria. Going beyond the EU-RED requirements, I additionally discuss which consequences such map brings for a sustainable land use planning in this region. Indonesia is the largest producer of palm oil in the world and due to the cheap price for palm oil on the world market, it is possibly used to produce biodiesel for the EU biofuel target. At the same time, Indonesia has experienced tremendous forest losses in the last decade causing accelerated biodiversity loss and very high land use change emissions from converted forest and peatland areas. Thus, a land use planning that accounts for the carbon emissions is urgent in Indonesia, not only for the sustainability requirements of the EU-RED. 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. Finally, I apply the carbon mapping to the sustainability requirements of the EU-RED 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 sustainability requirements of the EU-RED. 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% and 30%, unless evidence is provided that the carbon stock before and after conversion apply to saving greenhouse gas emission at least at 35% (EU-RED Art.17(3,4)).

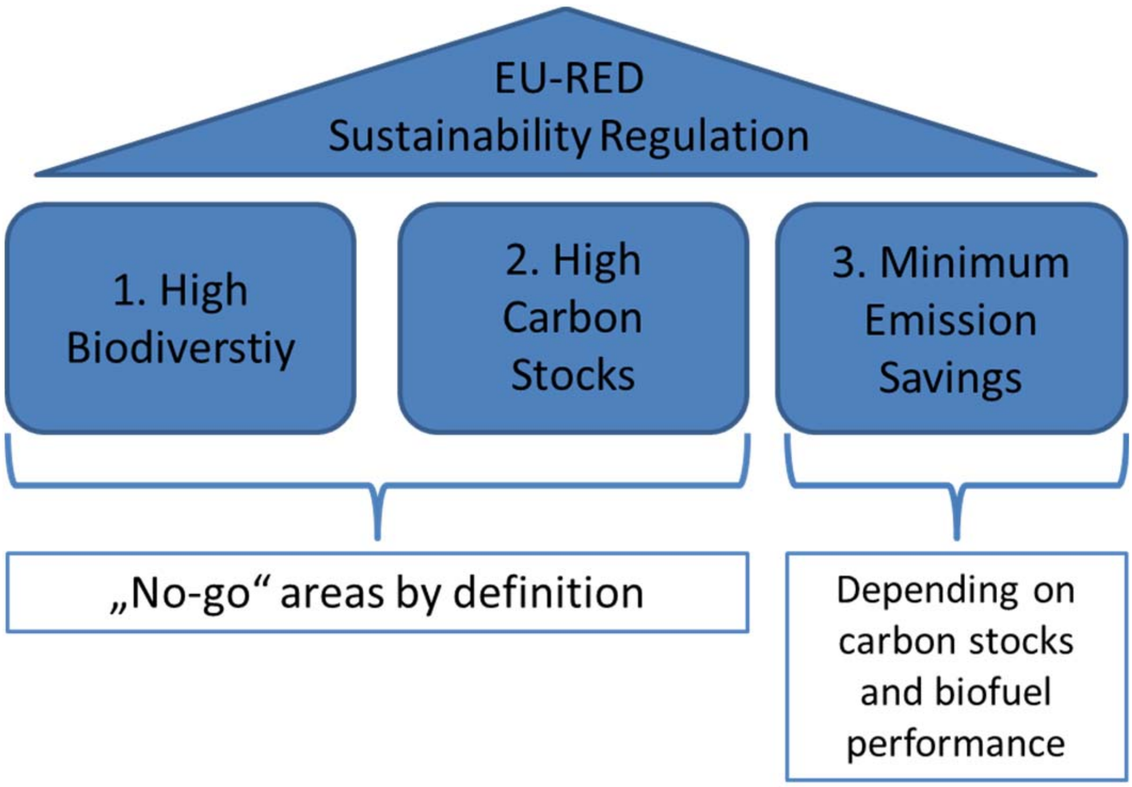
For all other production areas, accounting for possible emissions from DLUC and production and transportation emission, it has to be proved that the resulting biofuel will provide emission savings of at least 35% compared to the fossil fuel alternatives (EU-RED Art 17(2))(third column of Figure 1)

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

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 is all area which is not already excluded by definition from being suitable for biofuel production. However, as far as possible, 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 measurement 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 Sumatra and Kalimantan

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 Sumatra and Borneo.

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 producers 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, not the present but the land cover present in 2008 is the reference land cover. If there have been changes in between, it might be difficult to retrace the land cover in 2008.

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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.

The most commonly used method is to use land cover maps based on satellite images and to combine them with carbon values that represent the biome-average carbon value. This method 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 or 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 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.

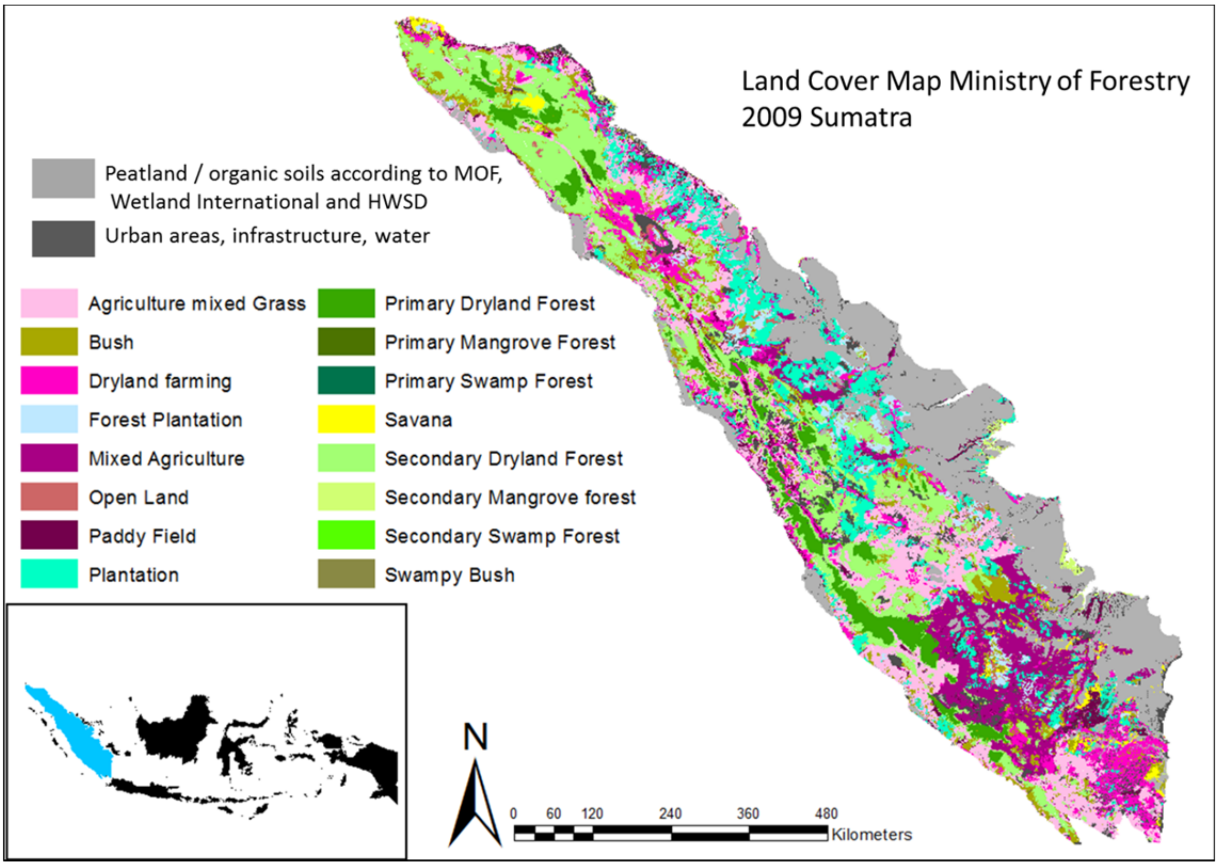
The purpose of this paper is not to evaluate the different methods but to demonstrate the use of the available data and maps for the sustainability regulation of the EU-RED[5] in the study regions. Therefore, I use two different methods due to the availability of data for the study regions. For Sumatra I use the official land cover map of the Ministry of Forestry of Indonesia combined with the biome-average approach (MOF) (Figure 1).

The use of a land cover map like the MOF map is appropriate here as the aim of this map is to provide a carbon mapping for the EU-RED. The motivation behind Lidar and Radar applications is mostly because REDD+ projects require an explicit determination of the carbon stored in the biomass of forest to determine a baseline for the payments for ecosystem service mechanism. For the EU-RED the land cover change/land use change emissions are the important figure to determine. However, this is

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

less relevant for forest as forests and wetlands are generally excluded from being suitable areas for feedstocks to produce biofuels. In addition, 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 MOF map is officially recognized by the Indonesian authorities which is important to feed in results into the political decision process of land use planning.

Figure 2



The land cover map for Sumatra in figure 2 shows already very large areas used for agricultural production and only small areas left with natural forest cover. The light grey areas represent peatswamp areas that I derive as the sum of 3 different sources. First I use all swamp areas of the MOF land cover map. In addition I use information from Wetlands International (Wetlands International 2008) on organic soil content as well as organic soils from a soil map based on the FAO harmonized world soil database generated by IIASA (FAO/IIASA/ISRIC/ISSCAS/JRC, (2012). I do not calculate the carbon content for these areas as first they are generally excluded from the suitable areas of the EU-RED and second the method presented here is not appropriate for the calculation of emissions from organic soils. [6] I will come back to the second point when presenting the method for the carbon content in the soil.

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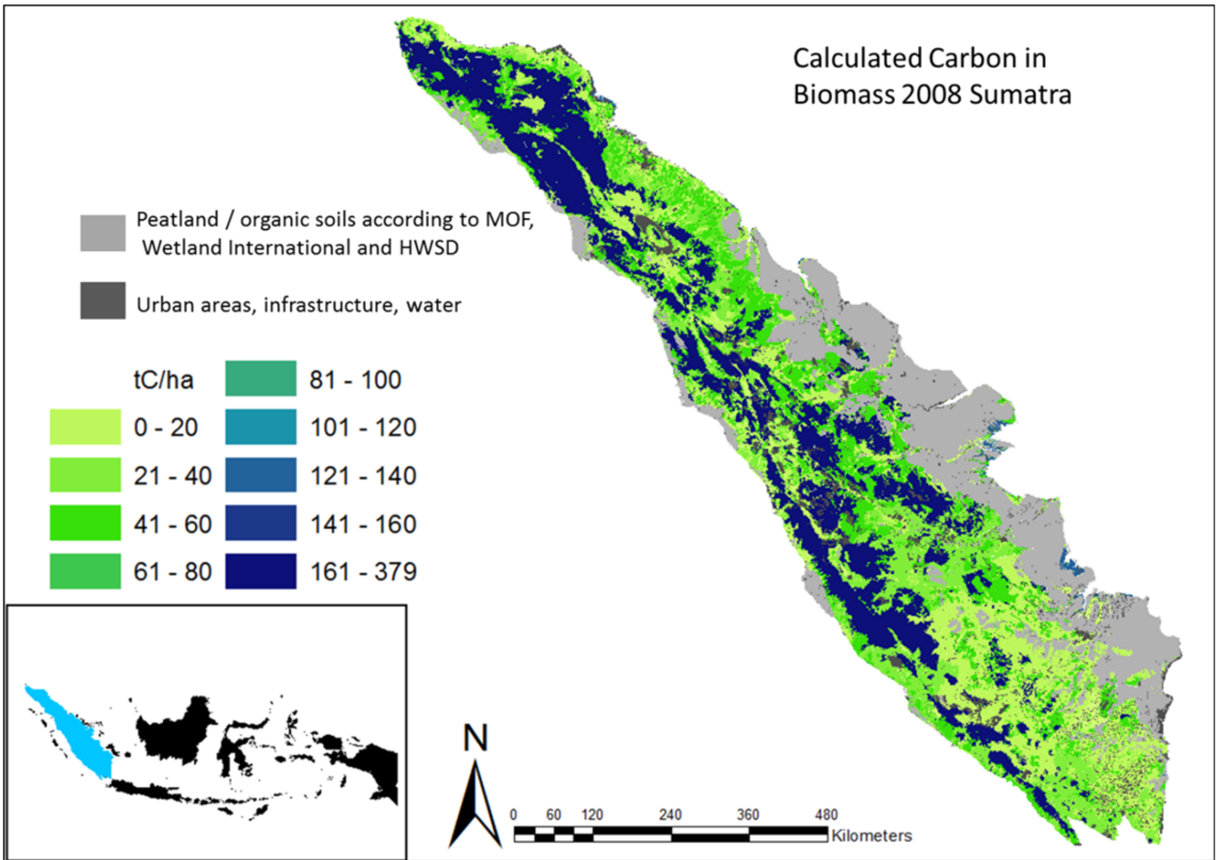
[6] The EU-RED allows production on peatland soils if they were already converted into palm plantations in 2008 and the production does not cause further drainage of the soil. With my databases I am not able to control for the

To convert the land cover map into a map that displays the carbon stock stored in above ground biomass, the values for carbon stock stored in above ground biomass associated with different land cover classes were taken from several sources. 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 Asia in general and not specific for Indonesia. 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 the 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).

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 and the very low carbon stocks in the already cleared and used areas.

Figure 3.



For Kalimantan, other data were available which were generated by Sarvision[7] within the Global Land Use Change Project of WWF Germany. A detailed description of the data generating process can be found in Sarvision (2011).

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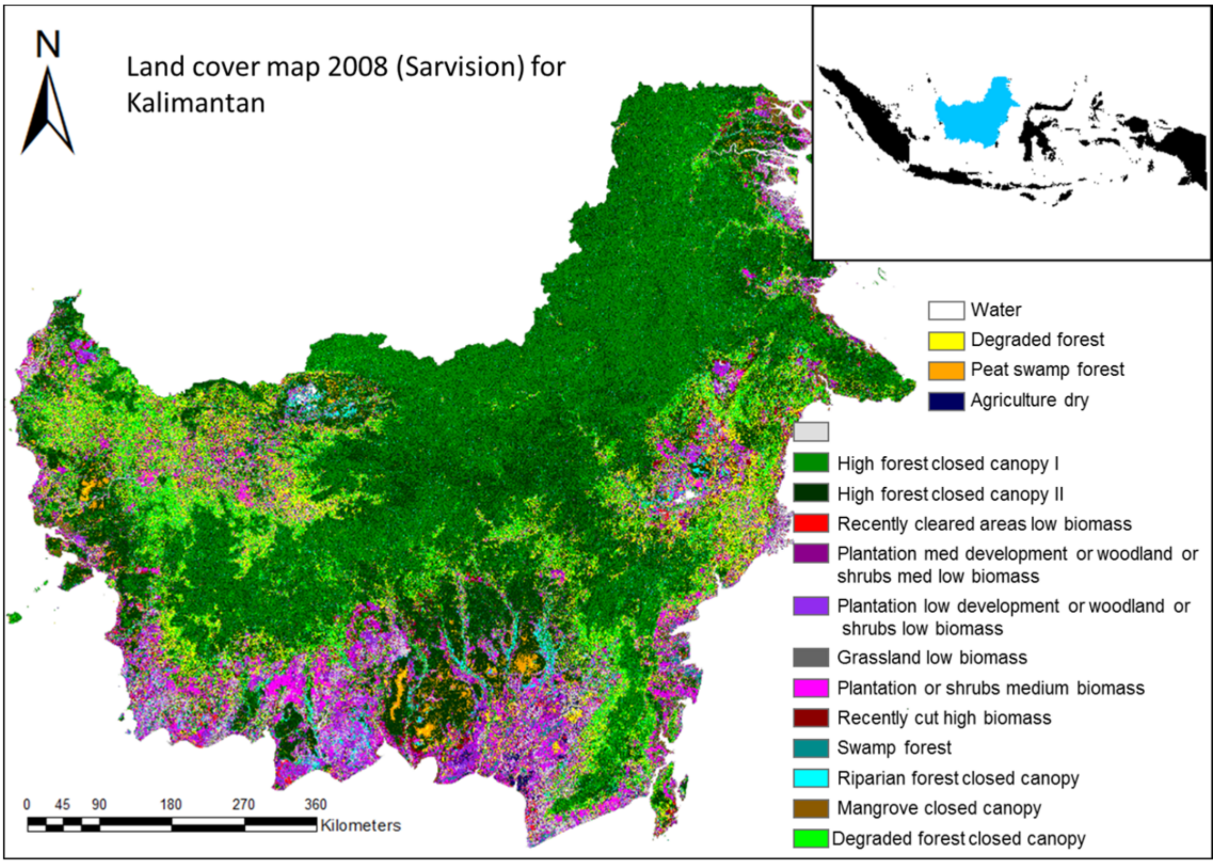
status of the peatland neither do I have information on the production possibilities on peat-soils not fully drained. In addition, I am not able to control whether fully drained peatland soils do not cause more emissions than mineral soils under continuous agricultural production.

[7] Sarvision is a spin-off of Wageningen Universtiy http://www.sarvision.nl/.

In order to derive a above ground biomass carbon map Sarvision (2011) used a combination of a vegetation structural type map derived from recent ALOS PALSAR radar satellite imagery that can see through clouds, and ICESat-GLAS spaceborne LIDAR height measurements that can be related to above ground biomass. A total of 17 different vegetation structural types were detected to be different in the coastal zones and the interior of Kalimantan using supervised classification techniques over the radar images (Sarvision 2011). Two different types of high forest were mapped in addition to peat swamp forest, mangrove forest, riparian forest, swamp forest and grasslands (Sarvision 2011). Detection of human affected areas was also possible including two types of degraded forest, shrublands, (oil palm) plantations and agricultural areas (Sarvision 2011). The vegetation structural type map was thoroughly validated using available field data observations in different areas of Kalimantan, georeferenced photographs and very high (0.5-1m) resolution remote sensing imagery available in Google Earth (Sarvision 2011). Validation of biomass map was done using biomass data based on field measurements collected for the assignment by Utrecht University (Sarvision 2011). Thus Sarvision 2011 provided two maps for this mapping exercise: A land cover map which is shown in figure 3 and map of above ground biomass density. I convert the unit of the map of biomass densities into carbon by multiplying the map with 0.47. In order to add carbon in below ground biomass I apply a constant ratio factor R (see equation 3). Figure 4 shows the resulting map displaying carbon stored in total biomass.

