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**Working Paper**

## EU biofuel policies in practise: A carbon map for Kalimantan and Sumatra

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## **Working Papers**

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

**by Mareike Lange**

**No. 1863 | August 2013**

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

Mareike Lange

### 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. Biofuels are 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 emphasise 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).

On the one hand, the 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, the increasing demand for feedstocks for biofuel production is seen as an opportunity to further develop the agricultural production in many developing countries.

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 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 in order to be counted towards the 10% target imposed on the

mineral oil industry. 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).

The EC implemented the EU-RED by adapting 13 certification schemes<sup>1</sup> 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. Due to the on-going discussion I do not consider the recent proposal of the EC to include ILUC emission factors into the emission balance of biofuels that did not cause any DLUC (EC 2012). However, I discuss ILUC in the context of carbon mapping at the end of this paper.

In practise, 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.

In addition to the direct accounting of possible emissions from DLUC, 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. 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

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<sup>1</sup> 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

pay developing countries to halt their deforestation (Gibbs et al. 2007) Such maps could be used to determine a baseline for the payments and to monitor deforestation over time. Two examples of global above ground carbon maps can be found in Saatchi et al. 2011 and Baccini et al. 2012.

In this paper I show how a carbon map that is in line with the EU-RED requirements could be derived for Kalimantan and Sumatra in Indonesia and 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 results of the calculation of the carbon mapping. 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. The sustainability requirements contained in the EU-RED mainly tackle the problem of possible DLUC to produce feedstocks for biofuel production. Under this framework 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%<sup>2</sup>, 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)). 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.

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<sup>2</sup> This corresponds to the upper level of canopy cover of the forest definition in UNFCCC (2001)

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.

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. I present this method in order to produce a carbon map for Kalimantan and Sumatra in the following.

### 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.

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 ( $A_i$ ).<sup>3</sup>

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

#### 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 ( $C_{DOM}$ )<sup>4</sup>. 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.

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

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

##### II. Data

In a certification process for the EU-RED, for the calculation of carbon stock stored in biomass in practise, the land cover on a unit area must be known. Different methods are available to determine

<sup>3</sup> 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.

<sup>4</sup> 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.

this information. The very basic method for a producer is to perform a local assessment to receive an inventory of the land cover classes represented on the area to be certified. Then, according to the Tier 1 method of the EU-RED, the corresponding carbon values associated to these land cover classes can be taken for instance from Carré *et al.* 2010 or scientific literature. However, an individual assessment can be very costly. 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. To overcome this problem, different methods for biomass carbon mapping are available on a broader scale.

The simplest but least precise method is to a land cover map generated by remote sensing technology and to link specific biomass values to each land cover class available in the scientific literature (Goetz *et al.* 2009). There has been a fast development of techniques to determine above ground biomass carbon in particular for tropical forests via 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<sup>5</sup>. Therefore, I use two different methods due to the availability of data. For Sumatra I use the official land cover map of the Ministry of Forestry of Indonesia (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

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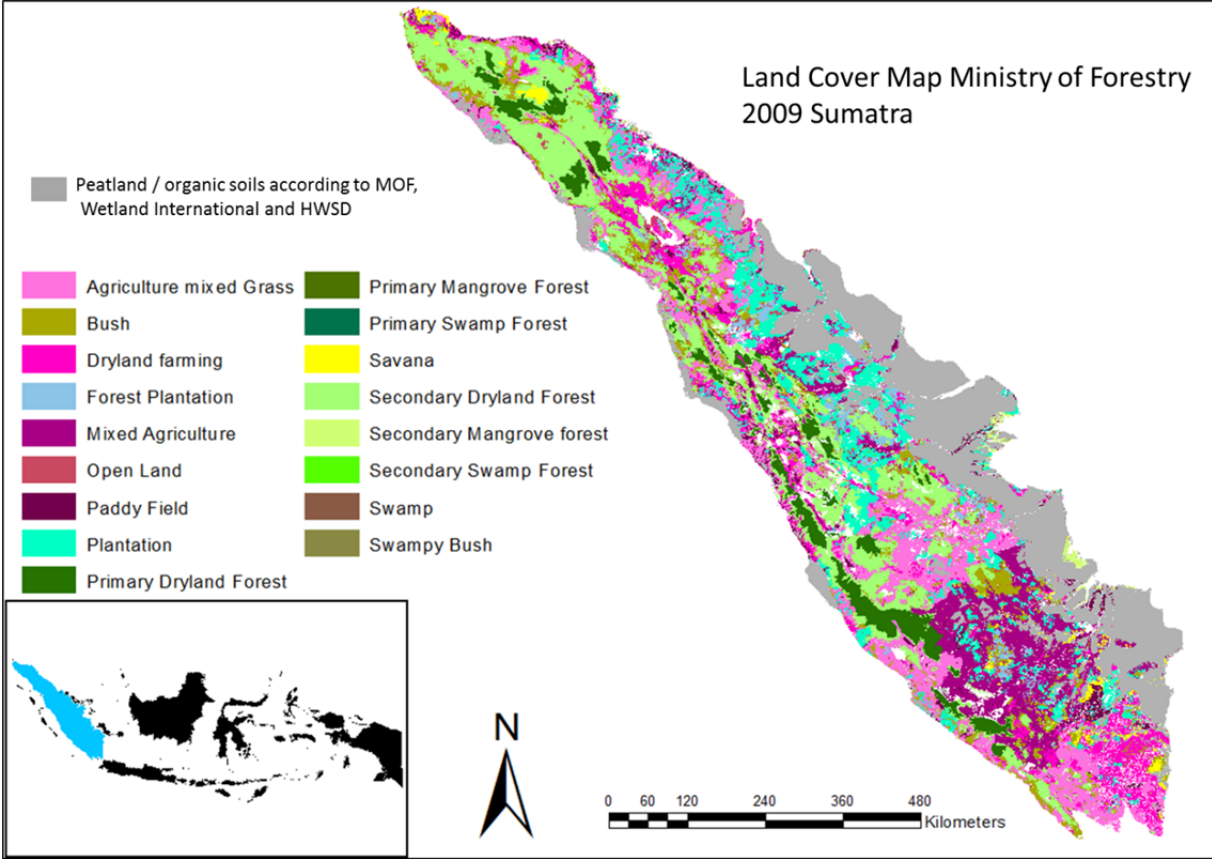
<sup>5</sup> A comparison of different methods can be found in Goetz *et al.* 2009



land cover change/land use change emissions are the important figure to determine. However, this is less relevant for forest as forests and wetlands are generally excluded from being suitable areas for feedstocks to produce biofuels. Last but not least, 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. In addition, to check the accuracy of this map would have been beyond this project. In addition, the impact of a derived carbon map strongly depends on acceptance of policy makers and producers in the country. The map is officially recognized by the Indonesian authorities which is important to feed in results into the political decision process of land use planning.