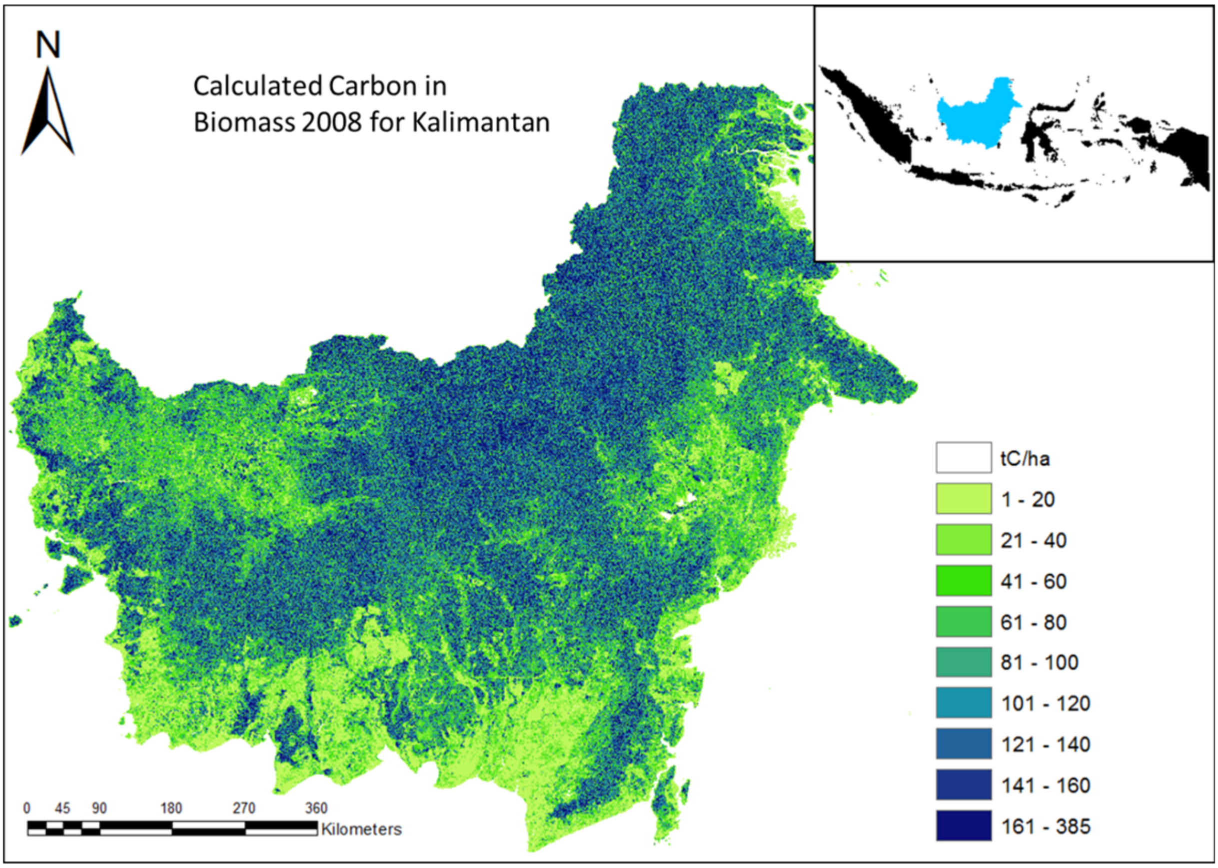
Figure 4



Compared to Sumatra, in Kalimantan large forest areas still remain. However, especially in the south of the island and in parts of the east, already large plantation areas and degraded forests exist. Naturally, this structure also shows in the biomass carbon map where the highest carbon stocks can be found in the forests of Central Kalimantan (figure 5).

Comparing both maps, on land cover and carbon in biomass, it clearly shows the strength of Lidar and Radar analysis compared to the use of only land cover maps combined with carbon values from the literature as done for Sumatra. The combination of both maps show the high range of carbon values within one land cover class. A unique value from the literature can at best show the average carbon stored in a particular land cover class. For instance, based on Figure 5, for the land cover class of high forest with closed canopy the mean value of carbon in biomass is 139 tC/ha. However, the standard deviation of 91tC/ha shows exemplary the high range of possible carbon values within one land cover class. The detailed carbon map in Figure 5 covers the whole range of carbon values and therefore represents the carbon stock at the local level with a much higher accuracy. As these data are produced to influence local production decisions their accuracy should be as high as possible.

Figure 5



b. Soil Carbon

I. Method

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.[8] 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).

The reasons why I generally exclude peatland areas from this mapping exercise are the following. The carbon content is to be calculated for the first 30 centimeters according to EU-RED as this is the layer where most of the carbon is stored in mineral soils. This does not apply for peatswamp areas which can have a thickness of several meters. In addition, the EU-RED method based on the IPCC 2006 assumes that the carbon content of a soil after a land use change stabilizes again after 20 years of agricultural production (excluding emissions from tillage and inputs). This is an arbitrary assumption for calculation purposes but not totally unrealistic for mineral soils. However, peatland soils converted to agriculture can keep on causing emissions for hundreds of years and for sure do not stabilize after 20 years. For a discussion of annual emission factors for different land uses in Southeast Asian peatlands see e.g. Hergoulc'h and Verchot (2013).

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

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 6 for Sumatra and figure 7 for Kalimantan).

[8] 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.

Figure 6

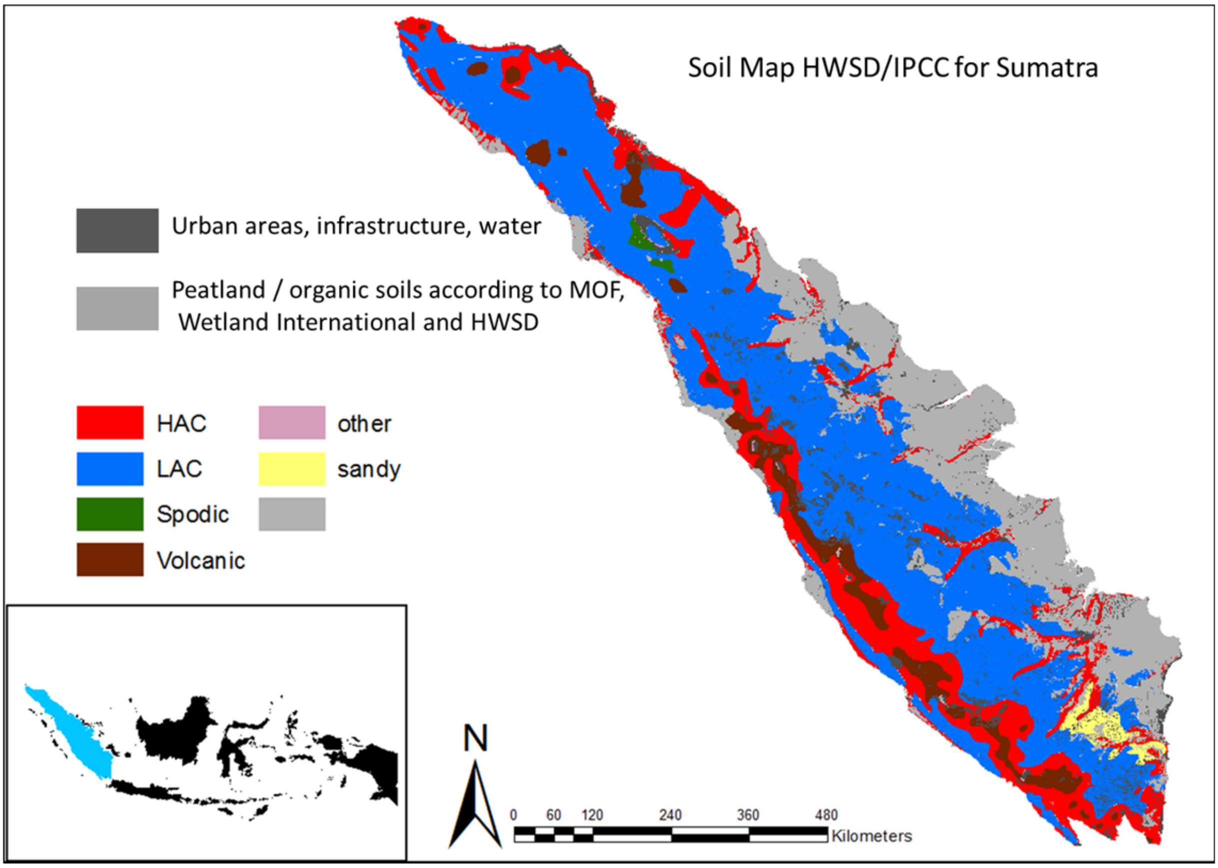
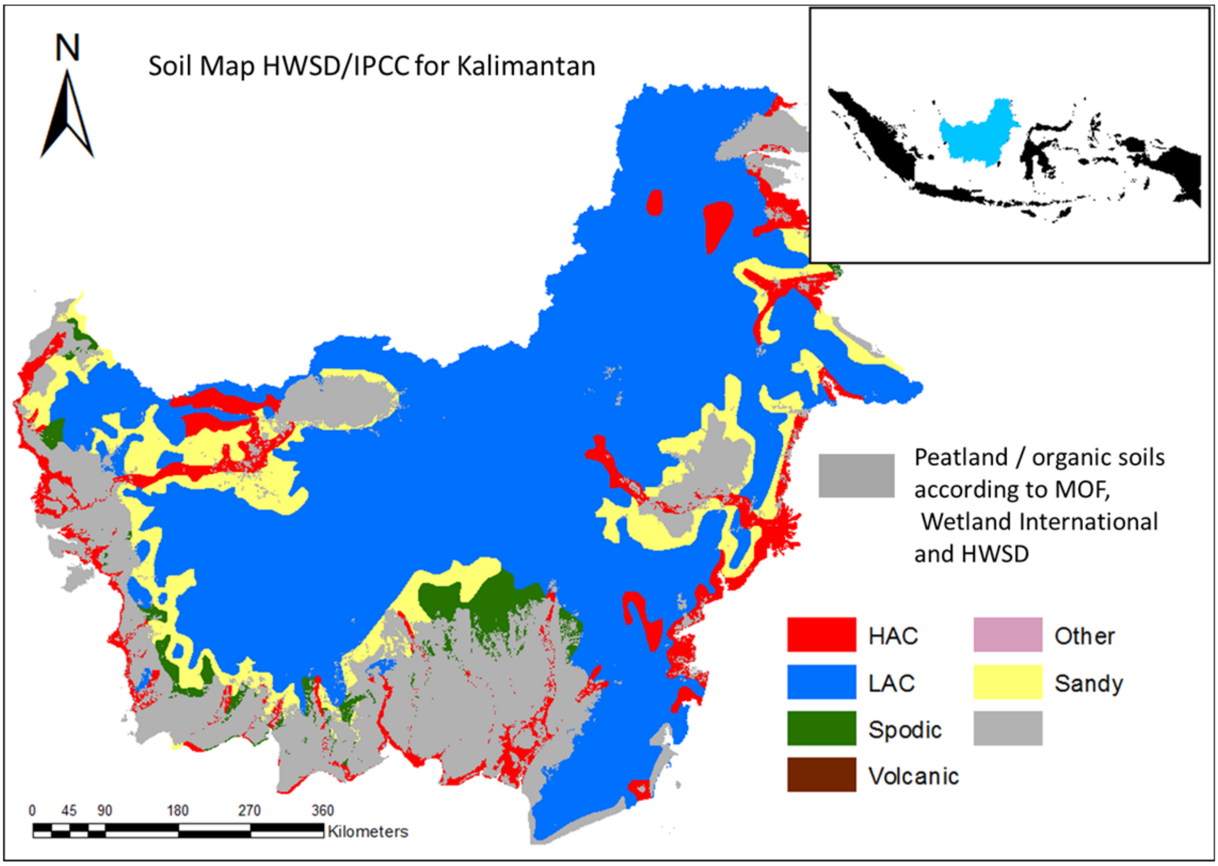
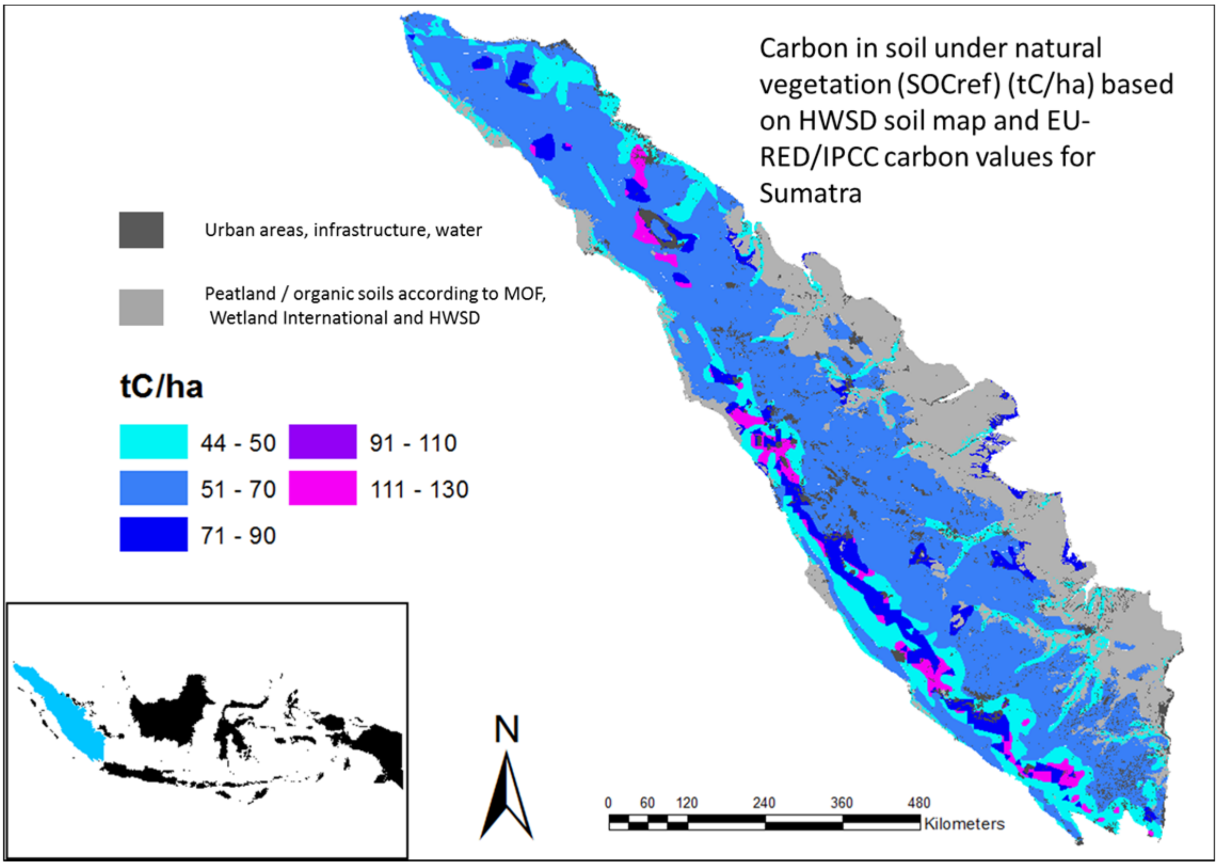


Figure 7



The categories used in this map correspond to the categories of the SOCref values in the IPCC 2006. These values are climate region specific. To determine the climate zone of a certain area I use the climate map provided by the EC. 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 (figure 8 SOCref Sumatra).

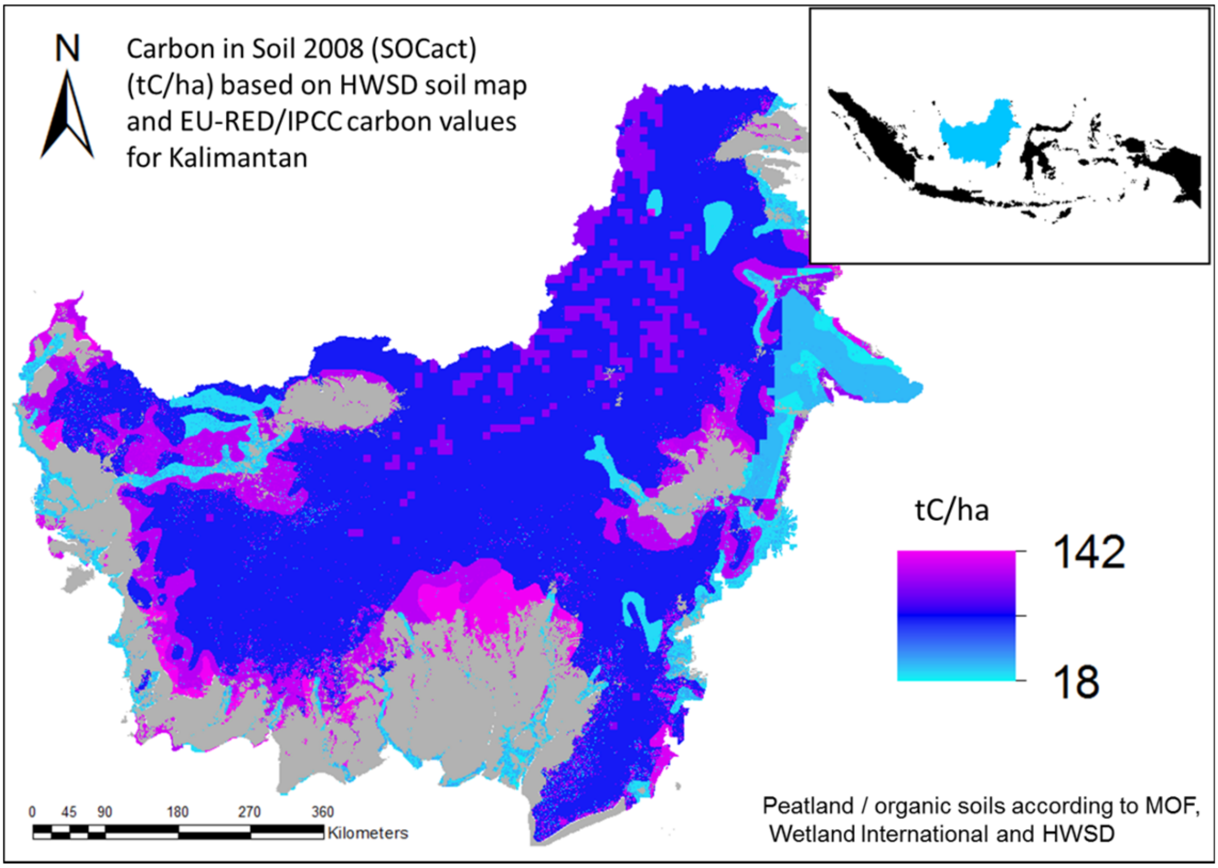
Figure 8



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 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). 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. (Figure 9 SOCact Kalimantan).