The map in figure 1 shows already very large areas used for agricultural production and only small areas left with natural forest cover in Sumatra. The light grey areas represent peat swamp 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. I will come back to the second point when presenting the method for the carbon content in the soil

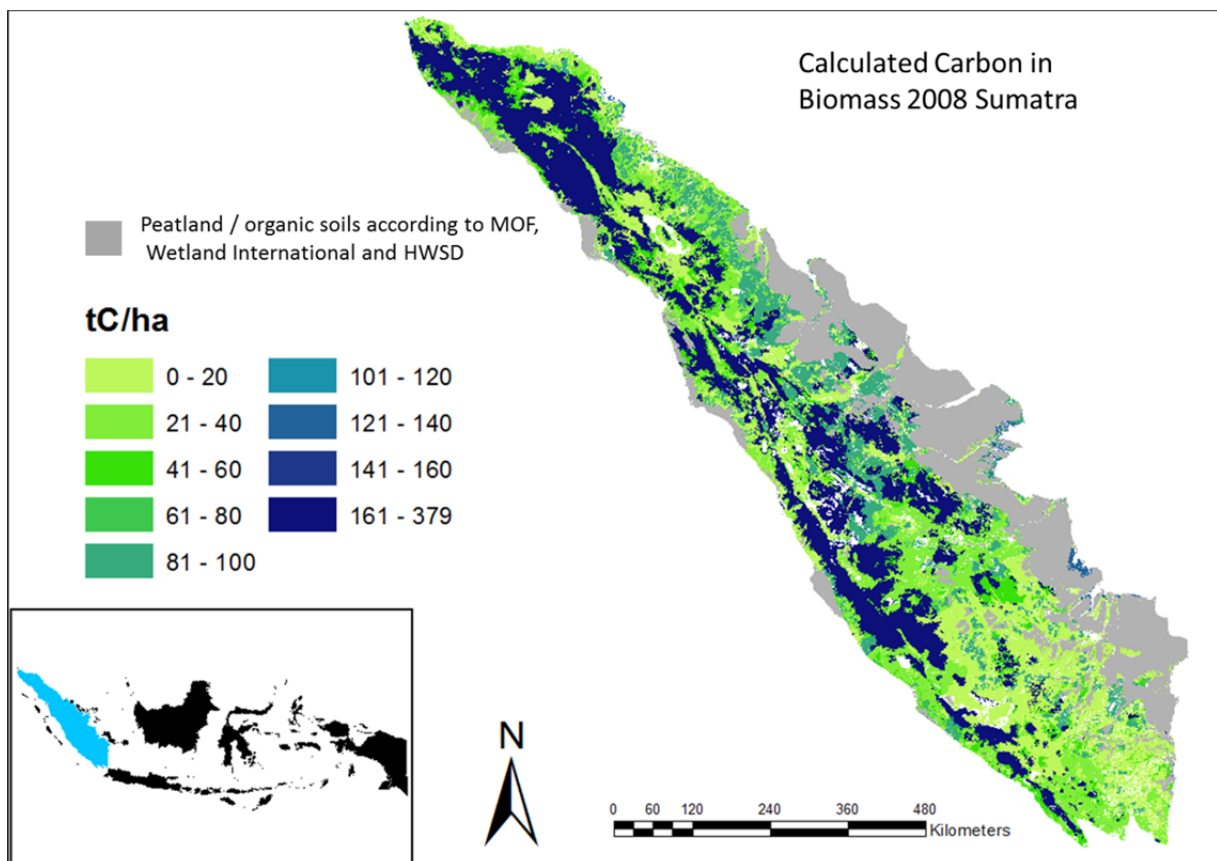
**Figure 1**



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 the EU Background Guide or the IPCC 2006, however, these carbon values do not always correspond one to one to the land cover classes in the map. Furthermore, EU Background Guide 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 EU Background Guide 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 showing carbon stock 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 2.**

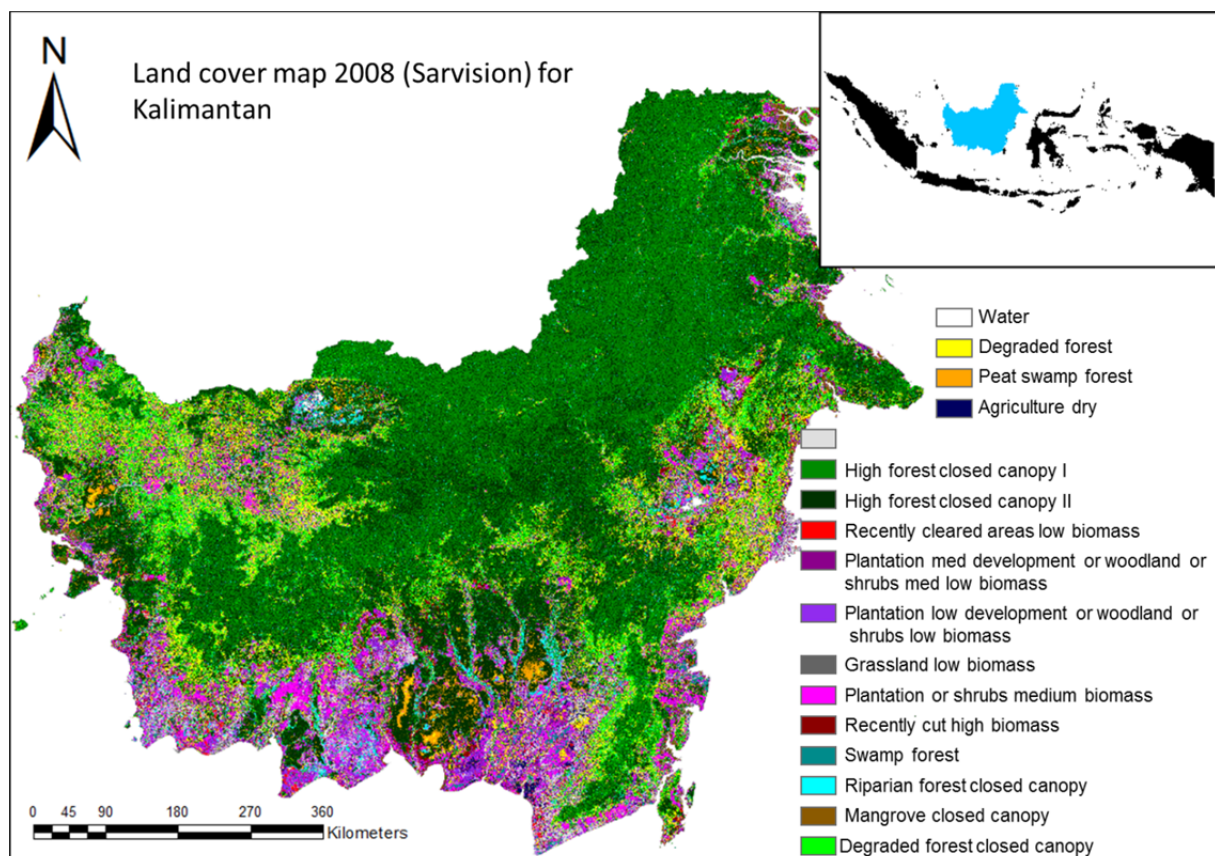


For Kalimantan, other data were available which were generated by Sarvision<sup>6</sup> within the Global Land Use Change Project of WWF Germany. A detailed description of the data generating process can be found in Sarvision (2011).

<sup>6</sup> Sarvision is a spin-off of Wageningen University <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.