Figure 9.



c. Total Carbon Map

I calculate the final carbon map by overlaying and summarizing the map about carbon stocks stored in total 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 10 and 11 show these maps for Sumatra and Kalimantan respectfully. Results mainly mirror the results of the carbon maps of only the biomass cover at a higher level as I excluded the very large carbon pools in peatland soils. This means very high carbon stocks in the forest areas and low carbon stocks in the areas already used for agricultural production. Again, the Kalimantan map shows in much greater detail the local carbon stocks as varying carbon values within one land cover class are possible. Therefore, particularly the areas with medium biomass cover in the transition areas to the forest and the areas at the deforestation frontier seem to be represented with a higher degree of detail. These areas will be the first deforested for new plantations as they are closest to already existing production areas. Thus, these areas will be important for certifiers and the higher accuracy of local carbon values will guide a more realistic result of the certification process.

Figure 10:

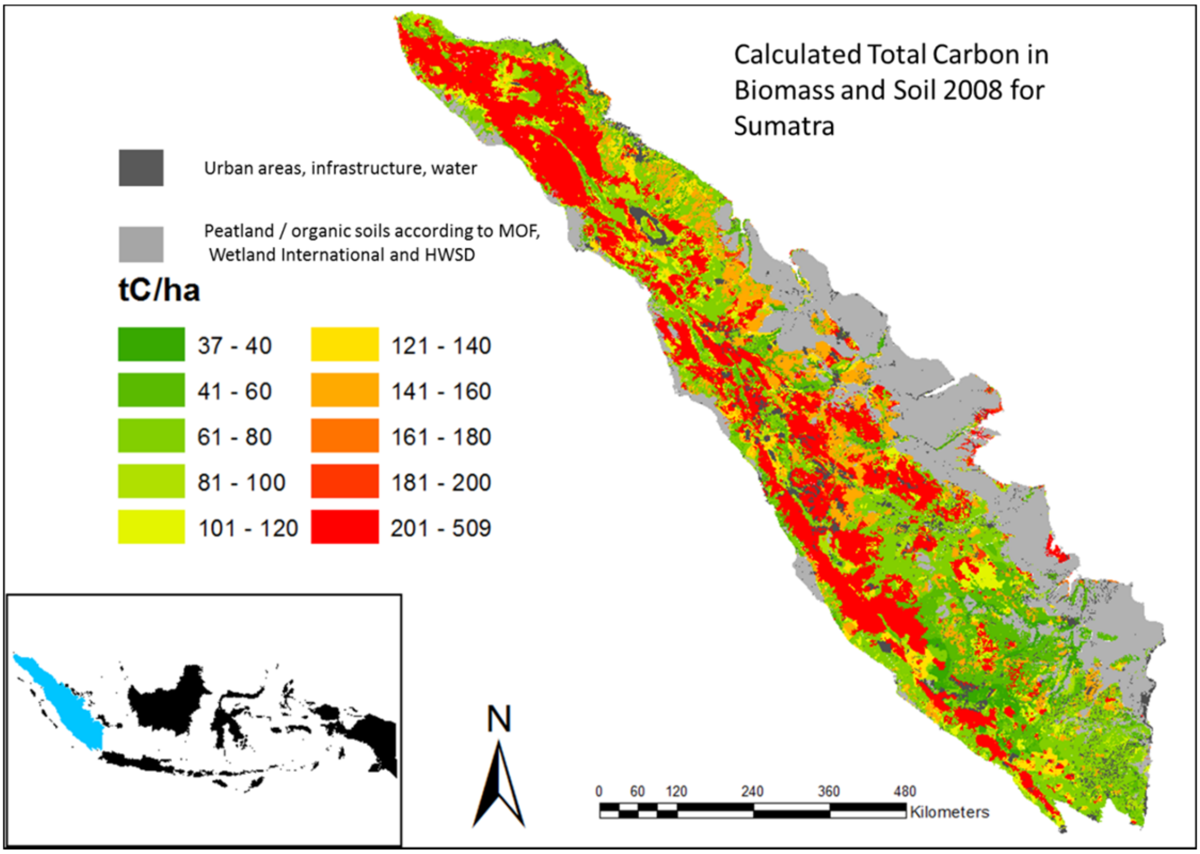
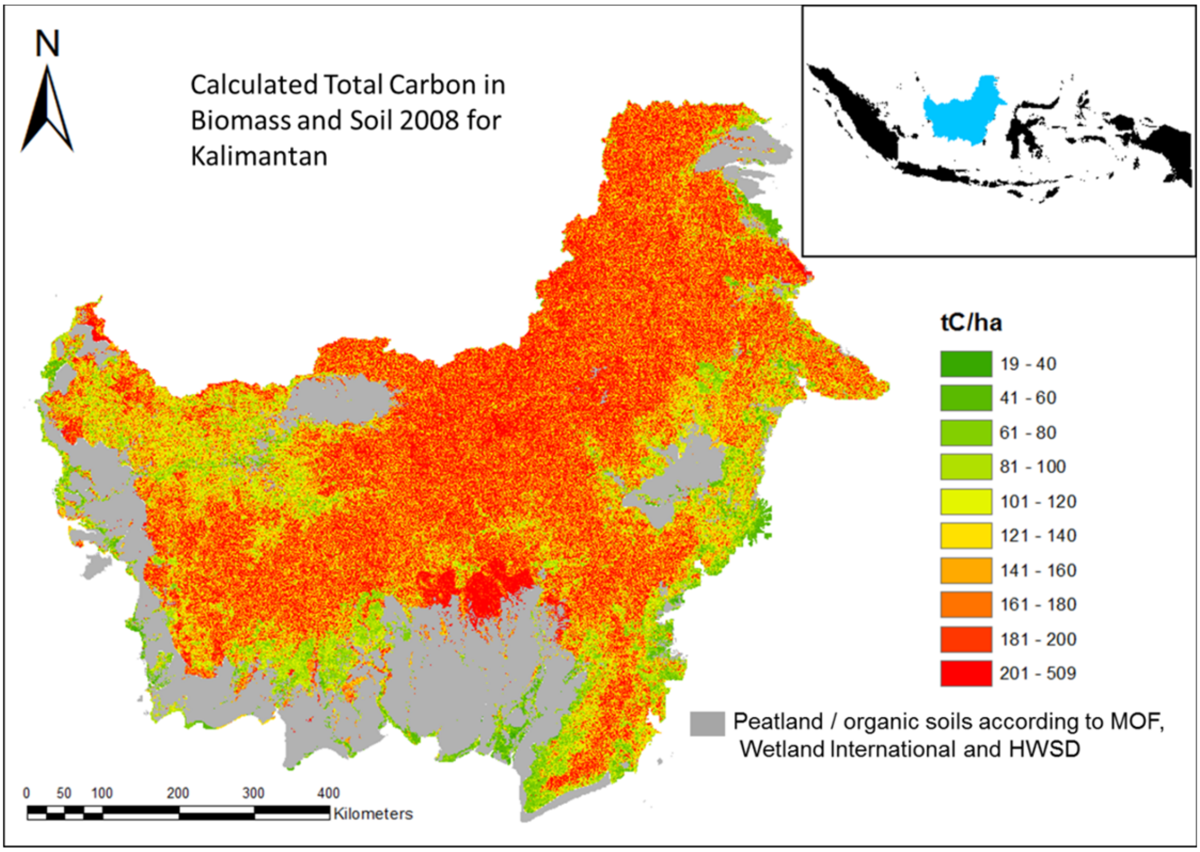


Figure 11:



In addition, the resulting carbon maps can serve as a basis for a low carbon spatial planning for a sustainably expanding agricultural sector. 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. Again, a higher detail in local carbon values will allow a more detailed and accurate land use planning process.

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

For the practical implementation of the sustainability regulation of the EU-RED, a further step of calculation is necessary. To prove the compliance with 35% emission saving threshold, the emission savings for each spatial unit that would occur if this spatial unit were to be converted into cropland to produced biofuel feedstock need to be calculated. Thus, I calculate the emission savings of each spatial unit if this unit were converted into a palm plantation to produce feedstock for biofuel production. Emission savings represent average annual savings for a production period of 20 years.[9]

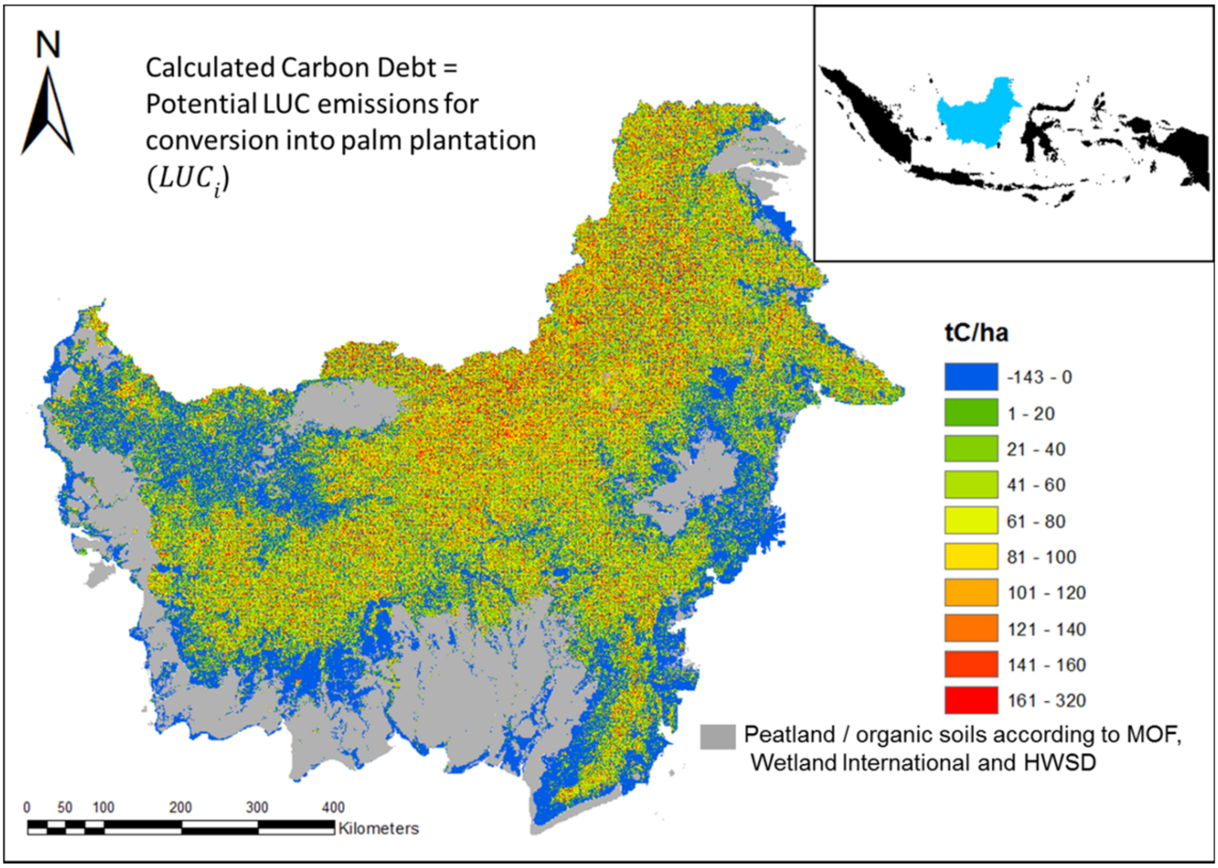
For the calculation, first, the emissions caused by the land use change (LUC_i) needs to be calculated by just taking the difference of the carbon stocks stored in the land use at t0 ($CS_{i_{before}}$) (which is 2008 for the current regulation) and the carbon stocks stored in the land use at t1 (which is the after the land use change). For our purpose, t1 represents the carbon stock stored in palm plantation ($CS_{i\_biofuel\_feedstock}$).

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

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

Figure 12 shows the result of this calculation step exemplarily for Kalimantan. Areas colored in blue would generate a gain in carbon storage when converted into a palm plantation. All other areas result in carbon emissions. Thus, the conversion of these areas into palm plantations would generate a carbon dept. Figure 12 shows that this mainly applies to all forest areas.

Figure 12:



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. 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). Consequently, the resulting LUC emissions per 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.[10]

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

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

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

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. Production processes and yields

	$P_i \frac{MJ}{ha}$	Source	AL_i	Source	WTW_i	Source
Palm biodiesel with methane capture in the production process	123344.4 = 17t/ha	Pancheco (2012) and FNR (2012)	0.91	IES 2008	37	EU-RED
Palm biodiesel without methane capture in the production process	123344.4 = 17t/ha	Pancheco (2012) and FNR (2012)	0.91	IES 2008	68	EU-RED
Palm biodiesel with methane capture in the production process and higher yields	145111.1 = 20t/ha	Pancheco (2012) and FNR (2012)	0.91	IES 2008	37	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 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[11] based on EU-JRC Data (IES 2008).

[11] 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.

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

I calculate the emission savings of 3 different palm production processes which are shown in the maps below: First, palm oil production with methane capture in the production process and an average yield of 17t/ha (Pancheco 2012)[12], second, palm oil production without methane capture in the production process and an average yield of 17t/ha and, third, palm oil production with methane capture in the production process and an average yield of 20t/ha (FNR 2012). I do this in order to check the results on sensitivity with respect to efficiency in the production process and productivity assumed in the calculation. 17t/ha is the average yield on Indonesian palm plantations. A yield of 20t/ha can be found on more modern an productive plantations (FNR 2012).

The methane emissions in the production process result from the storage of the palm oil mill effluent (POME). POME is the liquid residue when fresh palm fruit bunches are processed into crude palm oil. In many mills, POME is stored in a chain of open lagoons during a certain period of time, where it is cooled and where part of its organic matter content is degraded biologically which causes emissions of biogas (Waarts and Zwart 2013). Beside carbon dioxide, methane is a major component of this biogas. If the biogas escapes uncontrolled from the pond into the atmosphere it can strongly worsen the carbon balance of palm based biofuel since methane is 21 times more effective as a greenhouse gas than carbon dioxide (Waarts and Zwart 2013). In more modern palm oil mills methane is captured and can be used for power generation.

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”.[13] As the minimum emission savings threshold is about to rise to 50% for new installations from 2017[14] on, and to 60% in 2018 for installations built after 2017, I also indicate these thresholds in the maps of Figure 13-18 which show the emission saving maps for Sumatra and Kalimantan and the 3 assumed palm production processes. All green areas are sustainable production areas under the minimum emission saving criterion. The different shades of green indicate the different levels of the minimum emission saving threshold. 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.

[12] Methane capture means the capture of methane gas from the anaerobic digestion of palm oil mill effluent in open ponds.
[13] Hadian et al. 2013 map several biodiversity indicators for Sumatra and Kalimantan. Forthcoming on www.globallandusechange.org
[14] The threshold might be increased already in 2014.

Table 2: Area achieving the minimum emission saving threshold in Sumatra (47.3 million ha total island area)

Palm oil production process	Areas excluded from analysis	Area achieving the minimum emission saving threshold under different emission saving thresholds			
		Neutral Emission Balance	35%	50%	60%
No methane capture and 17t/ha yield	peatland soils / swamp areas (Figure 14)	16.7	16.7	16.7	16.7
Methane capture and 20t/ha yield	peatland soils / swamp areas (Figure 15)	20.5	16.7	16.7	16.7
Methane capture and 17t/ha yield	peatland soils / swamp areas (Figure 13)	20.5	16.7	16.7	16.7
	No-go areas by land cover definition (forest and peatland areas) and without areas already used (Figure 19)	3.4	3.4	3.4	3.4
	No-go areas by land cover definition (forest and peatland areas) (Figure 19)	20.5	16.7	16.7	16.7

For Sumatra (Figure 13.-15) results are clear and mainly independent on the production process and the assumed productivity. This is because the remaining forest areas are is under no assumption in line with the EU-RED sustainability criteria when converted into palm plantations. These areas are colored in red in all emission saving maps. It is only the non-forest areas which are in line with the EU-RED with respect to carbon. The planned increases in the minimum emission saving threshold, indicated with the different shades of green, only change results in very few hectares. Thus, one can roughly say that in 2008, the production area that achieves the minimum emission saving threshold in Sumatra is under all emission saving thresholds 16.7 million ha (see table 2 for an overview of areas achieving the minimum emission saving threshold). Only when considering a neutral emission balance, which would mean zero emission savings, methane capture and an increases in yield can slightly increase this area to 20.5 million ha.

Naturally, palm plantations remaining palm plantations and keeping their management practices have no LUC emissions. Here, results in Figure 13-15 are purely driven by the process and transport emissions. Under the EU-RED default WTW values, that means that a production with methane capture is in line with the 35% emission saving threshold but a production without methane capture is not.