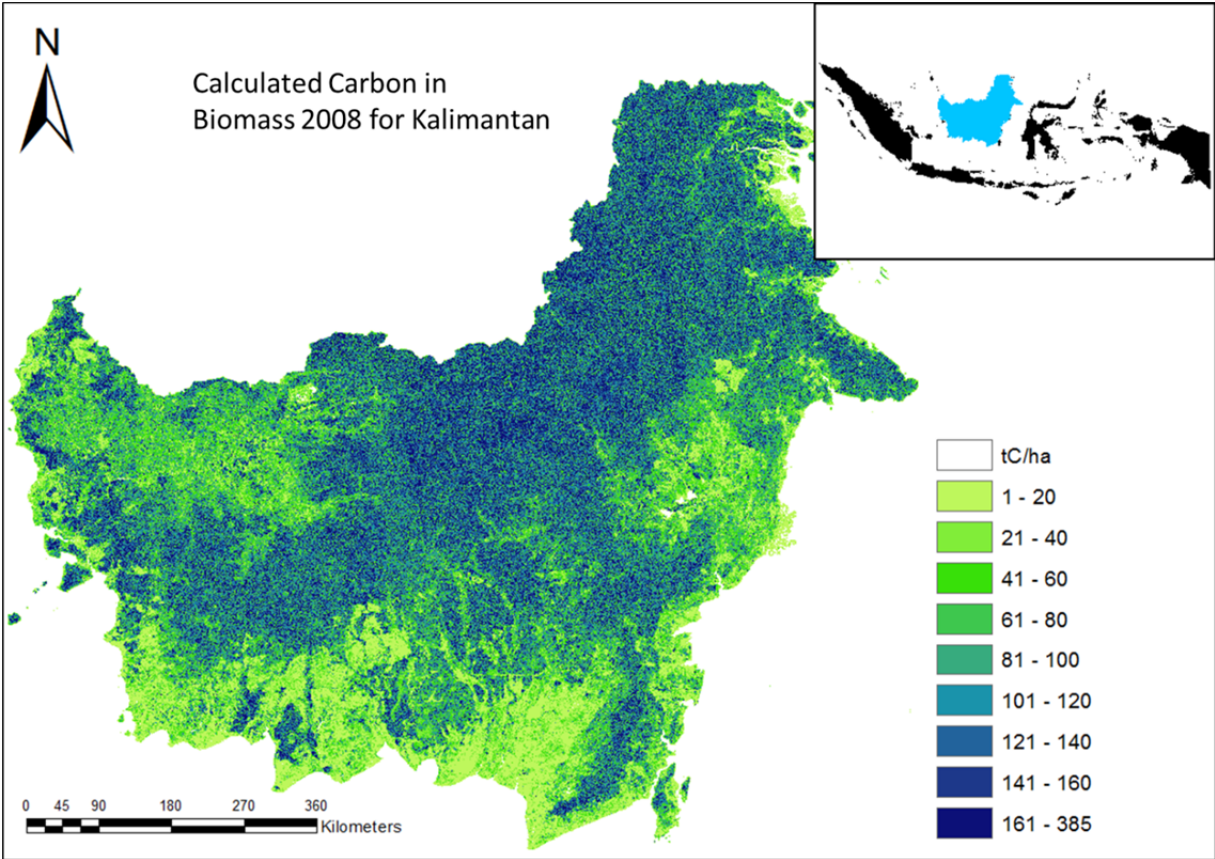
**Figure 3**



Compared to Sumatra, in Kalimantan still large forest areas are remained. 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.

Comparing both maps, on land cover and carbon in biomass, 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 4, 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 4 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 4**



## b. Soil Carbon

### I. Method

For the calculation of 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 ( $SOC_{act_{il}}$ ) is the product of the carbon stock under natural land cover ( $SOC_{ref_i}$ ) 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.<sup>7</sup> 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 centimetres according to EU-RED as this is the layer where most of the carbon is stored in mineral soils. This does not apply for peat swamp 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.

$$SOC_{act_{il}} \left( \frac{tC}{ha} \right) = SOC_{ref_i} \left( \frac{tC}{ha} \right) \times Flu_l \times Fmg_l \times Fi_l \quad (4)$$

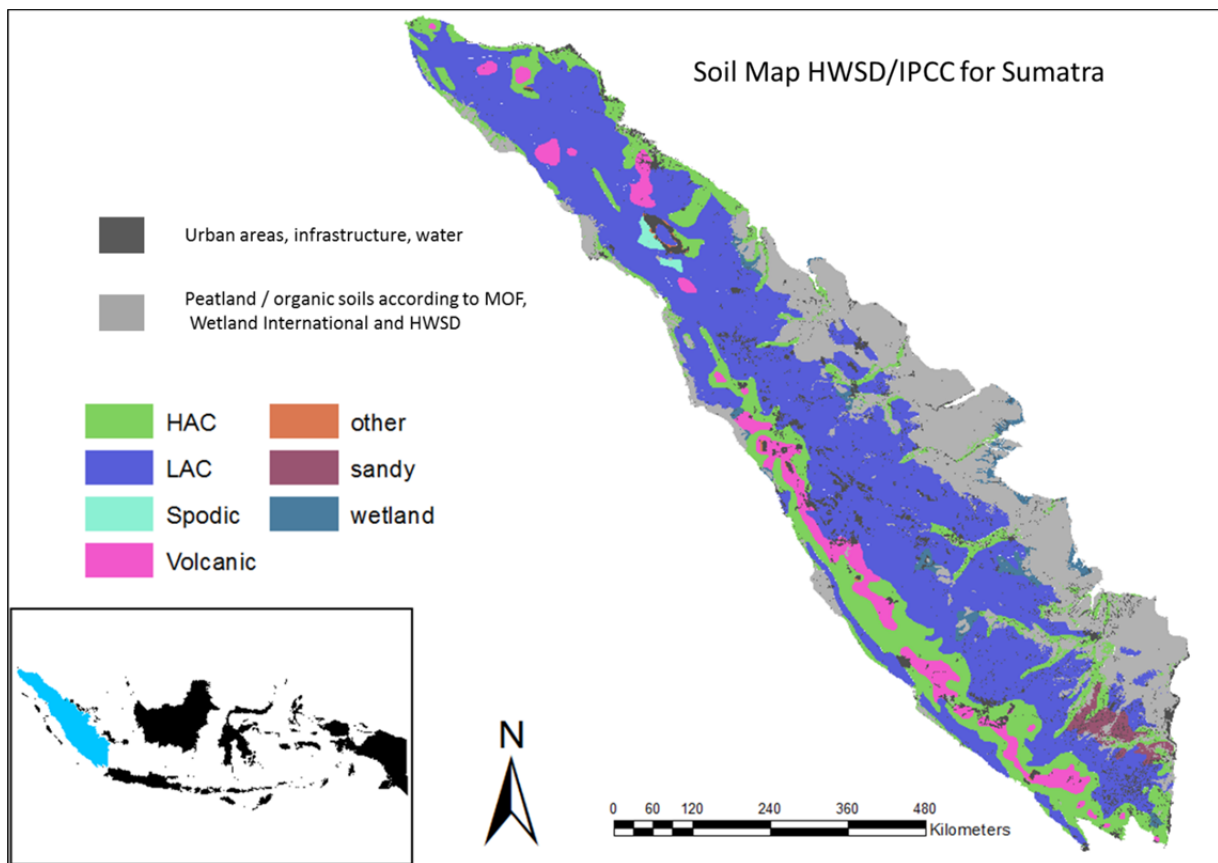
### II. Data

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 5 for Sumatra and figure 6 for Kalimantan).