Figure 13

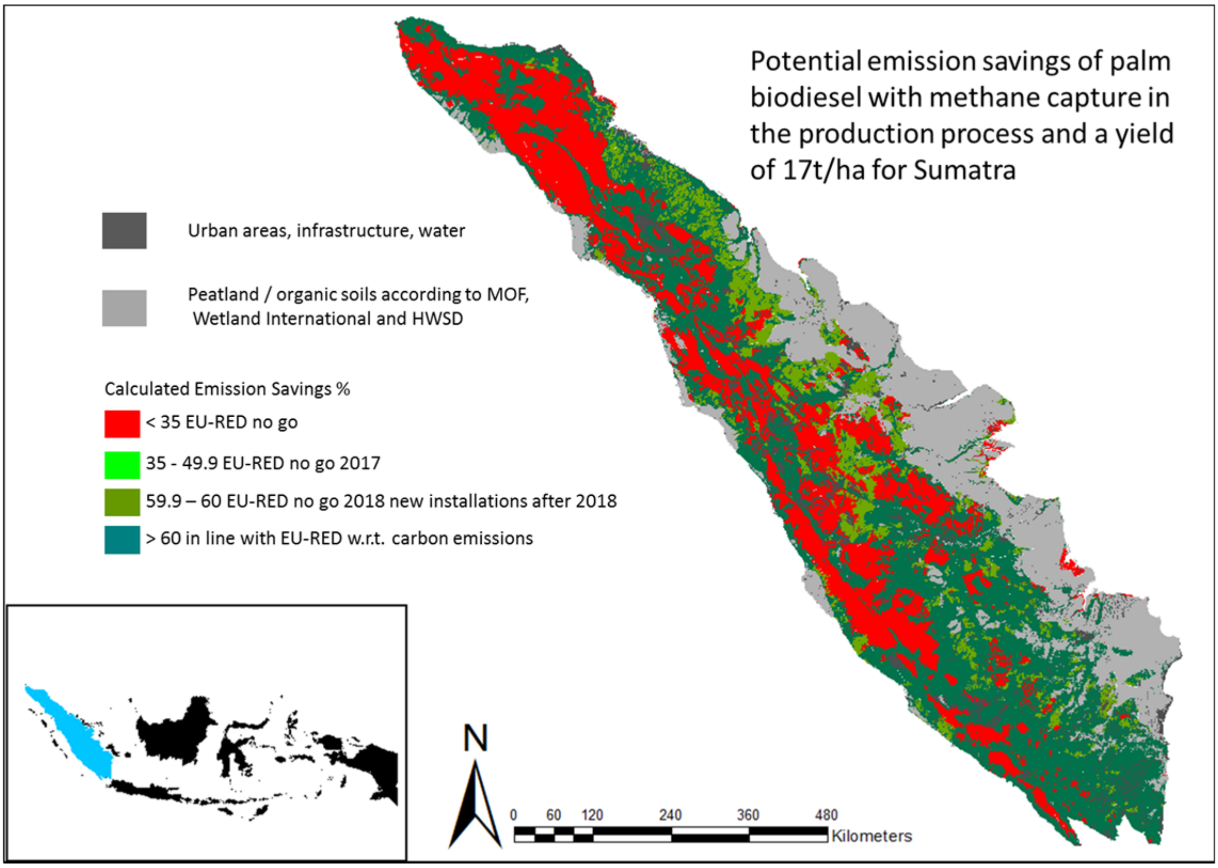


Figure 14

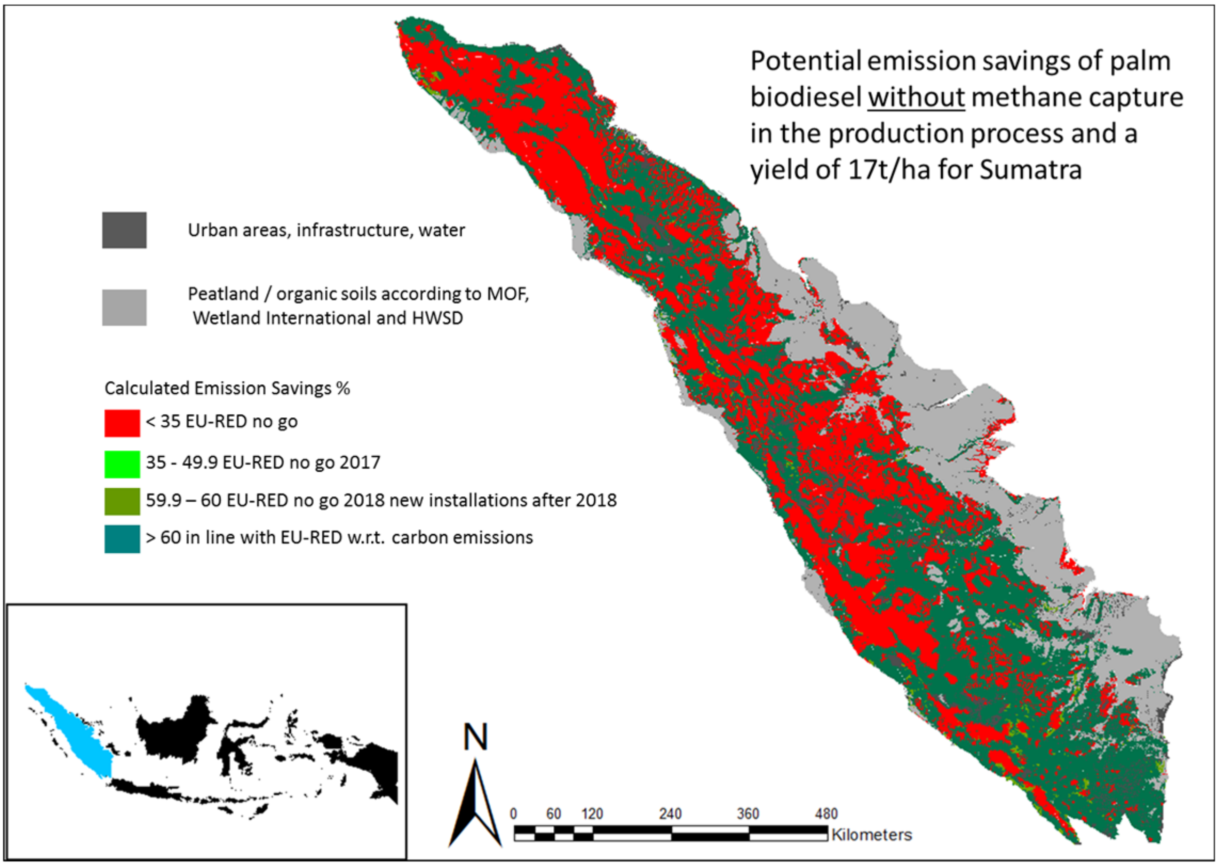
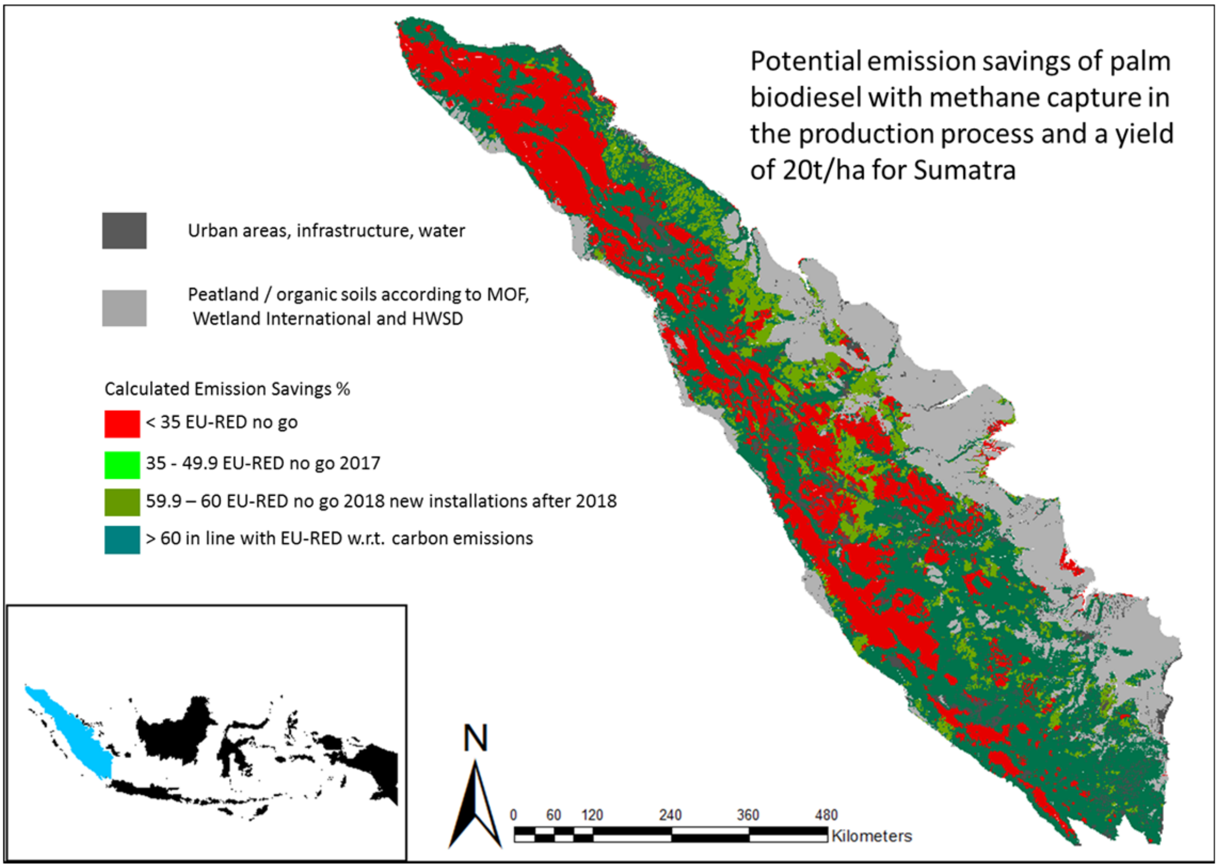


Figure 15



For Kalimantan results are similar to those in Sumatra (Figure 16-18). All forest and forest like biomass are well beyond the 35% emission saving threshold and in most cases even result in much higher emissions than those which can be saved in 20 years of biomass production. The different thresholds can make a difference on the local level which is due to the very high resolution of the Sarvision (2011) data which also captures small openings, water bodies and degraded areas. Thus, due to the high range of carbon values within one land cover class it is well possible to find pixel above and below the 35% emission saving threshold within this class.[15]

For a production process with methane capture and an average yield of 17t/ha the possible sustainable production areas under the emission saving threshold criterion range from 19.4 – 15.8 million ha for the 35% emission saving threshold to the 60% emission saving threshold. Thus, the increase of the threshold will further reduce the sustainable production area but does not substantially change the result (see Table 3).

15 It is interesting that this high variability of results seem to vanish if the resolution of the data decreases. A comparison of two global carbon maps from Saatchi et al. 2011 (1 km resolution) and Baccini et al. 2012 (500m resolution) by Ed Mitchard from the University of Edinburgh (http://carbonmaps.ourecosystem.com/interface/ access 10.07.2013) show local differences in results by up to +/- 150 tC and much less variability in values especially in the continuous forest areas. As more maps derived on active data emerge for this region the sensitivity of results against methodological differences and scales should be analyzed. This variability in carbon values are not that important for our results as the land cover map from Sarvision 2011 defines these areas as continuous forest which are no-go areas by definition in the EU-RED. However, for REDD+ assessments results should reflect the “real” carbon values as accurate as possible as payments are related to the carbon stored in the forest biomass.

The production process can have a substantial impact on the areas achieving the minimum emission saving threshold. If methane is not captured in the production process, it leads to a strong decrease of production possibilities to roughly ¼ for the 35% emission saving threshold (to 14.1 million ha) and to roughly 1/3 for the 60% emission saving threshold (to 10.4 million ha). Therefore, the implementation of methane capture into all production processes could increase the sustainable production area available under the emission saving criterion for the European market.

The increase in yield to 20t/ha, however, does only have an effect on available area under the 35% emission saving threshold. It slightly increases the available area to 20.9 million ha. Under the higher emission saving thresholds the higher yields do not reduce sustainable production areas compared to a yield of 17t/ha because both examples result in negative emission savings for areas with high biomass cover. Thus, increasing yields and implementing methane capture into the production process increases the sustainable production area in regions with a medium biomass cover but will not change the fact that an expansion into forest or forest like areas will never be sustainable in terms of carbon emissions.

Table 3: Area achieving the minimum emission saving threshold in Kalimantan (61.5 million ha total island area)

<table>
<tr><th rowspan="2">Palm oil production process</th><th rowspan="2">Areas excluded from analysis</th><th colspan="4">Area achieving the minimum emission saving threshold</th></tr>
<tr><th>Neutral Emission Balance</th><th>35%</th><th>50%</th><th>60%</th></tr>
<tr><td>No methane capture and 17t/ha yield</td><td>peatland soils / swamp areas (Figure 16)</td><td>19.3</td><td>14.1</td><td>12.4</td><td>10.4</td></tr>
<tr><td>Methane capture and 20t/ha yield</td><td>peatland soils / swamp areas (Figure 17)</td><td>26.8</td><td>20.9</td><td>17.9</td><td>15.8</td></tr>
<tr><td rowspan="3">Methane capture and 17t/ha yield</td><td>peatland soils / swamp areas (Figure 15)</td><td>25.3</td><td>19.4</td><td>17.9</td><td>15.8</td></tr>
<tr><td>No-go areas by land cover definition (forest and peatland areas) (Figure 19)</td><td>12.4</td><td>10.9</td><td>10.3</td><td>9.7</td></tr>
<tr><td>No-go areas by land cover definition (forest and peatland areas) and without areas already used (Figure 19)</td><td>8.8</td><td>7.3</td><td>6.7</td><td>6.4</td></tr>
</table>