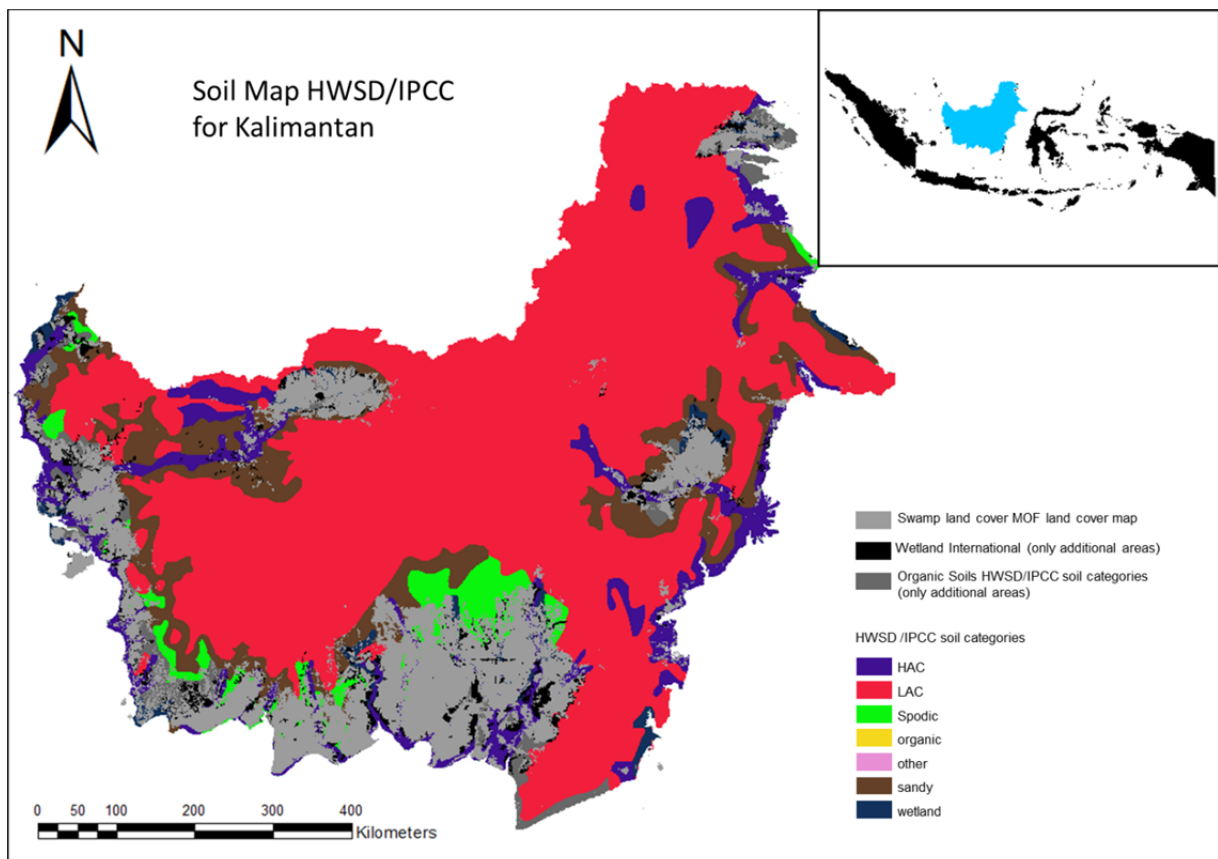
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<sup>7</sup> The EU Background Guide gives more details and data about land cover classes not explicitly covered by the IPCC 2006 e.g. savannahs and degraded land.

**Figure 5**

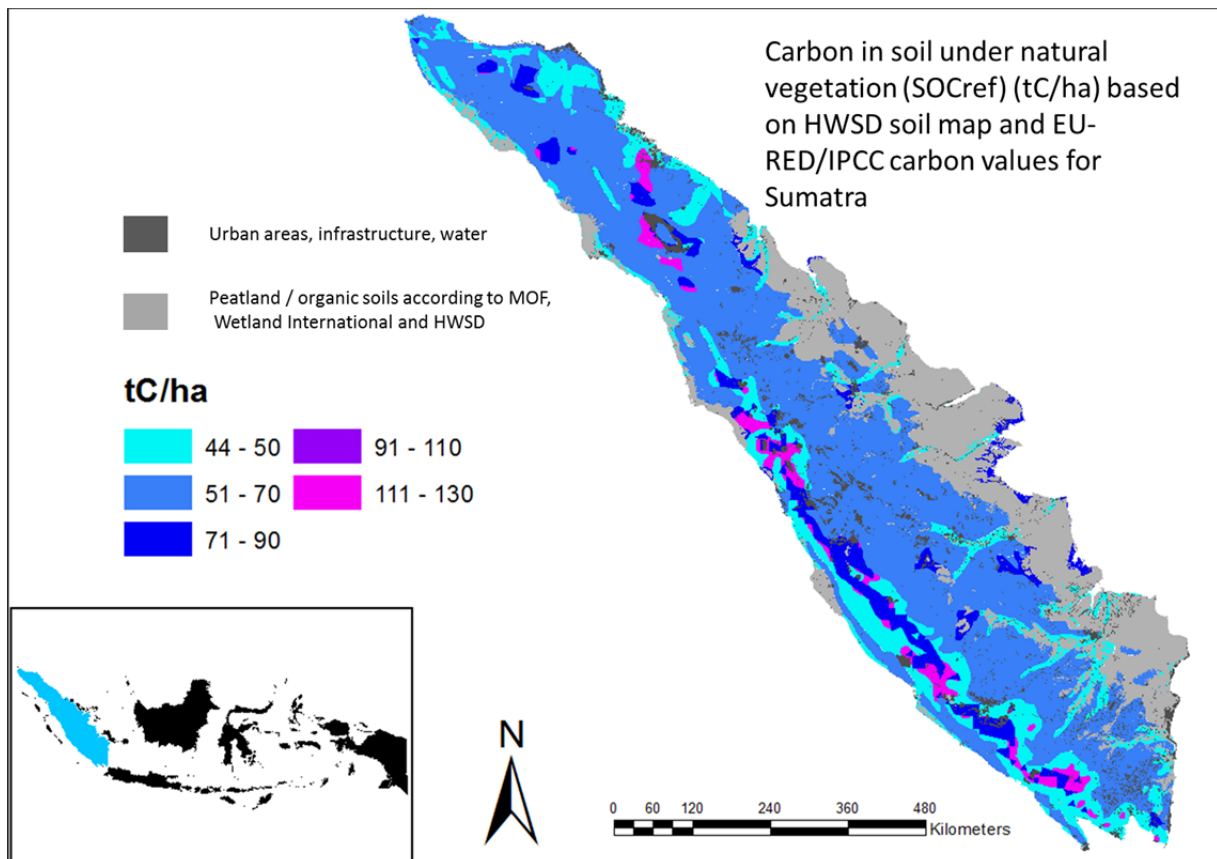


**Figure 6**



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 by combining the SOCref values with the HWSD soil map I generate a map of soil carbon as if the whole area where under natural land cover. The SOCref carbon values corresponding to the soil map categories are taken from the EU Guidelines which corresponds to the data in IPCC 2006 (figure 7 SOCref Sumatra).