Figure 16

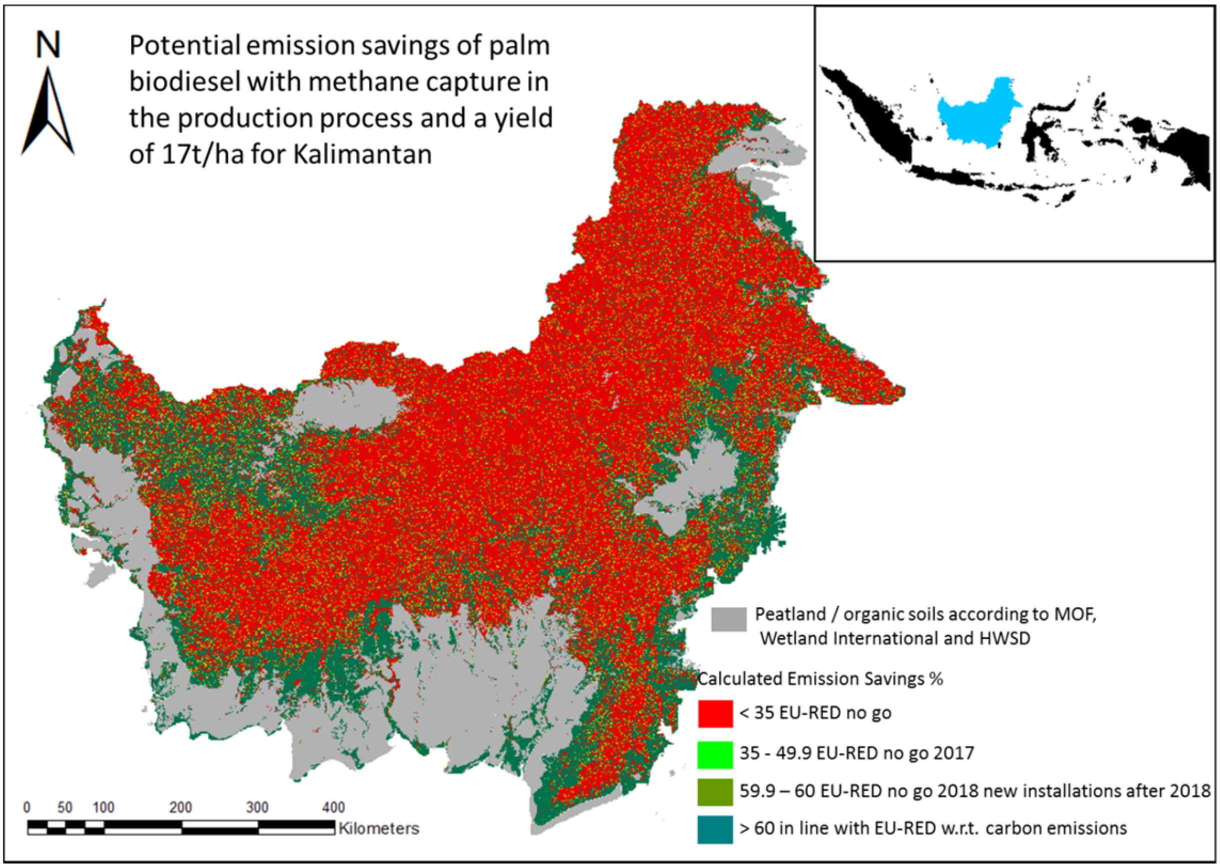


Figure 17

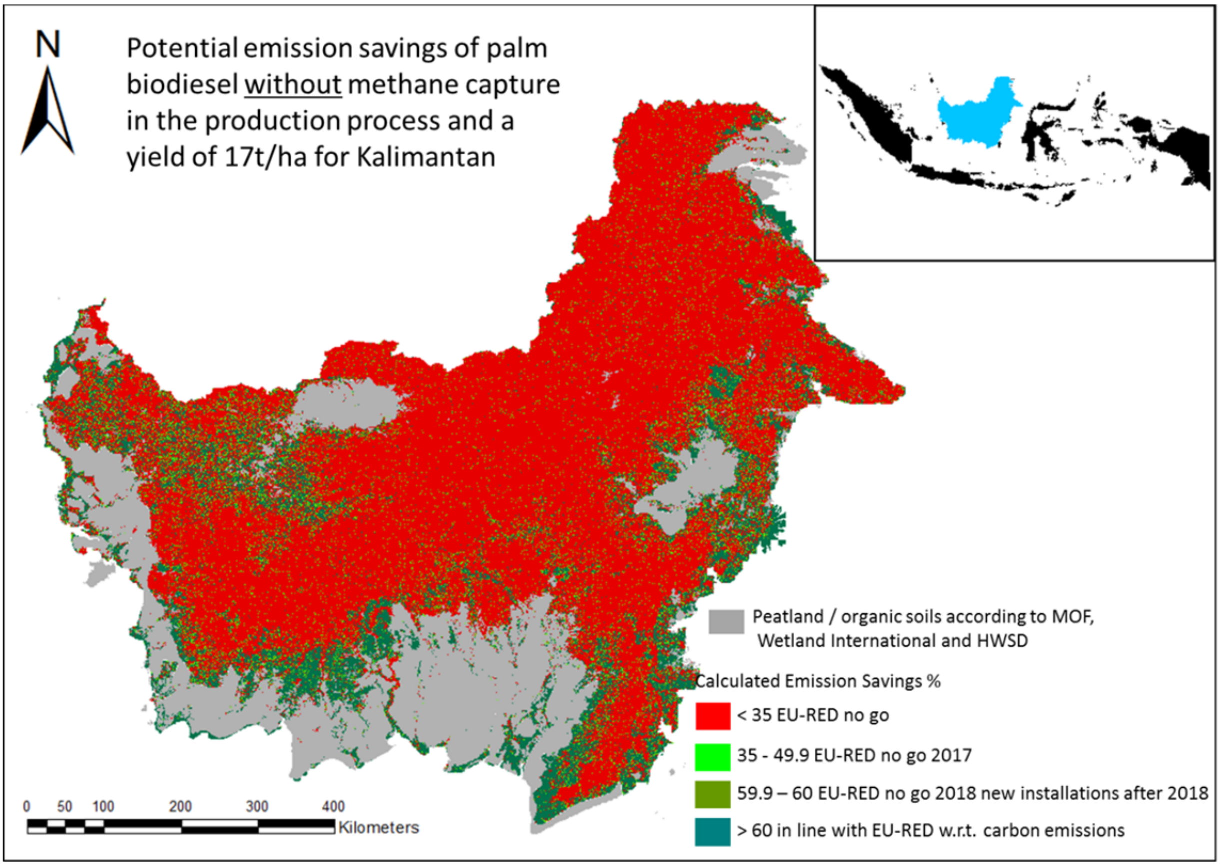
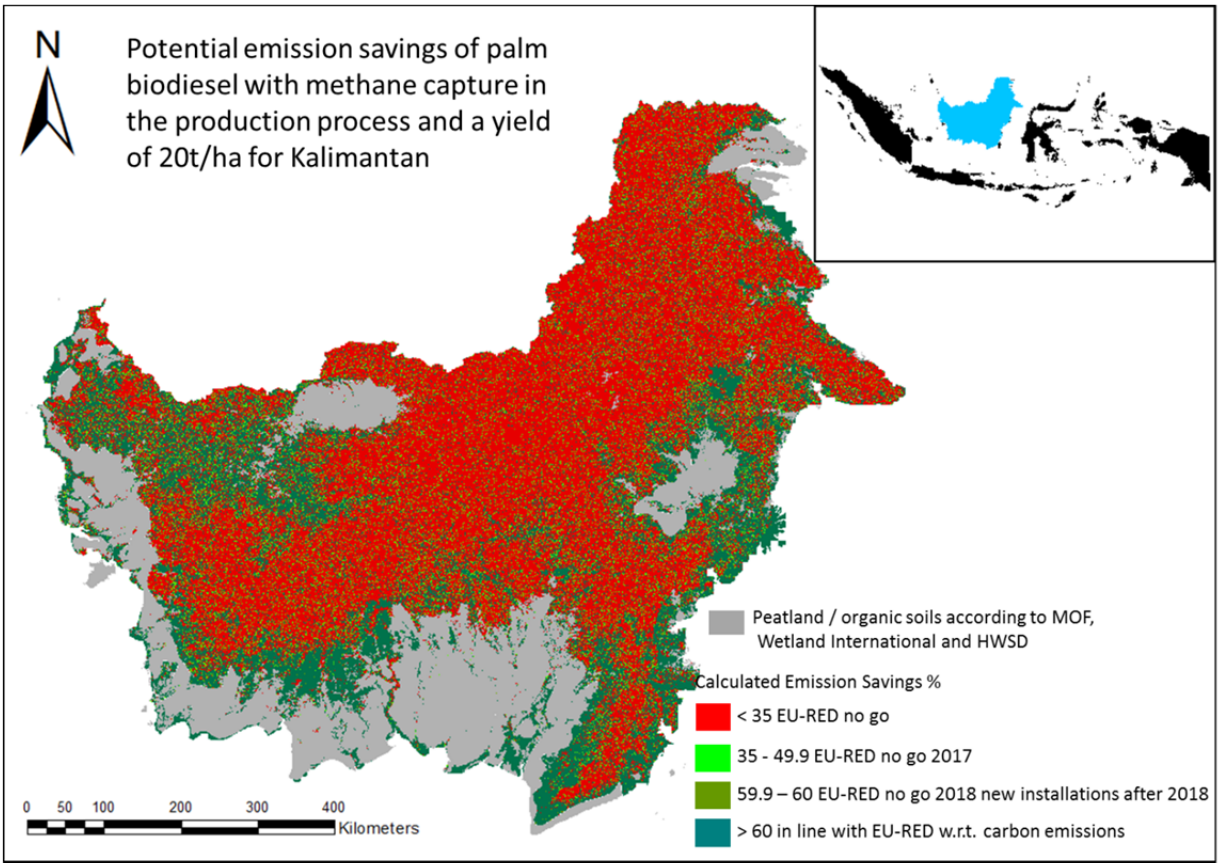


Figure 18



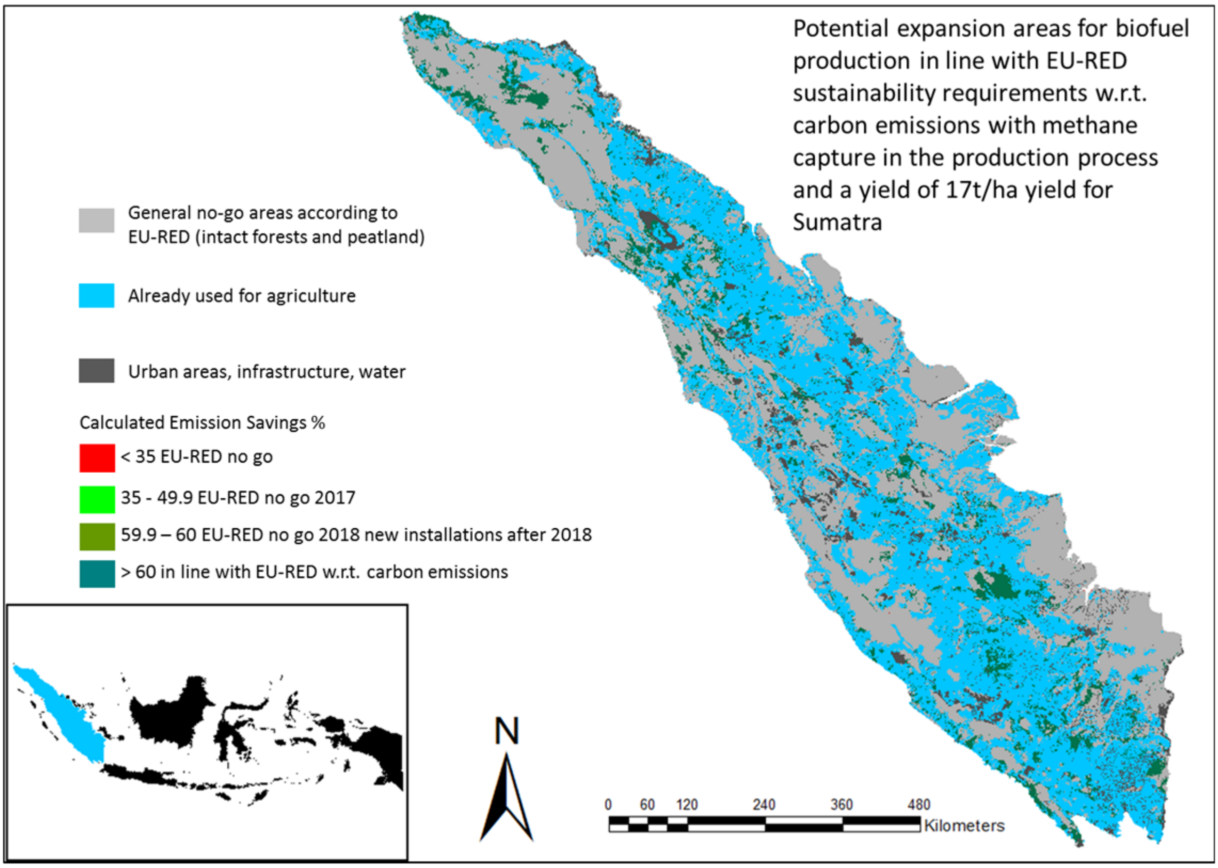
As a last step I want to raise the question of the overall implications of my results on possible land use change effects Indonesia. This is, first of all, a question on how much area for expansion still does exist which is not yet used for agricultural production but still achieves the minimum emission saving threshold. Thus, this is area where an expansion would cause DLUC emissions but still produce sufficient emission savings to be eligible under the EU-RED criteria. Thus, one needs to subtract the area already used for agricultural production from the sustainable production areas.

This is the basis for the analysis of ILUC implications of the EU-biofuel mandate from palm oil demand. Because, if palm oil for the EU biofuel mandate is produced on already existing plantation areas or on areas used for other agriculture production before, and the demand for palm oil from other sectors remains stable or increases, palm oil plantations will expand into natural areas due to increasing prices. This expansion of palm plantations producing palm oil for other markets than the EU-biofuel market is possible because no binding sustainable criteria exist for these markets.[16] These ILUC mechanisms can only be avoided if there are expansion areas in Indonesia which are both in line with the EU-RED sustainability criteria and not yet used for agricultural production.

[16] The same mechanism is in place if another vegetable oil than palm oil is used for European biofuel production and the "missing" oil in the food market (indicated by increasing prices for vegetable oils) is replaced with palm oil from Indonesia.

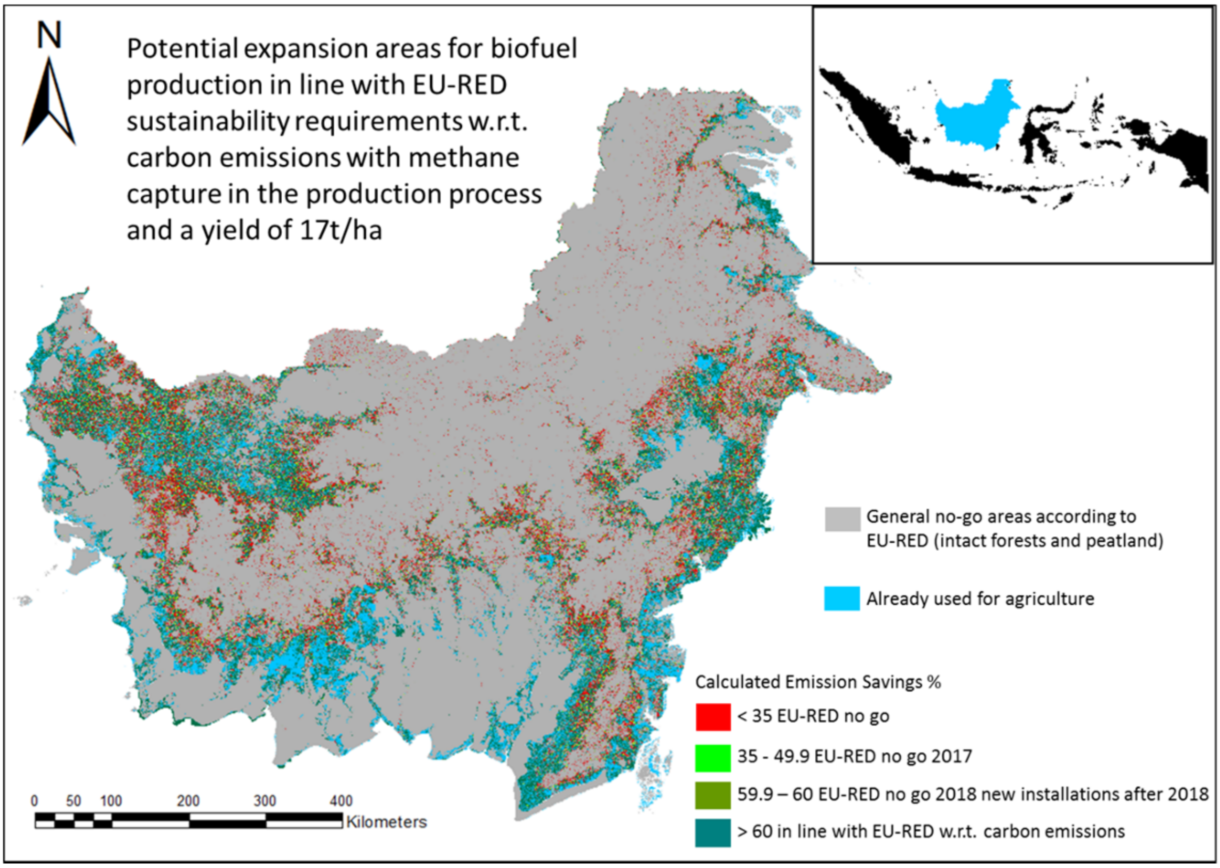
With respect to carbon I can determine these areas. Thus, in addition to Figure 13-18 where I already excluded wetland areas as well as peatswamp areas, I know exclude all forest areas (over 30% canopy cover) as they are no-go areas by definition in the EU-RED (light grey). This calculation step only changes the results for Kalimantan, as the Sarvision approach allows different carbon values within one land cover class (see Table 2 and 3). For Sumatra, the carbon value for forest is the same for all forest areas, which is clearly beyond the 35% emission saving threshold such that this area is already excluded in the emission saving maps for Sumatra (Figure 13.-15.). In addition, I mark the areas which are already used for agricultural production in light blue and indicate the emissions saving threshold as in the previous set of maps. The results of this exercise are shown in Figure 19 for Sumatra and Figure 20 for Kalimantan.

Figure 19



It becomes evident that there are not many areas left for expansion into unused areas. For Sumatra the subtraction of the areas already used for agricultural production has the highest impact as in 2008 large areas of the island are already deforested and used for production. Expansion areas under the emission saving criterion decrease to only 3.4 million ha (see Table 2).

Figure 20



For Kalimantan this calculation step is less substantial as less area is already used for agricultural production. However, the general exclusion of forested areas excludes pixels which are in forest areas but have low biomass due to degradation or small openings. However, as these pixels can be at very remote areas and normally do not represent a large contiguous area which would be needed for the installation of a palm plantation, they are likely to be not suitable expansion areas, even when only applying the emission saving threshold. Thus, for Kalimantan, after this calculation step, expansion areas under a production process with methane capture and a yield of 17t/ha reduce to 7.3 million ha (see Table 3). This further reduces to 6.4 million ha when the 60% emission saving threshold is implemented. This is only ~ 10% of the island area.

5. Discussion of results

For the evaluation of results one has to keep in mind that these maps do 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 will further decrease suitable areas. Thus, even though this conclusion is tempting, the10% will not be the whole available expansion area for palm oil production in Kalimantan, keeping in mind that in addition, all production would need to achieve a yield of 17t/ha and apply methane capture for this number to hold. Moreover, this area is only freely available if all other production remains constant.

If demand for palm oil and other agricultural products from Indonesia increases as well, and if production other than for the European fuel market remain under no sustainability regulation, the impact of the carbon maps will be limited. Palm oil for the European fuel market would be produced on certifiable areas and other production will freely expand into forest areas. Thus, the small amount of available area for a sustainable expansion increases the risk of ILUC. Therefore to evaluate the impact of the EU-RED and carbon maps on decreasing carbon emissions in Indonesia, the overall national development needs to be considered.

The OECD expects an increase in global consumption of vegetable oils of 30% till 2021 compared to 2009 (OECD Agricultural Outlook). In this context Indonesia wants to reach a production of 40m tonnes palm oil a year by 2020. In 2012 Indonesia produced roughly half of the global production of 50m tonnes. Thus, Indonesia's production is important to supply the world with cheap palm oil on the one hand. On the other hand, the sector accounts for 11% of total export earnings, second only to oil and gas and generates $5.7bn in export taxes for the government (McClanahan 2013). Therefore, the development of the sector has also national importance. Even though the government wants to achieve the goals in a sustainable manner, environmentalists doubt that it can be achieved without further forest destruction (McClanahan 2013). My results supports this in the context of EU-RED biofuel policies. Thus, Indonesia can be considered a key example of the challenge many developing countries face regarding the balance between protection of their natural resources and developing of their agricultural sector.

A sustainable expansion path without ILUC or leakage effects can only be achieved if all productions are subject to sustainability criteria. The implementation of a sustainable land use planning based on carbon maps that define areas for expansion and protection binding for all agricultural production is one strategy to achieve such sustainable expansion path. However the implementation of such maps into the official spatial planning processes is challenging when it hinders and sets limits to national development plans. This is especially true, when international increases in demand continue to set incentives for expansion of production as prospected by the OECD.

However, an important aspect to consider is the fact that not all area already used in the country is used in an efficient manner but can be degraded or with low productivity. Koh and Ghazoul (2010) show that a sustainable expansion of palm plantations without further substantial forest loss is possible with a suitable land use planning and development strategy that particularly accounts for a restoration of degraded areas. Thus, given the appropriate set of incentives, according to Koh and Ghazoul (2010) oil palm producers could completely abandon expansion in areas of high biomass and have plenty of growth opportunities in low biomass zones. Thus in order to achieve an expansion of production without leakage effects on natural areas, a sustainable land use management that includes the reactivation of degraded areas should be implemented. Consequently, if the EU wants to reduce the ILUC risk of its biofuel mandate, it should support the implementation of such policy. The feasibility of such policy in a country where weak institutions and corruption as part of the deforestation problem are not content of this analysis but represent a further hurdle to take for a sustainable production of biofuel feedstock in Indonesia (Lange and Bertelmann 2013).