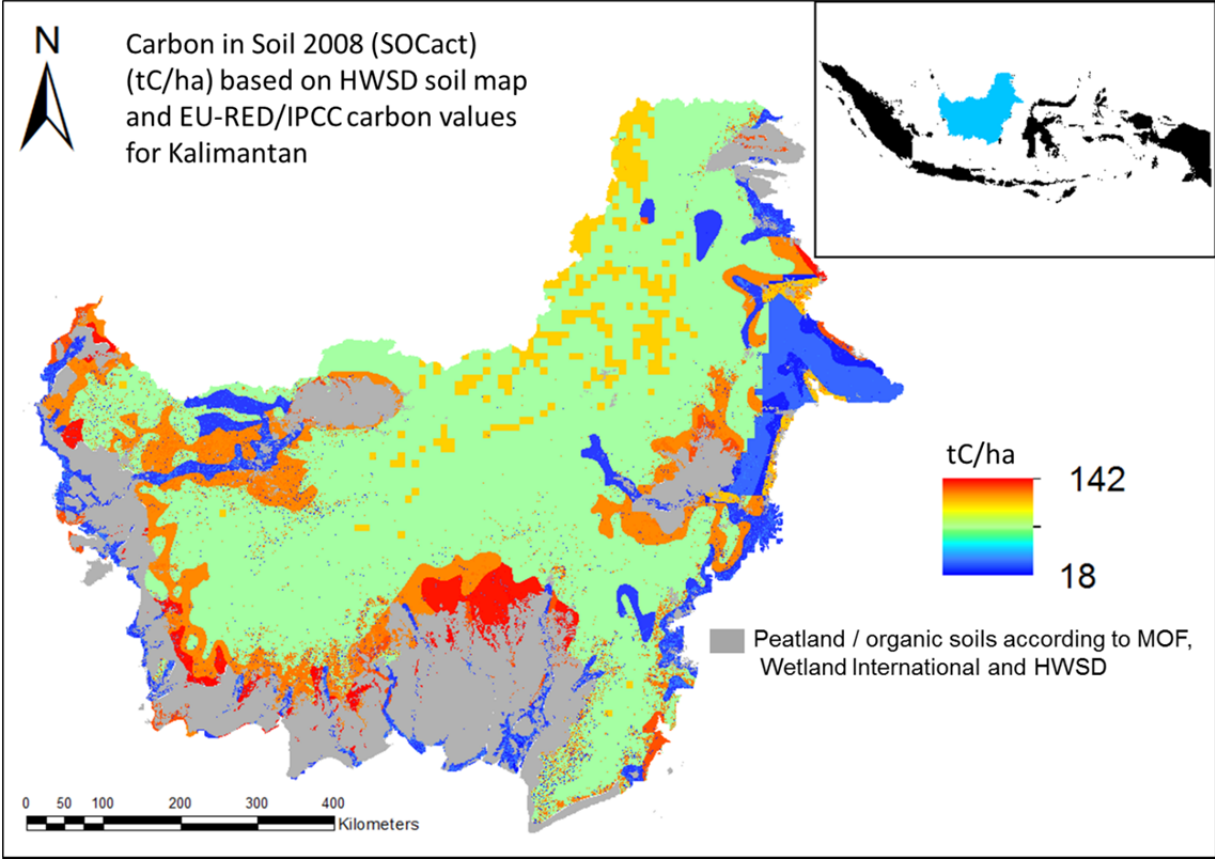
**Figure 7**



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. Thus, to determine the actual carbon stock stored in the soil ( $SO_{Cact_{il}}$ ) I multiply the  $SO_{Cref}$  calculated in the first step with these soil factors according to equation 4. (Figure 8  $SO_{Cact}$  Kalimantan).

**Figure 8.**



**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 9 and 10 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.

My 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.



Figure 9:

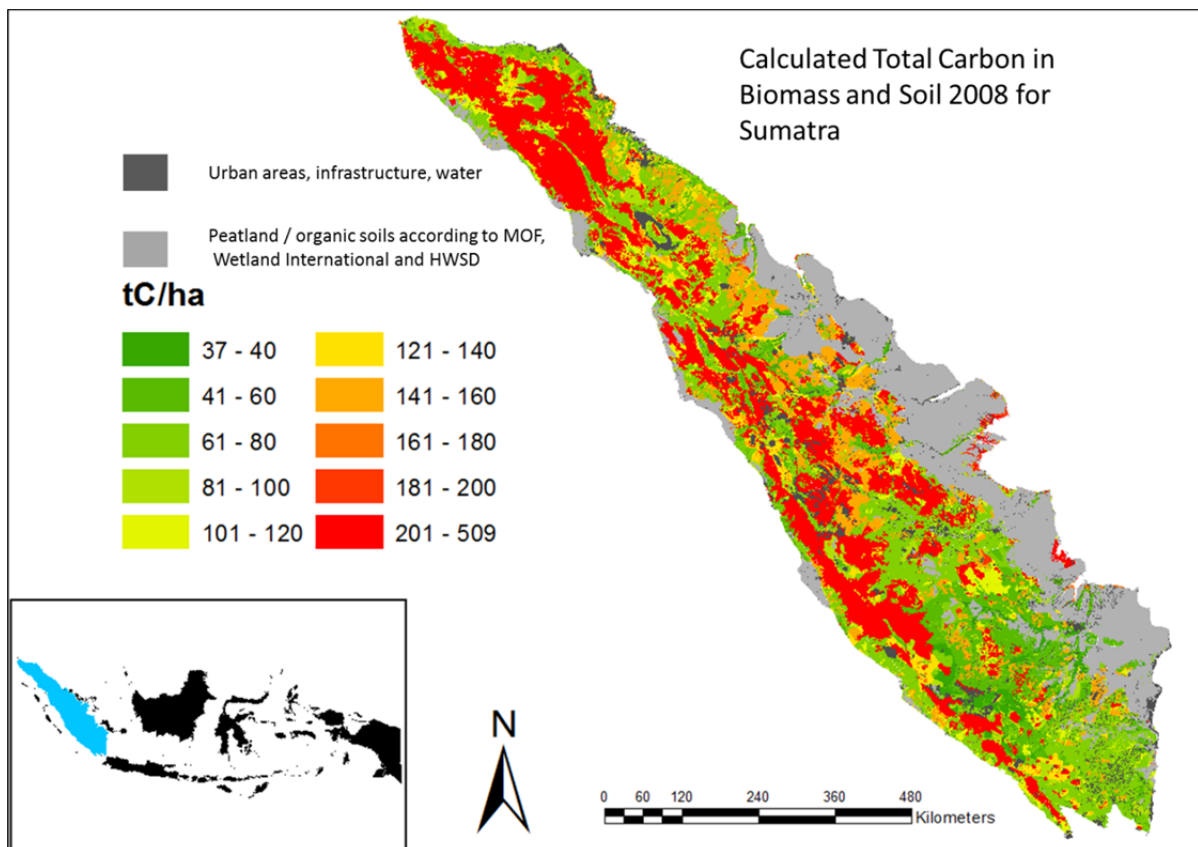
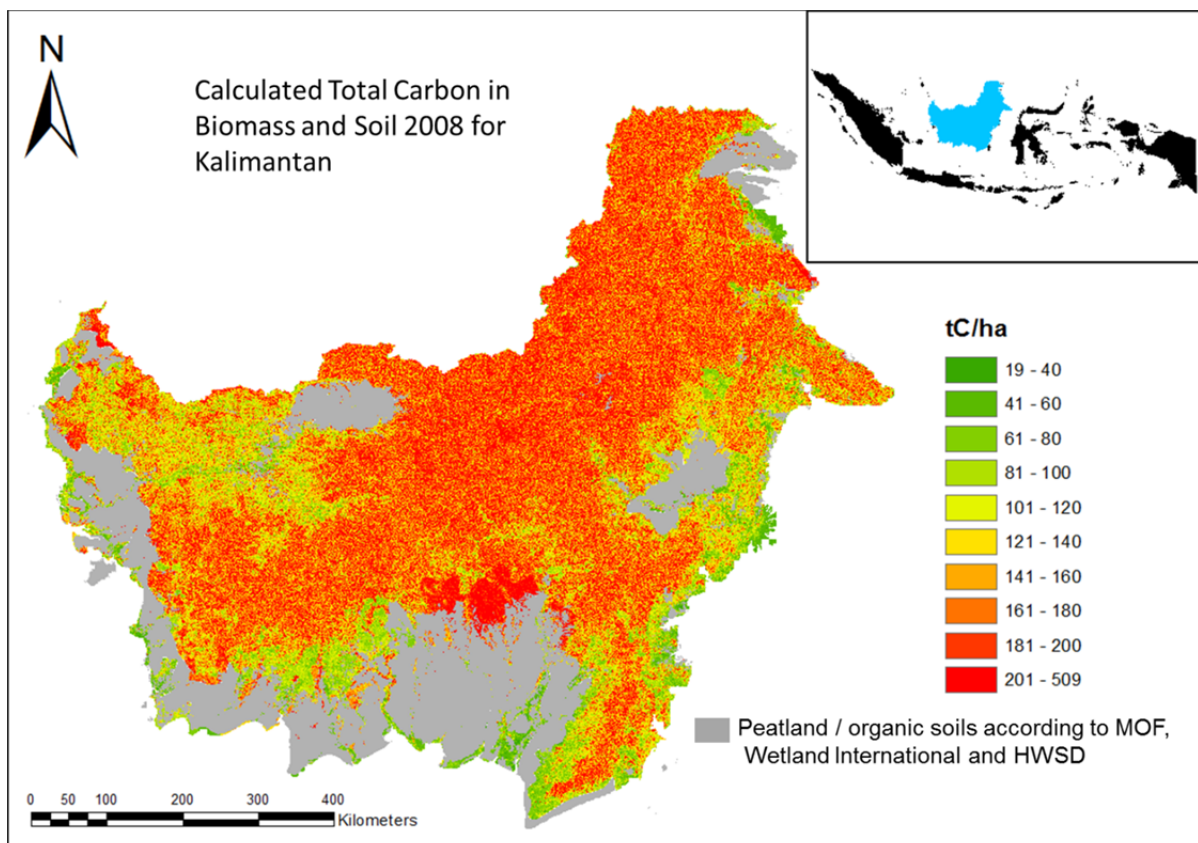