It is therefore evident that the EU-RED sustainability requirements for biofuels alone will not substantially change the land use change development in Indonesia. However, my results show that the European Commission is right in being concerned about ILUC even if producers fulfil the sustainability requirements for DLUC. This is because ILUC in Indonesia can only be overcome if deforestation in general is reduced. In order to decrease the ILUC impact of the EU biofuel mandate in Indonesia, the EC should support the country to recover degraded areas for palm oil production and to enforce forest protection via a sustainable land use planning. My carbon maps can serve as a basis for such sustainable land use planning.

1. Conclusion

I show how to calculate a carbon map according to the sustainability requirements of the EU-RED for biofuel production with the example of Kalimantan and Sumatra in Indonesia. Based on the carbon map I derive maps showing the emission savings for biodiesel based on palm assuming different production processes and productivity. It was important to fill this gab as Indonesia is the largest producer of palm oil, the most important vegetable oil in the world. My maps can be used for a low carbon development policy of the agricultural sector in Indonesia.

My maps can further serve as a basis for investors which want to produce biofuels for the European market. However, the results clearly indicate that, even though the implementation of methane capture in the production process and an increase in yield might have a small impact on possible expansion areas, there seem to be not too much area left for a sustainable expansion of the palm oil sector for the European market. This increases the risk of ILUC. It further points out the importance of a sustainable land use planning and sustainability regulation for all production in Indonesia.

The impact of a regulation such as EU-RED is ineffective if all other production does not underlie any sustainability regulation. 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, but food, feed and bioenergy production other than biofuel production are not. To avoid indirect effects, the carbon map can be the basis for a sustainable land use planning with a strategy to reactivate degraded areas that is binding for all agricultural production in the country.

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Appendix I Data tables Sumatra

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Montane	Volcanic	Agriculture mixed Grass	80	21	29	0.74	59	92	89	152.0	158	121	142
Tropical Wet	HAC	Agriculture mixed Grass	44	21	29	0.74	33	51	62	110.6	134	97	122
Tropical Wet	LAC	Agriculture mixed Grass	60	21	29	0.74	44	69	74	129.0	145	108	131
Tropical Wet	other	Agriculture mixed Grass	83	21	29	0.74	61	95	91	155.5	160	123	144
Tropical Wet	sandy	Agriculture mixed Grass	66	21	29	0.74	49	76	78	135.9	148	111	135
Tropical Wet	Volcanic	Agriculture mixed Grass	130	21	29	0.74	96	150	126	209.5	191	154	170
Tropical Wet	wetland	Agriculture mixed Grass	86	21	29	0.74	64	99	93	158.9	162	125	146
Warm Temperate Moist	HAC	Agriculture mixed Grass	88	21	29	0.74	65	101	94	161.2	163	126	147
Warm Temperate Moist	LAC	Agriculture mixed Grass	63	21	29	0.74	47	72	76	132.5	146	110	133
Warm Temperate Moist	Volcanic	Agriculture mixed Grass	80	21	29	0.74	59	92	89	152.0	158	121	142
Tropical Moist	HAC	Agriculture mixed Grass	65	21	29	0.74	48	75	77	134.8	148	111	134
Tropical Moist	LAC	Agriculture mixed Grass	47	21	29	0.74	35	54	64	114.1	136	99	124
Tropical Moist	Volcanic	Agriculture mixed Grass	70	21	29	0.74	52	81	81	140.5	151	114	137
Tropical Moist	wetland	Agriculture mixed Grass	86	21	29	0.74	64	99	93	158.9	162	125	146
Tropical Montane	HAC	Agriculture mixed Grass	88	21	29	0.74	65	101	94	161.2	163	126	147
Tropical Montane	LAC	Agriculture mixed Grass	63	21	29	0.74	47	72	76	132.5	146	110	133
Tropical Montane	other	Agriculture mixed Grass	83	21	29	0.74	61	95	91	155.5	160	123	144
Tropical Montane	Spodic	Agriculture mixed Grass	124	21	29	0.74	92	143	121	202.6	187	150	167
Tropical Montane	Volcanic	Bush	80	30	41	1.00	80	92	121	152.0	105	68	98
Tropical Wet	HAC	Bush	44	30	41	1.00	44	51	85	110.6	97	60	91
Tropical Wet	LAC	Bush	60	30	41	1.00	60	69	101	129.0	101	64	94
Tropical Wet	other	Bush	83	30	41	1.00	83	95	124	155.5	106	69	99
Tropical Wet	sandy	Bush	66	30	41	1.00	66	76	107	135.9	102	65	95
Tropical Wet	Volcanic	Bush	130	30	41	1.00	130	150	171	209.5	117	80	108

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Wet	wetland	Bush	86	30	41	1.00	86	99	127	158.9	107	70	99
Warm Temperate Moist	HAC	Bush	88	30	41	1.00	88	101	129	161.2	107	70	100
Warm Temperate Moist	LAC	Bush	63	30	41	1.00	63	72	104	132.5	101	64	95
Warm Temperate Moist	Spodic	Bush	124	30	41	1.00	124	143	165	202.6	116	79	107
Warm Temperate Moist	Volcanic	Bush	80	30	41	1.00	80	92	121	152.0	105	68	98
Tropical Moist	HAC	Bush	65	30	41	1.00	65	75	106	134.8	102	65	95
Tropical Moist	LAC	Bush	47	30	41	1.00	47	54	88	114.1	97	60	91
Tropical Moist	Volcanic	Bush	70	30	41	1.00	70	81	111	140.5	103	66	96
Tropical Moist	wetland	Bush	86	30	41	1.00	86	99	127	158.9	107	70	99
Tropical Montane	HAC	Bush	88	30	41	1.00	88	101	129	161.2	107	70	100
Tropical Montane	LAC	Bush	63	30	41	1.00	63	72	104	132.5	101	64	95
Tropical Montane	other	Bush	83	30	41	1.00	83	95	124	155.5	106	69	99
Tropical Montane	Spodic	Bush	124	30	41	1.00	124	143	165	202.6	116	79	107
Tropical Montane	Volcanic	Dryland farming	80	5	7	1.00	80	92	87	152.0	160	123	145
Tropical Wet	HAC	Dryland farming	44	5	7	1.00	44	51	51	110.6	152	115	137
Tropical Wet	LAC	Dryland farming	60	5	7	1.00	60	69	67	129.0	156	119	141
Tropical Wet	other	Dryland farming	83	5	7	1.00	83	95	90	155.5	161	124	145
Tropical Wet	sandy	Dryland farming	66	5	7	1.00	66	76	73	135.9	157	120	142
Tropical Wet	Spodic	Dryland farming	124	5	7	1.00	124	143	131	202.6	171	134	154
Tropical Wet	Volcanic	Dryland farming	130	5	7	1.00	130	150	137	209.5	172	135	155
Tropical Wet	wetland	Dryland farming	86	5	7	1.00	86	99	93	158.9	162	125	146
Warm Temperate Moist	HAC	Dryland farming	88	5	7	1.00	88	101	95	161.2	162	125	146
Warm Temperate Moist	LAC	Dryland farming	63	5	7	1.00	63	72	70	132.5	156	119	141
Warm Temperate Moist	Spodic	Dryland farming	124	5	7	1.00	124	143	131	202.6	171	134	154
Warm Temperate Moist	Volcanic	Dryland farming	80	5	7	1.00	80	92	87	152.0	160	123	145

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Moist	HAC	Dryland farming	65	5	7	1.00	65	75	72	134.8	157	120	142
Tropical Moist	LAC	Dryland farming	47	5	7	1.00	47	54	54	114.1	152	115	138
Tropical Moist	Volcanic	Dryland farming	70	5	7	1.00	70	81	77	140.5	158	121	143
Tropical Moist	wetland	Dryland farming	86	5	7	1.00	86	99	93	158.9	162	125	146
Tropical Montane	HAC	Dryland farming	88	5	7	1.00	88	101	95	161.2	162	125	146
Tropical Montane	LAC	Dryland farming	63	5	7	1.00	63	72	70	132.5	156	119	141
Tropical Montane	other	Dryland farming	83	5	7	1.00	83	95	90	155.5	161	124	145
Tropical Montane	Spodic	Dryland farming	124	5	7	1.00	124	143	131	202.6	171	134	154
Tropical Montane	Volcanic	Forest Plantation	80	151	207	1.00	80	92	287	152.0	-161	-198	-129
Tropical Wet	HAC	Forest Plantation	44	151	207	1.00	44	51	251	110.6	-170	-207	-136
Tropical Wet	LAC	Forest Plantation	60	151	207	1.00	60	69	267	129.0	-166	-203	-133
Tropical Wet	other	Forest Plantation	83	151	207	1.00	83	95	290	155.5	-161	-197	-128
Tropical Wet	sandy	Forest Plantation	66	151	207	1.00	66	76	273	135.9	-165	-202	-132
Tropical Wet	Spodic	Forest Plantation	124	151	207	1.00	124	143	331	202.6	-151	-188	-120
Tropical Wet	Volcanic	Forest Plantation	130	151	207	1.00	130	150	337	209.5	-149	-186	-118
Tropical Wet	wetland	Forest Plantation	86	151	207	1.00	86	99	293	158.9	-160	-197	-127
Warm Temperate Moist	LAC	Forest Plantation	63	151	207	1.00	63	72	270	132.5	-165	-202	-132
Warm Temperate Moist	Spodic	Forest Plantation	124	151	207	1.00	124	143	331	202.6	-151	-188	-120
Tropical Moist	HAC	Forest Plantation	65	151	207	1.00	65	75	272	134.8	-165	-202	-132
Tropical Moist	LAC	Forest Plantation	47	151	207	1.00	47	54	254	114.1	-169	-206	-135
Tropical Moist	Volcanic	Forest Plantation	70	151	207	1.00	70	81	277	140.5	-164	-201	-131
Tropical Montane	HAC	Forest Plantation	88	151	207	1.00	88	101	295	161.2	-159	-196	-127
Tropical Montane	LAC	Forest Plantation	63	151	207	1.00	63	72	270	132.5	-165	-202	-132
Tropical Montane	other	Forest Plantation	83	151	207	1.00	83	95	290	155.5	-161	-197	-128
Tropical Montane	Spodic	Forest Plantation	124	151	207	1.00	124	143	331	202.6	-151	-188	-120

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Montane	Volcanic	Mixed Agriculture	80	5	7	0.69	55	92	62	152.0	200	163	178
Tropical Wet	HAC	Mixed Agriculture	44	5	7	0.69	31	51	37	110.6	173	136	156
Tropical Wet	LAC	Mixed Agriculture	60	5	7	0.69	42	69	48	129.0	185	148	166
Tropical Wet	other	Mixed Agriculture	83	5	7	0.69	58	95	64	155.5	202	165	180
Tropical Wet	sandy	Mixed Agriculture	66	5	7	0.69	46	76	53	135.9	189	152	169
Tropical Wet	Volcanic	Mixed Agriculture	130	5	7	0.69	90	150	97	209.5	236	199	209
Tropical Wet	wetland	Mixed Agriculture	86	5	7	0.69	60	99	66	158.9	204	167	182
Warm Temperate Moist	HAC	Mixed Agriculture	88	5	7	0.69	61	101	68	161.2	206	169	183
Warm Temperate Moist	Volcanic	Mixed Agriculture	80	5	7	0.69	55	92	62	152.0	200	163	178
Tropical Montane	HAC	Mixed Agriculture	88	5	7	0.69	61	101	68	161.2	206	169	183
Tropical Montane	LAC	Mixed Agriculture	63	5	7	0.69	44	72	51	132.5	187	150	168
Tropical Montane	Volcanic	Open Land	80	0	23	1.00	80	92	103	152.0	134	97	122
Tropical Wet	HAC	Open Land	44	0	23	1.00	44	51	67	110.6	125	88	115
Tropical Wet	LAC	Open Land	60	0	23	1.00	60	69	83	129.0	129	92	118
Tropical Wet	other	Open Land	83	0	23	1.00	83	95	106	155.5	135	98	123
Tropical Wet	sandy	Open Land	66	0	23	1.00	66	76	89	135.9	130	93	119
Tropical Wet	Spodic	Open Land	124	0	23	1.00	124	143	147	202.6	144	107	131
Tropical Wet	Volcanic	Open Land	130	0	23	1.00	130	150	153	209.5	146	109	132
Tropical Wet	wetland	Open Land	86	0	23	1.00	86	99	109	158.9	135	98	123
Warm Temperate Moist	HAC	Open Land	88	0	23	1.00	88	101	111	161.2	136	99	124
Warm Temperate Moist	LAC	Open Land	63	0	23	1.00	63	72	86	132.5	130	93	119
Warm Temperate Moist	Spodic	Open Land	124	0	23	1.00	124	143	147	202.6	144	107	131
Warm Temperate Moist	Volcanic	Open Land	80	0	23	1.00	80	92	103	152.0	134	97	122
Tropical Moist	HAC	Open Land	65	0	23	1.00	65	75	88	134.8	130	93	119
Tropical Moist	LAC	Open Land	47	0	23	1.00	47	54	70	114.1	126	89	115

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Moist	wetland	Open Land	86	0	23	1.00	86	99	109	158.9	135	98	123
Tropical Montane	HAC	Open Land	88	0	23	1.00	88	101	111	161.2	136	99	124
Tropical Montane	LAC	Open Land	63	0	23	1.00	63	72	86	132.5	130	93	119
Tropical Montane	other	Open Land	83	0	23	1.00	83	95	106	155.5	135	98	123
Tropical Montane	Spodic	Open Land	124	0	23	1.00	124	143	147	202.6	144	107	131
Tropical Montane	Volcanic	Paddy Field	80	3	4	1.10	88	92	92	152.0	152	115	137
Tropical Wet	HAC	Paddy Field	44	3	4	1.10	48	51	53	110.6	149	112	135
Tropical Wet	LAC	Paddy Field	60	3	4	1.10	66	69	70	129.0	150	113	136
Tropical Wet	other	Paddy Field	83	3	4	1.10	91	95	96	155.5	152	115	138
Tropical Wet	sandy	Paddy Field	66	3	4	1.10	73	76	77	135.9	151	114	136
Tropical Wet	Volcanic	Paddy Field	130	3	4	1.10	143	150	147	209.5	156	119	141
Tropical Wet	wetland	Paddy Field	86	3	4	1.10	95	99	99	158.9	152	115	138
Warm Temperate Moist	Spodic	Paddy Field	124	3	4	1.10	136	143	141	202.6	155	118	140
Warm Temperate Moist	Volcanic	Paddy Field	80	3	4	1.10	88	92	92	152.0	152	115	137
Tropical Moist	HAC	Paddy Field	65	3	4	1.10	72	75	76	134.8	150	113	136
Tropical Moist	LAC	Paddy Field	47	3	4	1.10	52	54	56	114.1	149	112	135
Tropical Moist	Volcanic	Paddy Field	70	3	4	1.10	77	81	81	140.5	151	114	137
Tropical Moist	wetland	Paddy Field	86	3	4	1.10	95	99	99	158.9	152	115	138
Tropical Montane	HAC	Paddy Field	88	3	4	1.10	97	101	101	161.2	152	115	138
Tropical Montane	LAC	Paddy Field	63	3	4	1.10	69	72	74	132.5	150	113	136
Tropical Montane	other	Paddy Field	83	3	4	1.10	91	95	96	155.5	152	115	138
Tropical Montane	Spodic	Paddy Field	124	3	4	1.10	136	143	141	202.6	155	118	140
Tropical Montane	Volcanic	Plantation	80		60	1.15	92	92	152	152.0	56	19	56
Tropical Wet	HAC	Plantation	44		60	1.15	51	51	111	110.6	56	19	56
Tropical Wet	LAC	Plantation	60		60	1.15	69	69	129	129.0	56	19	56

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Wet	sandy	Plantation	66		60	1.15	76	76	136	135.9	56	19	56
Tropical Wet	Volcanic	Plantation	130		60	1.15	150	150	210	209.5	56	19	56
Tropical Wet	wetland	Plantation	86		60	1.15	99	99	159	158.9	56	19	56
Warm Temperate Moist	Volcanic	Plantation	80		60	1.15	92	92	152	152.0	56	19	56
Tropical Moist	HAC	Plantation	65		60	1.15	75	75	135	134.8	56	19	56
Tropical Moist	LAC	Plantation	47		60	1.15	54	54	114	114.1	56	19	56
Tropical Montane	HAC	Plantation	88		60	1.15	101	101	161	161.2	56	19	56
Tropical Montane	LAC	Plantation	63		60	1.15	72	72	132	132.5	56	19	56
Tropical Montane	Volcanic	Primary Dryland Forest	80	277	379	1.00	80	92	459	152.0	-437	-474	-363
Tropical Wet	HAC	Primary Dryland Forest	44	277	379	1.00	44	51	423	110.6	-445	-482	-370
Tropical Wet	LAC	Primary Dryland Forest	60	277	379	1.00	60	69	439	129.0	-441	-478	-367
Tropical Wet	other	Primary Dryland Forest	83	277	379	1.00	83	95	462	155.5	-436	-473	-362
Tropical Wet	Spodic	Primary Dryland Forest	124	277	379	1.00	124	143	503	202.6	-426	-463	-354
Tropical Wet	Volcanic	Primary Dryland Forest	130	277	379	1.00	130	150	509	209.5	-424	-461	-352
Warm Temperate Moist	HAC	Primary Dryland Forest	88	277	379	1.00	88	101	467	161.2	-435	-472	-361
Warm Temperate Moist	LAC	Primary Dryland Forest	63	277	379	1.00	63	72	442	132.5	-441	-478	-366
Warm Temperate Moist	Volcanic	Primary Dryland Forest	80	277	379	1.00	80	92	459	152.0	-437	-474	-363
Tropical Moist	LAC	Primary Dryland Forest	47	277	379	1.00	47	54	426	114.1	-444	-481	-369
Tropical Montane	HAC	Primary Dryland Forest	88	277	379	1.00	88	101	467	161.2	-435	-472	-361
Tropical Montane	LAC	Primary Dryland Forest	63	277	379	1.00	63	72	442	132.5	-441	-478	-366
Tropical Wet	HAC	Primary Mangrove Forest	44	159	218	1.00	44	51	262	110.6	-187	-224	-150
Tropical Wet	wetland	Primary Mangrove Forest	86	159	218	1.00	86	99	304	158.9	-177	-214	-142
Tropical Moist	HAC	Primary Mangrove Forest	65	159	218	1.00	65	75	283	134.8	-182	-219	-146
Tropical Montane	Volcanic	Savana	80	13	18	1.00	80	92	98	152.0	142	105	129
Tropical Wet	HAC	Savana	44	13	18	1.00	44	51	62	110.6	133	96	122