Figure 10:



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

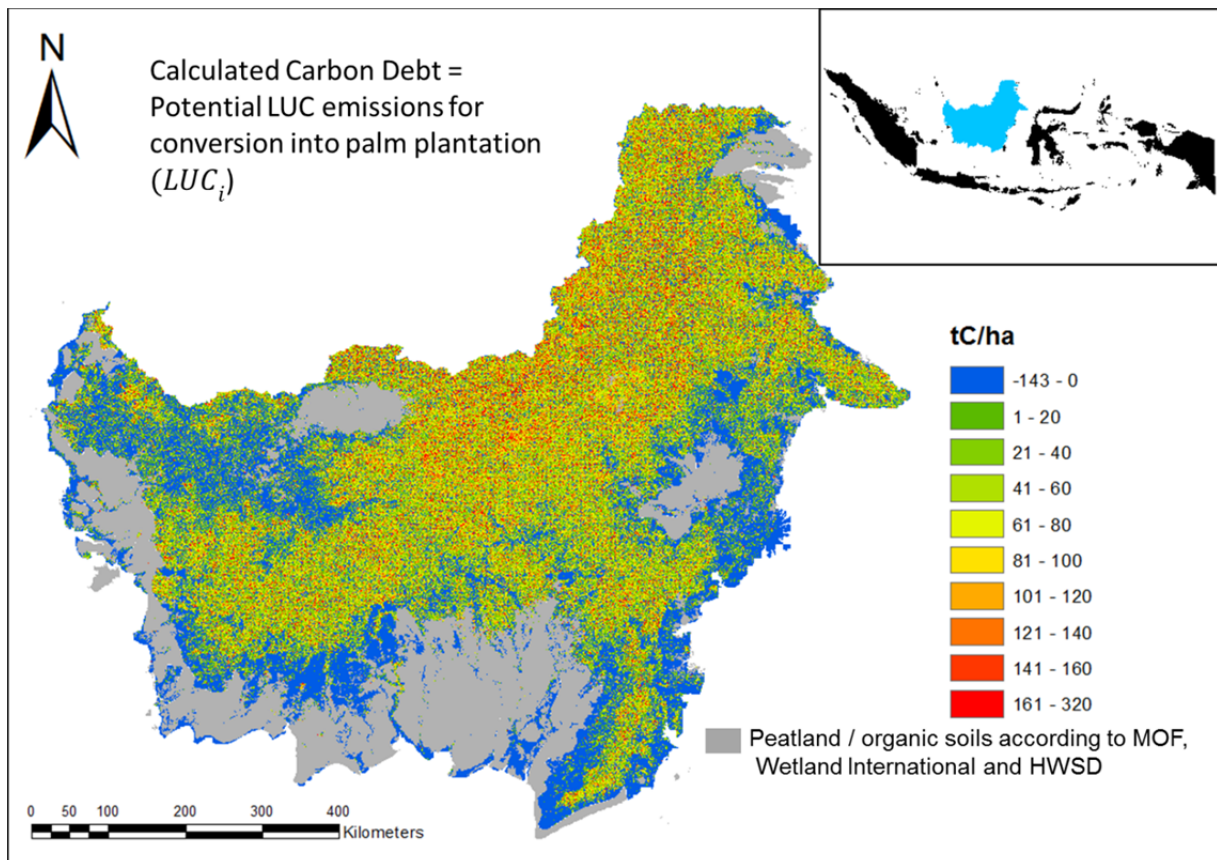
However, in terms of the practical implementation of the sustainability regulation of the EU-RED, a further step of calculation is necessary. To prove the compliance with 35% emission saving threshold, I need to calculate the emission savings for each spatial unit that would occur if this spatial unit were to be converted into cropland to produced biofuel feedstock. Thus, I calculate the emission savings of each spatial unit if this unit were converted into a cultivation area to produce feedstock for biofuel production. Emission savings represent average annual savings for a production period of 20 years.<sup>8</sup>

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 the feedstock for biofuel production ( $CS_{i_{biofuel\_feedstock}}$ ).

$$LUC_i = CS_{i_{before}} - CS_{i_{biofuel\_feedstock}} \quad (5)$$

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

**Figure 11:**



<sup>8</sup> This is another reason why this method do not apply for organic soils as the carbon content does not stabilize after 20 years.

Figure 11 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 debt. Figure 11 shows that this applies to mainly all forest areas.

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.<sup>9</sup>

$$LUC_{mj,i} \frac{CO_2}{MJ} = LUC_i \frac{C}{ha} * 3.664 * \frac{1}{20} * \frac{1000000}{P_i \frac{MJ}{ha}} * AL_i \quad (6)$$

To complete the calculation of the LUC emissions, the EC allows for an allocation of the resulting LUC emission to each biofuel or its intermediate products and possible by-products. The allocation factor (AL) should be calculated on the basis of the energy content, that is, the lower heating value. This means that for example from the soy bean, only the oil is used for biodiesel production. The remaining soy cake is mainly used as animal feed. Consequently both the soy cake and the soy oil are evaluated with their lower heating values. Then, land use and production pathway emissions are allocated to the emissions caused by the soy biodiesel in the same proportion as the proportion of the soy oil on the total lower heating value of the harvested soy bean.

**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”

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

used by the EU-RED is slightly misleading as it does not indicate that every biofuel saves emissions. It 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.**

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 Table 1 for the values used for equation 6 and 7 in my 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<sup>10</sup> based on EU-JRC Data (IES 2008). The total resulting emissions are then compared to 83.8gCO<sub>2</sub>/MJ emissions the fossil fuel alternative and emission savings are derived in %.

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

I calculate the emission savings of 3 different palm production process 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)<sup>11</sup>, 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.

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”.<sup>12</sup> As the minimum emission savings threshold is about to rise to 50% for new installations from 2017<sup>13</sup> on, and to 60% in 2018 for installations built after 2017, I also indicate these thresholds in the maps of Figure 12-17 which show the emission saving maps for Sumatra and Kalimantan and the 3 assumed

<sup>10</sup> 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.

<sup>11</sup> Methane capture means the capture of methane gas from the anaerobic digestion of palm oil mill effluent in open ponds.

<sup>12</sup> Hadian et al. 2013 map several biodiversity indicators for Sumatra and Kalimantan. Forthcoming on [www.globallandusechange.org](http://www.globallandusechange.org)

<sup>13</sup> The threshold might be increased already in 2014.

palm production processes. All green areas are sustainable production areas under the minimum emission saving criterion.

Based on the total carbon map derived above, it is only logical that areas with high carbon stocks are less likely to achieve the 35% minimum emission saving threshold than areas with low carbon stocks.

**Table 3: Available area for expansion in Sumatra (47.3 million ha total island area)**

Palm oil production process	Areas excluded from analysis	Area available for expansion in million ha under different emission saving thresholds			
		Neutral Emission Balance	35%	50%	60%
No methane capture and 17t/ha yield	peatland soils / swamp areas (Figure 13)	16.7	16.7	16.7	16.7
Methane capture and 20t/ha yield	peatland soils / swamp areas (Figure 14)	20.5	16.7	16.7	16.7
Methane capture and 17t/ha yield	peatland soils / swamp areas (Figure 12)	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 18)	3.4	3.4	3.4	3.4
	No-go areas by land cover definition (forest and peatland areas) (Figure 18)	20.5	16.7	16.7	16.7

For Sumatra (Figure 12.-14) results are clear and mainly independent on the production process and the assumed productivity. This is because the remaining forest areas are 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 in the maps with different shades of green, only change results in very few hectares. Thus, one can roughly say that in 2008, the possible sustainable production area in Sumatra is under all emission saving thresholds 16.7 million ha. Only when considering a neutral emission balance, which would mean zero emission savings, methane capture and an increase in yield can slightly increase the production area to 20.5 million ha.