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Tropical Wet	LAC	Savana	60	13	18	1.00	60	69	78	129.0	137	100	125
Tropical Wet	other	Savana	83	13	18	1.00	83	95	101	155.5	143	106	130
Tropical Wet	sandy	Savana	66	13	18	1.00	66	76	84	135.9	139	102	126
Tropical Wet	Volcanic	Savana	130	13	18	1.00	130	150	148	209.5	154	117	139
Tropical Wet	wetland	Savana	86	13	18	1.00	86	99	104	158.9	144	107	130
Warm Temperate Moist	HAC	Savana	88	13	18	1.00	88	101	106	161.2	144	107	131
Warm Temperate Moist	LAC	Savana	63	13	18	1.00	63	72	81	132.5	138	101	126
Warm Temperate Moist	Volcanic	Savana	80	13	18	1.00	80	92	98	152.0	142	105	129
Tropical Moist	HAC	Savana	65	13	18	1.00	65	75	83	134.8	139	102	126
Tropical Moist	LAC	Savana	47	13	18	1.00	47	54	65	114.1	134	97	122
Tropical Moist	Volcanic	Savana	70	13	18	1.00	70	81	88	140.5	140	103	127
Tropical Moist	wetland	Savana	86	13	18	1.00	86	99	104	158.9	144	107	130
Tropical Montane	HAC	Savana	88	13	18	1.00	88	101	106	161.2	144	107	131
Tropical Montane	LAC	Savana	63	13	18	1.00	63	72	81	132.5	138	101	126
Tropical Montane	Volcanic	Secondary Dryland Forest	80	200	273	1.00	80	92	353	152.0	-267	-304	-219
Tropical Wet	HAC	Secondary Dryland Forest	44	200	273	1.00	44	51	317	110.6	-276	-313	-226
Tropical Wet	LAC	Secondary Dryland Forest	60	200	273	1.00	60	69	333	129.0	-272	-309	-223
Tropical Wet	other	Secondary Dryland Forest	83	200	273	1.00	83	95	356	155.5	-266	-303	-218
Tropical Wet	sandy	Secondary Dryland Forest	66	200	273	1.00	66	76	339	135.9	-270	-307	-222
Tropical Wet	Spodic	Secondary Dryland Forest	124	200	273	1.00	124	143	397	202.6	-256	-293	-210
Tropical Wet	Volcanic	Secondary Dryland Forest	130	200	273	1.00	130	150	403	209.5	-255	-292	-208
Tropical Wet	wetland	Secondary Dryland Forest	86	200	273	1.00	86	99	359	158.9	-266	-303	-217
Warm Temperate Moist	HAC	Secondary Dryland Forest	88	200	273	1.00	88	101	361	161.2	-265	-302	-217
Warm Temperate Moist	LAC	Secondary Dryland Forest	63	200	273	1.00	63	72	336	132.5	-271	-308	-222
Warm Temperate Moist	Spodic	Secondary Dryland Forest	124	200	273	1.00	124	143	397	202.6	-256	-293	-210

Climate	Soil	Land Cover	SOCref*	AGC	Total Biomass Carbon	Total Soil factors	SOCact**	SOCpalm	Total carbon	Total Carbon Palm	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
Warm Temperate Moist	Volcanic	Secondary Dryland Forest	80	200	273	1.00	80	92	353	152.0	-267	-304	-219
Tropical Moist	HAC	Secondary Dryland Forest	65	200	273	1.00	65	75	338	134.8	-271	-308	-222
Tropical Moist	LAC	Secondary Dryland Forest	47	200	273	1.00	47	54	320	114.1	-275	-312	-225
Tropical Moist	Volcanic	Secondary Dryland Forest	70	200	273	1.00	70	81	343	140.5	-269	-306	-221
Tropical Montane	HAC	Secondary Dryland Forest	88	200	273	1.00	88	101	361	161.2	-265	-302	-217
Tropical Montane	LAC	Secondary Dryland Forest	63	200	273	1.00	63	72	336	132.5	-271	-308	-222
Tropical Montane	other	Secondary Dryland Forest	83	200	273	1.00	83	95	356	155.5	-266	-303	-218
Tropical Montane	Spodic	Secondary Dryland Forest	124	200	273	1.00	124	143	397	202.6	-256	-293	-210
Tropical Wet	HAC	Secondary Mangrove forest	44	91	124	1.00	44	51	168	110.6	-36	-73	-23
Tropical Wet	LAC	Secondary Mangrove forest	60	91	124	1.00	60	69	184	129.0	-33	-70	-19
Tropical Wet	wetland	Secondary Mangrove forest	86	91	124	1.00	86	99	210	158.9	-26	-63	-14
Tropical Moist	HAC	Secondary Mangrove forest	65	91	124	1.00	65	75	189	134.8	-31	-68	-18

* for Podzols no data are available for tropical regions from the EU-RED. I use values from Montes et al. (2011) and assume 20 cm upper organic-rich horizons with 170tC/ha and 10 cm middle sandy horizons with 31tC/ha

** I assume total soil factors for palm plantations of 1.15 and 1.09 in montane regions and 60tC/ha in biomass according to EU-RED

*** For all caluclations I assume 4.5 kg biomass per 1 l fuel and a heating value of 32.65 MJ/l biodiesel (FNR 2012)

Table 2.Source values for above ground carbon

Land Cover Class	AGC	Source
	tC/ha	
Paddy Field	3	APN 2001; Lasco et al. 1999
Plantation	60	EU-RED palm plantation
Primary Dryland Forest	277	Murdiyarso and Wasrin 1995 (Primary humid evergreen; lower montane; lowland dipterocarp); Hairiah and Sitompul (2000); Noorwijk et al.(2000)
Primary Mangrove Forest	159	Donato et al. (2011)
Savana	13	Murdiyarso and Wasrin (1996); Prasetyo et al.2000)
Secondary Dryland Forest	200	57% of Primary Forest APN (2001) average of studies on logged over forest
Secondary Mangrove forest	91	57% of Primary Forest APN (2001) average of studies on logged over forest
Agriculture mixed Grass	21	Sitompul and Hairiah (2000) (Chromolaena); Gintings (2000) (Imperate; Cassava);Noordwijk et al.(2000) (Cassava/imperata sp.; uplandrice/bush fallo rotation); Murdiyarso and Wasrin (1996) (grassland);Prasetyo et al. (2000) (grassland)
Bush	30	Lasco and Pulhin (2004)
Dryland farming	5	Murdiyarso and Wasrin (1996)
Forest Plantation	151	Sitompul and Hairiah (2000) (rubber agroforestry); IPCC (2006)(broadleaf; other)
Mixed Agriculture	5	Murdiyarso and Wasrin (1996)
Open Land	0	

APPENDIX 2 Data tables Kalimantan

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
water	Tropical Montane	HAC	1.00	0	88	88	88	155.92	165	128	148
water	Tropical Wet	HAC	1.00	0	44	44	44	110.6	163	126	147
water	Tropical Moist	HAC	1.00	0	65	65	65	134.75	168	131	151
water	Tropical Montane	LAC	1.00	0	63	63	63	128.67	161	124	145
water	Tropical Wet	LAC	1.00	0	60	60	60	129	167	130	150
water	Tropical Moist	LAC	1.00	0	47	47	47	114.05	163	126	147
water	Tropical Montane	Sandy	1.00	0	34	34	34	97.06	157	120	142
water	Tropical Wet	Sandy	1.00	0	66	66	66	135.9	168	131	151
water	Tropical Moist	Sandy	1.00	0	39	39	39	104.85	161	124	146
water	Tropical Montane	Spodic	1.00	0	123.67	123.67	123.67	194.8003	170	133	153
water	Tropical Wet	Spodic	1.00	0	123.67	123.67	123.67	202.2205	182	145	163
water	Tropical Moist	Spodic	1.00	0	123.67	123.67	123.67	202.2205	182	145	163
water	Tropical Montane	Wetland	1.00	0	86	86	86	153.74	165	128	148
water	Tropical Wet	Wetland	1.00	0	86	86	86	158.9	173	136	155
water	Tropical Moist	Wetland	1.00	0	86	86	86	158.9	173	136	155
degraded forest	Tropical Montane	HAC	1.00	50.17	88	88	138.17	155.92	84	47	80
degraded forest	Tropical Wet	HAC	1.00	50.17	44	44	94.17	110.6	82	45	78
degraded forest	Tropical Moist	HAC	1.00	50.17	65	65	115.17	134.75	87	50	83
degraded forest	Tropical Montane	LAC	1.00	50.17	63	63	113.17	128.67	81	44	77
degraded forest	Tropical Wet	LAC	1.00	50.17	60	60	110.17	129	86	49	82
degraded forest	Tropical Moist	LAC	1.00	50.17	47	47	97.17	114.05	83	46	79
degraded forest	Tropical Montane	Sandy	1.00	50.17	34	34	84.17	97.06	77	40	73
degraded forest	Tropical Wet	Sandy	1.00	50.17	66	66	116.17	135.9	87	51	83

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
degraded forest	Tropical Moist	Sandy	1.00	50.17	39	39	89.17	104.85	81	44	77
degraded forest	Tropical Montane	Spodic	1.00	50.17	123.67	123.67	173.84	194.8003	89	52	84
degraded forest	Tropical Wet	Spodic	1.00	50.17	123.67	123.67	173.84	202.2205	101	64	95
degraded forest	Tropical Moist	Spodic	1.00	50.17	123.67	123.67	173.84	202.2205	101	64	95
degraded forest	Tropical Montane	Wetland	1.00	50.17	86	86	136.17	153.74	84	47	80
degraded forest	Tropical Wet	Wetland	1.00	50.17	86	86	136.17	158.9	92	55	87
degraded forest	Tropical Moist	Wetland	1.00	50.17	86	86	136.17	158.9	92	55	87
peat swamp forest	Tropical Montane	HAC	1.00	68.98	88	88	156.98	155.92	54	17	54
peat swamp forest	Tropical Wet	HAC	1.00	68.98	44	44	112.98	110.6	52	15	53
peat swamp forest	Tropical Moist	HAC	1.00	68.98	65	65	133.98	134.75	57	20	57
peat swamp forest	Tropical Montane	LAC	1.00	68.98	63	63	131.98	128.67	51	14	51
peat swamp forest	Tropical Wet	LAC	1.00	68.98	60	60	128.98	129	56	19	56
peat swamp forest	Tropical Moist	LAC	1.00	68.98	47	47	115.98	114.05	53	16	53
peat swamp forest	Tropical Montane	Sandy	1.00	68.98	34	34	102.98	97.06	46	9	48
peat swamp forest	Tropical Wet	Sandy	1.00	68.98	66	66	134.98	135.9	57	20	57
peat swamp forest	Tropical Moist	Sandy	1.00	68.98	39	39	107.98	104.85	51	14	52
peat swamp forest	Tropical Montane	Spodic	1.00	68.98	123.67	123.67	192.65	194.8003	59	22	59
peat swamp forest	Tropical Wet	Spodic	1.00	68.98	123.67	123.67	192.65	202.2205	71	34	69
peat swamp forest	Tropical Moist	Spodic	1.00	68.98	123.67	123.67	192.65	202.2205	71	34	69
peat swamp forest	Tropical Montane	Wetland	1.00	68.98	86	86	154.98	153.74	54	17	54
peat swamp forest	Tropical Wet	Wetland	1.00	68.98	86	86	154.98	158.9	62	25	61
peat swamp forest	Tropical Moist	Wetland	1.00	68.98	86	86	154.98	158.9	62	25	61
agriculture dry	Tropical Montane	HAC	0.64	3.56	88	56.32	59.88	155.92	210	173	187
agriculture dry	Tropical Wet	HAC	0.48	3.56	44	21.12	24.68	110.6	194	157	173

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
agriculture dry	Tropical Moist	HAC	0.48	3.56	65	31.2	34.76	134.75	216	179	192
agriculture dry	Tropical Montane	LAC	0.64	3.56	63	40.32	43.88	128.67	192	155	171
agriculture dry	Tropical Wet	LAC	0.48	3.56	60	28.8	32.36	129	211	174	188
agriculture dry	Tropical Moist	LAC	0.48	3.56	47	22.56	26.12	114.05	197	160	176
agriculture dry	Tropical Montane	Sandy	0.64	3.56	34	21.76	25.32	97.06	171	134	154
agriculture dry	Tropical Wet	Sandy	0.48	3.56	66	31.68	35.24	135.9	217	180	193
agriculture dry	Tropical Moist	Sandy	0.48	3.56	39	18.72	22.28	104.85	188	151	168
agriculture dry	Tropical Montane	Spodic	0.64	3.56	123.67	79.1488	82.7088	194.8003	236	199	209
agriculture dry	Tropical Wet	Spodic	0.48	3.56	123.67	59.3616	62.9216	202.2205	279	242	246
agriculture dry	Tropical Moist	Spodic	0.48	3.56	123.67	59.3616	62.9216	202.2205	279	242	246
agriculture dry	Tropical Montane	Wetland	0.64	3.56	86	55.04	58.6	153.74	208	171	186
agriculture dry	Tropical Wet	Wetland	0.48	3.56	86	41.28	44.84	158.9	239	202	211
agriculture dry	Tropical Moist	Wetland	0.48	3.56	86	41.28	44.84	158.9	239	202	211
high grassland, shrubland	Tropical Montane	HAC	1.00	3.71	88	88	91.71	155.92	159	122	143
high grassland, shrubland	Tropical Wet	HAC	1.00	3.71	44	44	47.71	110.6	157	120	142
high grassland, shrubland	Tropical Moist	HAC	1.00	3.71	65	65	68.71	134.75	162	125	146
high grassland, shrubland	Tropical Montane	LAC	1.00	3.71	63	63	66.71	128.67	155	118	140
high grassland, shrubland	Tropical Wet	LAC	1.00	3.71	60	60	63.71	129	161	124	145
high grassland, shrubland	Tropical Moist	LAC	1.00	3.71	47	47	50.71	114.05	157	120	142
high grassland, shrubland	Tropical Montane	Sandy	1.00	3.71	34	34	37.71	97.06	151	114	137
high grassland, shrubland	Tropical Wet	Sandy	1.00	3.71	66	66	69.71	135.9	162	125	146
high grassland, shrubland	Tropical Moist	Sandy	1.00	3.71	39	39	42.71	104.85	156	119	141
high grassland, shrubland	Tropical Montane	Spodic	1.00	3.71	123.67	123.67	127.38	194.8003	164	127	148
high grassland, shrubland	Tropical Wet	Spodic	1.00	3.71	123.67	123.67	127.38	202.2205	176	139	158

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
high grassland, shrubland	Tropical Moist	Spodic	1.00	3.71	123.67	123.67	127.38	202.2205	176	139	158
high grassland, shrubland	Tropical Montane	Wetland	1.00	3.71	86	86	89.71	153.74	159	122	143
high grassland, shrubland	Tropical Wet	Wetland	1.00	3.71	86	86	89.71	158.9	167	130	150
high grassland, shrubland	Tropical Moist	Wetland	1.00	3.71	86	86	89.71	158.9	167	130	150
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Montane	HAC	1.00	139.4	88	88	227.4	155.92	-59	-96	-42
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Wet	HAC	1.00	139.4	44	44	183.4	110.6	-61	-98	-43
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Moist	HAC	1.00	139.4	65	65	204.4	134.75	-56	-93	-39
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Montane	LAC	1.00	139.4	63	63	202.4	128.67	-62	-99	-45
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Wet	LAC	1.00	139.4	60	60	199.4	129	-57	-94	-40
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Moist	LAC	1.00	139.4	47	47	186.4	114.05	-60	-97	-43
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Montane	Sandy	1.00	139.4	34	34	173.4	97.06	-67	-104	-48
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Wet	Sandy	1.00	139.4	66	66	205.4	135.9	-56	-93	-39
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Moist	Sandy	1.00	139.4	39	39	178.4	104.85	-62	-99	-44
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Montane	Spodic	1.00	139.4	123.67	123.67	263.07	194.8003	-54	-91	-37
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Wet	Spodic	1.00	139.4	123.67	123.67	263.07	202.2205	-42	-79	-27
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Moist	Spodic	1.00	139.4	123.67	123.67	263.07	202.2205	-42	-79	-27
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Montane	Wetland	1.00	139.4	86	86	225.4	153.74	-59	-96	-42
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Wet	Wetland	1.00	139.4	86	86	225.4	158.9	-51	-88	-35
high forest closed canopy. Lowland and montane dipterocarp forest types on flat and mountainous terrain, well drained	Tropical Moist	Wetland	1.00	139.4	86	86	225.4	158.9	-51	-88	-35

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Montane	HAC	1.00	131.2	88	88	219.2	155.92	-46	-83	-30
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Wet	HAC	1.00	131.2	44	44	175.2	110.6	-48	-85	-32
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Moist	HAC	1.00	131.2	65	65	196.2	134.75	-43	-80	-28
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Montane	LAC	1.00	131.2	63	63	194.2	128.67	-49	-86	-34
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Wet	LAC	1.00	131.2	60	60	191.2	129	-44	-81	-29
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Moist	LAC	1.00	131.2	47	47	178.2	114.05	-47	-84	-32
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Montane	Sandy	1.00	131.2	34	34	165.2	97.06	-53	-90	-37
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Wet	Sandy	1.00	131.2	66	66	197.2	135.9	-42	-79	-28
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Moist	Sandy	1.00	131.2	39	39	170.2	104.85	-49	-86	-33
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Montane	Spodic	1.00	131.2	123.67	123.67	254.87	194.8003	-41	-78	-26
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Wet	Spodic	1.00	131.2	123.67	123.67	254.87	202.2205	-29	-66	-16
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Moist	Spodic	1.00	131.2	123.67	123.67	254.87	202.2205	-29	-66	-16
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Montane	Wetland	1.00	131.2	86	86	217.2	153.74	-46	-83	-31
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Wet	Wetland	1.00	131.2	86	86	217.2	158.9	-38	-75	-24
high forest closed canopy. Mixed peat swamp forest and tall heath forest on flat terrain in poorly drained areas.	Tropical Moist	Wetland	1.00	131.2	86	86	217.2	158.9	-38	-75	-24
Recently cleared areas, low biomass	Tropical Wet	HAC	1.00	2.61	88	88	90.61	161.2	169	132	152
Recently cleared areas, low biomass	Tropical Wet	HAC	1.00	2.61	44	44	46.61	110.6	158	121	143
Recently cleared areas, low biomass	Tropical Moist	HAC	1.00	2.61	65	65	67.61	134.75	164	127	147
Recently cleared areas, low biomass	Tropical Montane	LAC	1.00	2.61	63	63	65.61	128.67	157	120	142