Figure 12

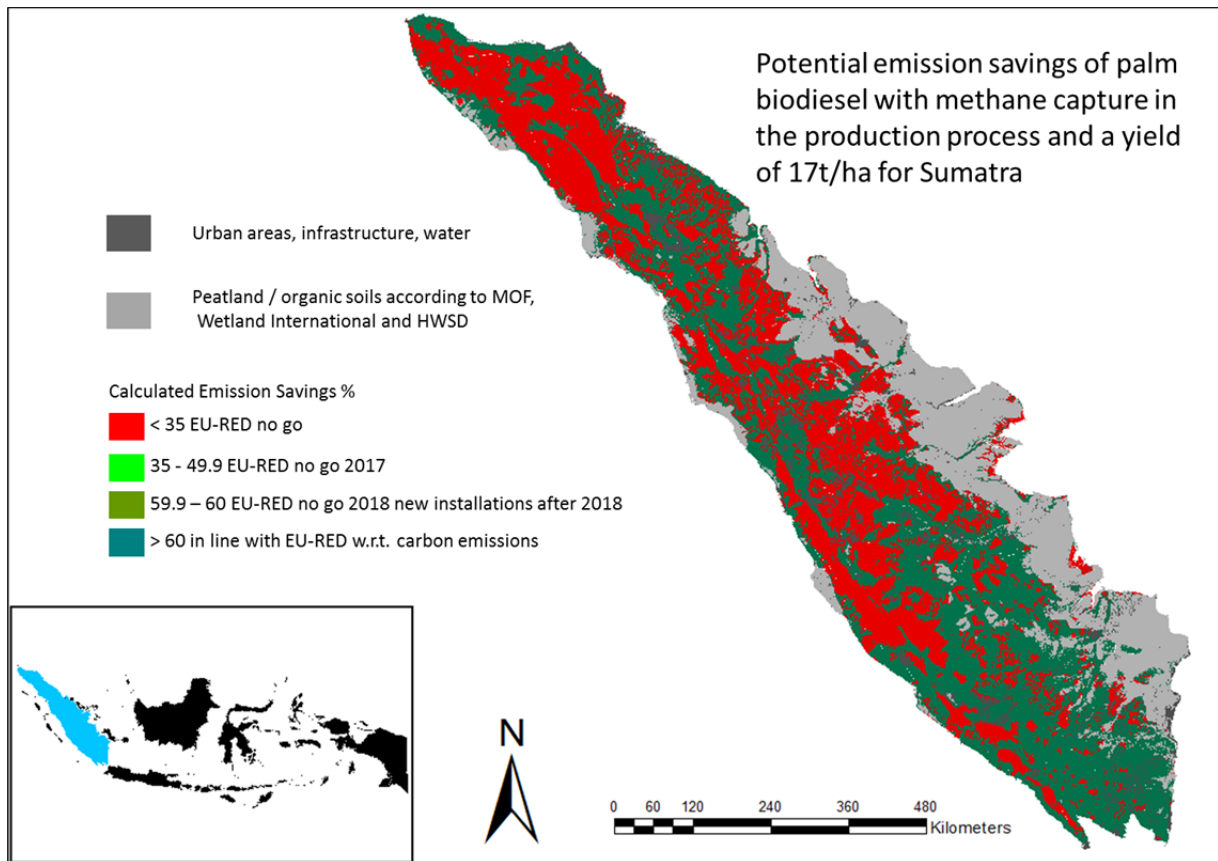
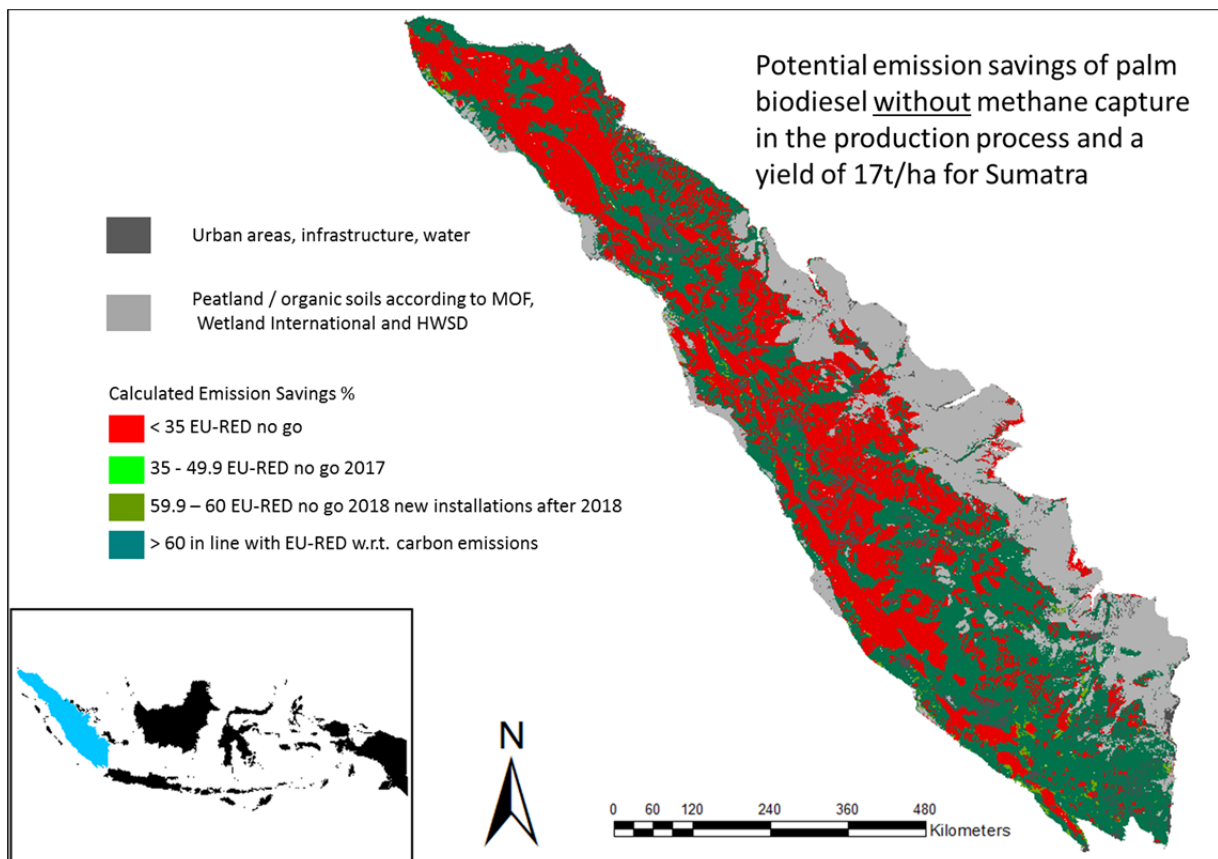
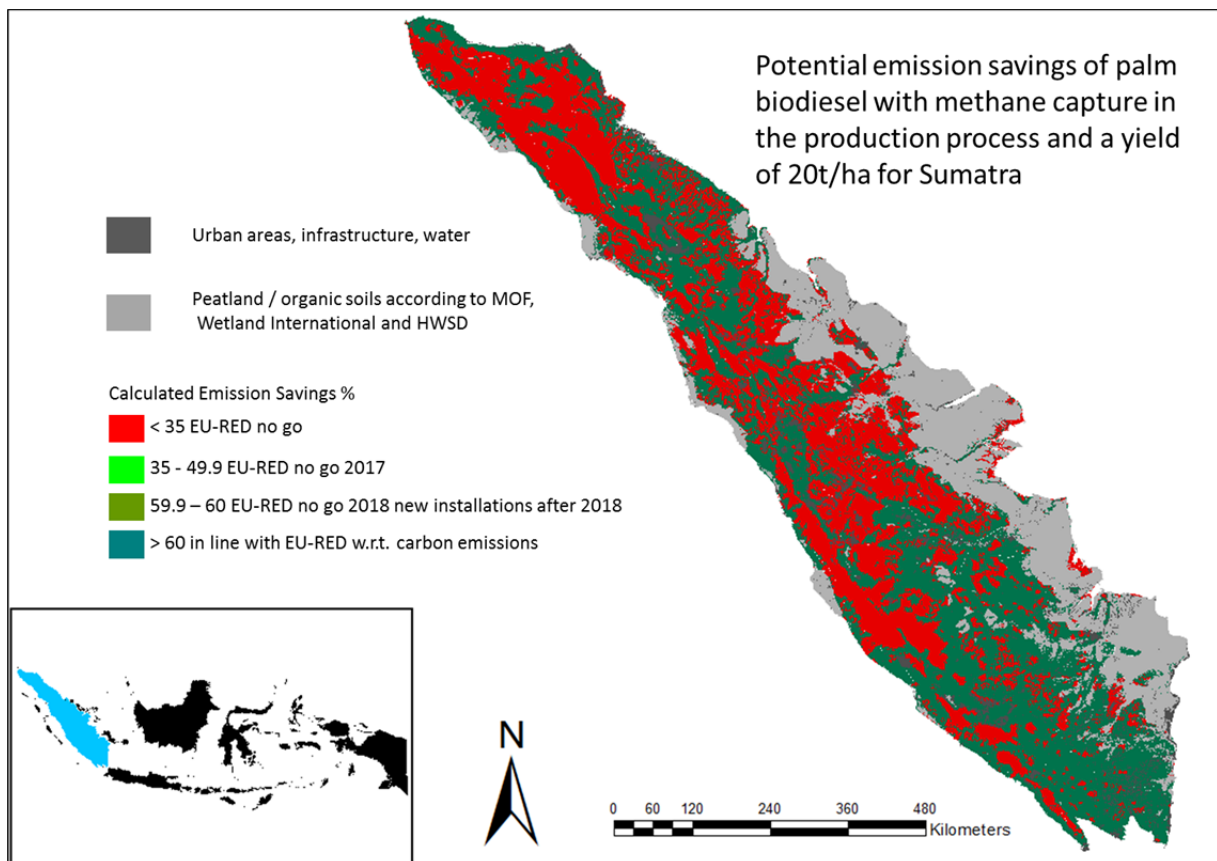