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Recently cleared areas, low biomass	Tropical Wet	LAC	1.00	2.61	60	60	62.61	129	162	125	146
Recently cleared areas, low biomass	Tropical Moist	LAC	1.00	2.61	47	47	49.61	114.05	159	122	144
Recently cleared areas, low biomass	Tropical Montane	Sandy	1.00	2.61	34	34	36.61	97.06	153	116	138
Recently cleared areas, low biomass	Tropical Wet	Sandy	1.00	2.61	66	66	68.61	135.9	164	127	148
Recently cleared areas, low biomass	Tropical Moist	Sandy	1.00	2.61	39	39	41.61	104.85	157	120	142
Recently cleared areas, low biomass	Tropical Montane	Spodic	1.00	2.61	123.67	123.67	126.28	194.8003	166	129	149
Recently cleared areas, low biomass	Tropical Wet	Spodic	1.00	2.61	123.67	123.67	126.28	202.2205	178	141	159
Recently cleared areas, low biomass	Tropical Moist	Spodic	1.00	2.61	123.67	123.67	126.28	202.2205	178	141	159
Recently cleared areas, low biomass	Tropical Montane	Wetland	1.00	2.61	86	86	88.61	153.74	160	123	145
Recently cleared areas, low biomass	Tropical Wet	Wetland	1.00	2.61	86	86	88.61	158.9	169	132	152
Recently cleared areas, low biomass	Tropical Moist	Wetland	1.00	2.61	86	86	88.61	158.9	169	132	152
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Montane	HAC	1.09	21.62	88	95.92	117.54	155.92	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Wet	HAC	1.15	21.62	44	50.6	72.22	110.6	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Moist	HAC	1.15	21.62	65	74.75	96.37	134.75	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Montane	LAC	1.09	21.62	63	68.67	90.29	128.67	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Wet	LAC	1.15	21.62	60	69	90.62	129	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Moist	LAC	1.15	21.62	47	54.05	75.67	114.05	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Montane	Sandy	1.09	21.62	34	37.06	58.68	97.06	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Wet	Sandy	1.15	21.62	66	75.9	97.52	135.9	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Moist	Sandy	1.15	21.62	39	44.85	66.47	104.85	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Montane	Spodic	1.09	21.62	123.67	134.8003	156.4203	194.8003	117	80	108

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Wet	Spodic	1.15	21.62	123.67	142.2205	163.8405	202.2205	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Moist	Spodic	1.15	21.62	123.67	142.2205	163.8405	202.2205	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Montane	Wetland	1.09	21.62	86	93.74	115.36	153.74	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Wet	Wetland	1.15	21.62	86	98.9	120.52	158.9	117	80	108
Plantation med development or woodland or shrubs med-low biomass (canopy 10-30%)	Tropical Moist	Wetland	1.15	21.62	86	98.9	120.52	158.9	117	80	108
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Montane	HAC	1.09	10.34	88	95.92	106.26	155.92	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Wet	HAC	1.15	10.34	44	50.6	60.94	110.6	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Moist	HAC	1.15	10.34	65	74.75	85.09	134.75	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Montane	LAC	1.15	10.34	63	72.45	82.79	128.67	129	92	118
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Wet	LAC	1.15	10.34	60	69	79.34	129	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Moist	LAC	1.15	10.34	47	54.05	64.39	114.05	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Montane	Sandy	1.15	10.34	34	39.1	49.44	97.06	132	95	121
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Wet	Sandy	1.15	10.34	66	75.9	86.24	135.9	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Moist	Sandy	1.15	10.34	39	44.85	55.19	104.85	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Montane	Spodic	1.15	10.34	123.67	142.2205	152.5605	194.8003	124	87	113
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Wet	Spodic	1.15	10.34	123.67	142.2205	152.5605	202.2205	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Moist	Spodic	1.15	10.34	123.67	142.2205	152.5605	202.2205	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Montane	Wetland	1.15	10.34	86	98.9	109.24	153.74	127	90	117
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Wet	Wetland	1.15	10.34	86	98.9	109.24	158.9	136	99	124
Plantations low biomass or shrubs low biomass (canopy less than 10%)	Tropical Moist	Wetland	1.15	10.34	86	98.9	109.24	158.9	136	99	124
Grassland low biomass	Tropical Montane	HAC	1.00	2.36	88	88	90.36	155.92	161	124	145
Grassland low biomass	Tropical Wet	HAC	1.00	2.36	44	44	46.36	110.6	159	122	143

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Grassland low biomass	Tropical Moist	HAC	1.00	2.36	65	65	67.36	134.75	164	127	148
Grassland low biomass	Tropical Montane	LAC	1.00	2.36	63	63	65.36	128.67	157	120	142
Grassland low biomass	Tropical Wet	LAC	1.00	2.36	60	60	62.36	129	163	126	147
Grassland low biomass	Tropical Moist	LAC	1.00	2.36	47	47	49.36	114.05	160	123	144
Grassland low biomass	Tropical Montane	Sandy	1.00	2.36	34	34	36.36	97.06	153	116	139
Grassland low biomass	Tropical Wet	Sandy	1.00	2.36	66	66	68.36	135.9	164	127	148
Grassland low biomass	Tropical Moist	Sandy	1.00	2.36	39	39	41.36	104.85	158	121	142
Grassland low biomass	Tropical Montane	Spodic	1.00	2.36	123.67	123.67	126.03	194.8003	166	129	150
Grassland low biomass	Tropical Wet	Spodic	1.00	2.36	123.67	123.67	126.03	202.2205	178	141	160
Grassland low biomass	Tropical Moist	Spodic	1.00	2.36	123.67	123.67	126.03	202.2205	178	141	160
Grassland low biomass	Tropical Montane	Wetland	1.00	2.36	86	86	88.36	153.74	161	124	145
Grassland low biomass	Tropical Wet	Wetland	1.00	2.36	86	86	88.36	158.9	169	132	152
Grassland low biomass	Tropical Moist	Wetland	1.00	2.36	86	86	88.36	158.9	169	132	152
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	HAC	1.09	26.67	88	95.92	122.59	161.2	118	81	108
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	HAC	1.15	26.67	44	50.6	77.27	110.6	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Moist	HAC	1.15	26.67	65	74.75	101.42	134.75	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Montane	LAC	1.09	26.67	63	68.67	95.34	128.67	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	LAC	1.15	26.67	60	69	95.67	129	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Moist	LAC	1.15	26.67	47	54.05	80.72	114.05	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Montane	Sandy	1.09	26.67	34	37.06	63.73	97.06	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	Sandy	1.15	26.67	66	75.9	102.57	135.9	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Moist	Sandy	1.15	26.67	39	44.85	71.52	104.85	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Montane	Spodic	1.09	26.67	123.67	134.8003	161.4703	194.8003	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	Spodic	1.15	26.67	123.67	142.2205	168.8905	202.2205	109	72	101

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Moist	Spodic	1.15	26.67	123.67	142.2205	168.8905	202.2205	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Montane	Wetland	1.09	26.67	86	93.74	120.41	153.74	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	Wetland	1.15	26.67	86	98.9	125.57	158.9	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Moist	Wetland	1.15	26.67	86	98.9	125.57	158.9	109	72	101
Plantation medium biomass (canopy 10-30%) high biomass	Tropical Wet	HAC	1.00	18.07	88	88	106.07	161.2	144	107	131
Recently cleared areas, high biomass	Tropical Wet	HAC	1.00	18.07	44	44	62.07	110.6	134	97	122
Recently cleared areas, high biomass	Tropical Moist	HAC	1.00	18.07	65	65	83.07	134.75	139	102	126
Recently cleared areas, high biomass	Tropical Montane	LAC	1.00	18.07	63	63	81.07	128.67	132	95	121
Recently cleared areas, high biomass	Tropical Wet	LAC	1.00	18.07	60	60	78.07	129	138	101	125
Recently cleared areas, high biomass	Tropical Moist	LAC	1.00	18.07	47	47	65.07	114.05	134	97	123
Recently cleared areas, high biomass	Tropical Montane	Sandy	1.00	18.07	34	34	52.07	97.06	128	91	117
Recently cleared areas, high biomass	Tropical Wet	Sandy	1.00	18.07	66	66	84.07	135.9	139	102	127
Recently cleared areas, high biomass	Tropical Moist	Sandy	1.00	18.07	39	39	57.07	104.85	132	95	121
Recently cleared areas, high biomass	Tropical Montane	Spodic	1.00	18.07	123.67	123.67	141.74	194.8003	141	104	128
Recently cleared areas, high biomass	Tropical Wet	Spodic	1.00	18.07	123.67	123.67	141.74	202.2205	153	116	138
Recently cleared areas, high biomass	Tropical Moist	Spodic	1.00	18.07	123.67	123.67	141.74	202.2205	153	116	138
Recently cleared areas, high biomass	Tropical Montane	Wetland	1.00	18.07	86	86	104.07	153.74	136	99	124
Recently cleared areas, high biomass	Tropical Wet	Wetland	1.00	18.07	86	86	104.07	158.9	144	107	131
Recently cleared areas, high biomass	Tropical Moist	Wetland	1.00	18.07	86	86	104.07	158.9	144	107	131
Swamp forest	Tropical Montane	HAC	1.00	30.39	88	88	118.39	155.92	116	79	107
Swamp forest	Tropical Wet	HAC	1.00	30.39	44	44	74.39	110.6	114	77	105
Swamp forest	Tropical Moist	HAC	1.00	30.39	65	65	95.39	134.75	119	82	110
Swamp forest	Tropical Montane	LAC	1.00	30.39	63	63	93.39	128.67	112	75	104
Swamp forest	Tropical Wet	LAC	1.00	30.39	60	60	90.39	129	118	81	108

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Swamp forest	Tropical Moist	LAC	1.00	30.39	47	47	77.39	114.05	115	78	106
Swamp forest	Tropical Montane	Sandy	1.00	30.39	34	34	64.39	97.06	108	71	100
Swamp forest	Tropical Wet	Sandy	1.00	30.39	66	66	96.39	135.9	119	82	110
Swamp forest	Tropical Moist	Sandy	1.00	30.39	39	39	69.39	104.85	113	76	104
Swamp forest	Tropical Montane	Spodic	1.00	30.39	123.67	123.67	154.06	194.8003	121	84	111
Swamp forest	Tropical Wet	Spodic	1.00	30.39	123.67	123.67	154.06	202.2205	133	96	122
Swamp forest	Tropical Moist	Spodic	1.00	30.39	123.67	123.67	154.06	202.2205	133	96	122
Swamp forest	Tropical Montane	Wetland	1.00	30.39	86	86	116.39	153.74	116	79	107
Swamp forest	Tropical Wet	Wetland	1.00	30.39	86	86	116.39	158.9	124	87	114
Swamp forest	Tropical Moist	Wetland	1.00	30.39	86	86	116.39	158.9	124	87	114
Reparian forest closed canopy	Tropical Montane	HAC	1.00	57.55	88	88	145.55	155.92	72	35	70
Reparian forest closed canopy	Tropical Wet	HAC	1.00	57.55	44	44	101.55	110.6	70	33	68
Reparian forest closed canopy	Tropical Moist	HAC	1.00	57.55	65	65	122.55	134.75	75	38	72
Reparian forest closed canopy	Tropical Montane	LAC	1.00	57.55	63	63	120.55	128.67	69	32	67
Reparian forest closed canopy	Tropical Wet	LAC	1.00	57.55	60	60	117.55	129	74	37	71
Reparian forest closed canopy	Tropical Moist	LAC	1.00	57.55	47	47	104.55	114.05	71	34	69
Reparian forest closed canopy	Tropical Montane	Sandy	1.00	57.55	34	34	91.55	97.06	65	28	63
Reparian forest closed canopy	Tropical Wet	Sandy	1.00	57.55	66	66	123.55	135.9	76	39	73
Reparian forest closed canopy	Tropical Moist	Sandy	1.00	57.55	39	39	96.55	104.85	69	32	67
Reparian forest closed canopy	Tropical Montane	Spodic	1.00	57.55	123.67	123.67	181.22	194.8003	78	41	74
Reparian forest closed canopy	Tropical Wet	Spodic	1.00	57.55	123.67	123.67	181.22	202.2205	90	53	84
Reparian forest closed canopy	Tropical Moist	Spodic	1.00	57.55	123.67	123.67	181.22	202.2205	90	53	84
Reparian forest closed canopy	Tropical Montane	Wetland	1.00	57.55	86	86	143.55	153.74	72	35	70
Reparian forest closed canopy	Tropical Wet	Wetland	1.00	57.55	86	86	143.55	158.9	80	43	77

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Reparian forest closed canopy	Tropical Moist	Wetland	1.00	57.55	86	86	143.55	158.9	80	43	77
Mangrove closed canopy	Tropical Montane	HAC	1.00	85.79	88	88	173.79	155.92	27	-10	31
Mangrove closed canopy	Tropical Wet	HAC	1.00	85.79	44	44	129.79	110.6	25	-12	30
Mangrove closed canopy	Tropical Moist	HAC	1.00	85.79	65	65	150.79	134.75	30	-7	34
Mangrove closed canopy	Tropical Montane	LAC	1.00	85.79	63	63	148.79	128.67	24	-13	28
Mangrove closed canopy	Tropical Wet	LAC	1.00	85.79	60	60	145.79	129	29	-8	33
Mangrove closed canopy	Tropical Moist	LAC	1.00	85.79	47	47	132.79	114.05	26	-11	30
Mangrove closed canopy	Tropical Montane	Sandy	1.00	85.79	34	34	119.79	97.06	19	-18	25
Mangrove closed canopy	Tropical Wet	Sandy	1.00	85.79	66	66	151.79	135.9	30	-7	34
Mangrove closed canopy	Tropical Moist	Sandy	1.00	85.79	39	39	124.79	104.85	24	-13	29
Mangrove closed canopy	Tropical Montane	Spodic	1.00	85.79	123.67	123.67	209.46	194.8003	32	-5	36
Mangrove closed canopy	Tropical Wet	Spodic	1.00	85.79	123.67	123.67	209.46	202.2205	44	7	46
Mangrove closed canopy	Tropical Moist	Spodic	1.00	85.79	123.67	123.67	209.46	202.2205	44	7	46
Mangrove closed canopy	Tropical Montane	Wetland	1.00	85.79	86	86	171.79	153.74	27	-10	31
Mangrove closed canopy	Tropical Wet	Wetland	1.00	85.79	86	86	171.79	158.9	35	-2	38
Mangrove closed canopy	Tropical Moist	Wetland	1.00	85.79	86	86	171.79	158.9	35	-2	38
Degraded forest closed canopy	Tropical Montane	HAC	1.00	99	88	88	187	155.92	6	-31	13
Degraded forest closed canopy	Tropical Wet	HAC	1.00	99	44	44	143	110.6	4	-33	12
Degraded forest closed canopy	Tropical Moist	HAC	1.00	99	65	65	164	134.75	9	-28	16
Degraded forest closed canopy	Tropical Montane	LAC	1.00	99	63	63	162	128.67	2	-35	10
Degraded forest closed canopy	Tropical Wet	LAC	1.00	99	60	60	159	129	8	-29	15
Degraded forest closed canopy	Tropical Moist	LAC	1.00	99	47	47	146	114.05	5	-32	12
Degraded forest closed canopy	Tropical Montane	Sandy	1.00	99	34	34	133	97.06	-2	-39	7
Degraded forest closed canopy	Tropical Wet	Sandy	1.00	99	66	66	165	135.9	9	-28	16

Land Cover	Climate	Soil	Total Soil Factors	Total Carbon in Biomass	SOCref*	SOCact	Total Carbon	Total Carbon Palm**	Emission Savings methane capture and 17t/ha harvest***	Emission Savings no methane capture and 17t/ha harvest***	Emission Savings methane capture and 20t/ha harvest***
				tC/ha	tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Degraded forest closed canopy	Tropical Moist	Sandy	1.00	99	39	39	138	104.85	3	-34	11
Degraded forest closed canopy	Tropical Montane	Spodic	1.00	99	123.67	123.67	222.67	194.8003	11	-26	18
Degraded forest closed canopy	Tropical Wet	Spodic	1.00	99	123.67	123.67	222.67	202.2205	23	-14	28
Degraded forest closed canopy	Tropical Moist	Spodic	1.00	99	123.67	123.67	222.67	202.2205	23	-14	28
Degraded forest closed canopy	Tropical Montane	Wetland	1.00	99	86	86	185	153.74	6	-31	13
Degraded forest closed canopy	Tropical Wet	Wetland	1.00	99	86	86	185	158.9	14	-23	20
Degraded forest closed canopy	Tropical Moist	Wetland	1.00	99	86	86	185	158.9	14	-23	20

* for Podzols no data are available for tropical regions from the EU-RED. I use values from Montes et al. (2011) and assume 20 cm upper organic-rich horizons with 170tC/ha and 10 cm middle sandy horizons with 31tC/ha

** I assume total soil factors for palm plantations of 1.15 and 1.09 in montane regions and 60tC/ha in biomass according to EU-RED

*** For all caluclations I assume 4.5 kg biomass per 1 l fuel and a heating value of 32.65 MJ/l biodiesel (FNR 2012)