Figure 13



**Figure 14**



For Kalimantan results are similar to those in Sumatra (Figure 15-18). 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 in one land cover class it is well possible to find pixel above and below the 35% emission saving threshold.<sup>14</sup>

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 until 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). This is also true for the two other production processes considered. If methane is

<sup>14</sup> 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 analysed. 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.

not captured in the production process, this 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 of palm production for the European market.

The increase in yield to 20t/ha, however, does only have an effect on the sustainable production area under the 35% emission saving threshold. It slightly increases the sustainable production 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, which means forest areas. 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.

**Table 3: Available area for expansion in Kalimantan (61.5 million ha total island area)**

Palm oil production process	Areas excluded from analysis	Area available for expansion in million ha under different emission saving thresholds			
		Neutral Emission Balance	35%	50%	60%
No methane capture and 17t/ha yield	peatland soils / swamp areas (Figure 16)	19.3	14.1	12.4	10.4
Methane capture and 20t/ha yield	peatland soils / swamp areas (Figure 17)	26.8	20.9	17.9	15.8
Methane capture and 17t/ha yield	peatland soils / swamp areas (Figure 15)	25.3	19.4	17.9	15.8
	No-go areas by land cover definition (forest and peatland areas) (Figure 19)	12.4	10.9	10.3	9.7
	No-go areas by land cover definition (forest and peatland areas) and without areas already used (Figure 19)	8.8	7.3	6.7	6.4



Figure 15

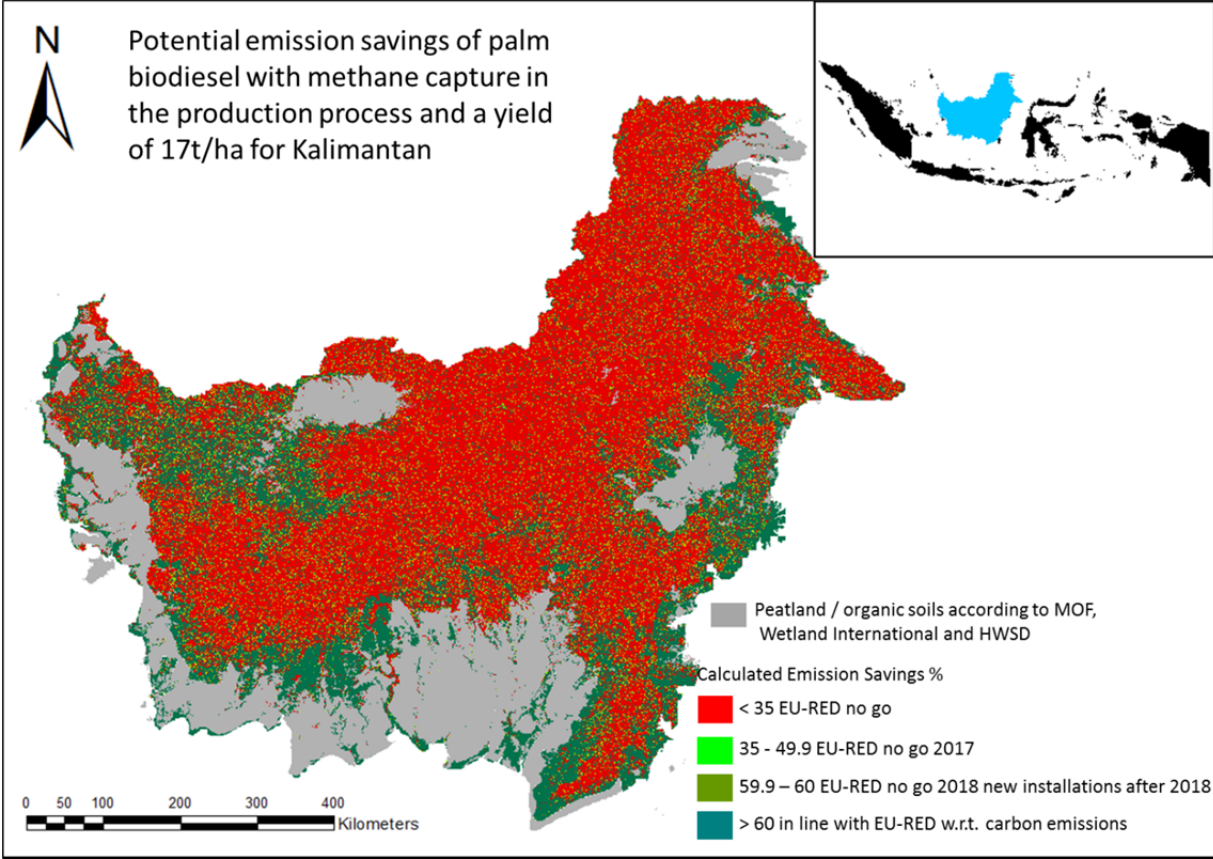
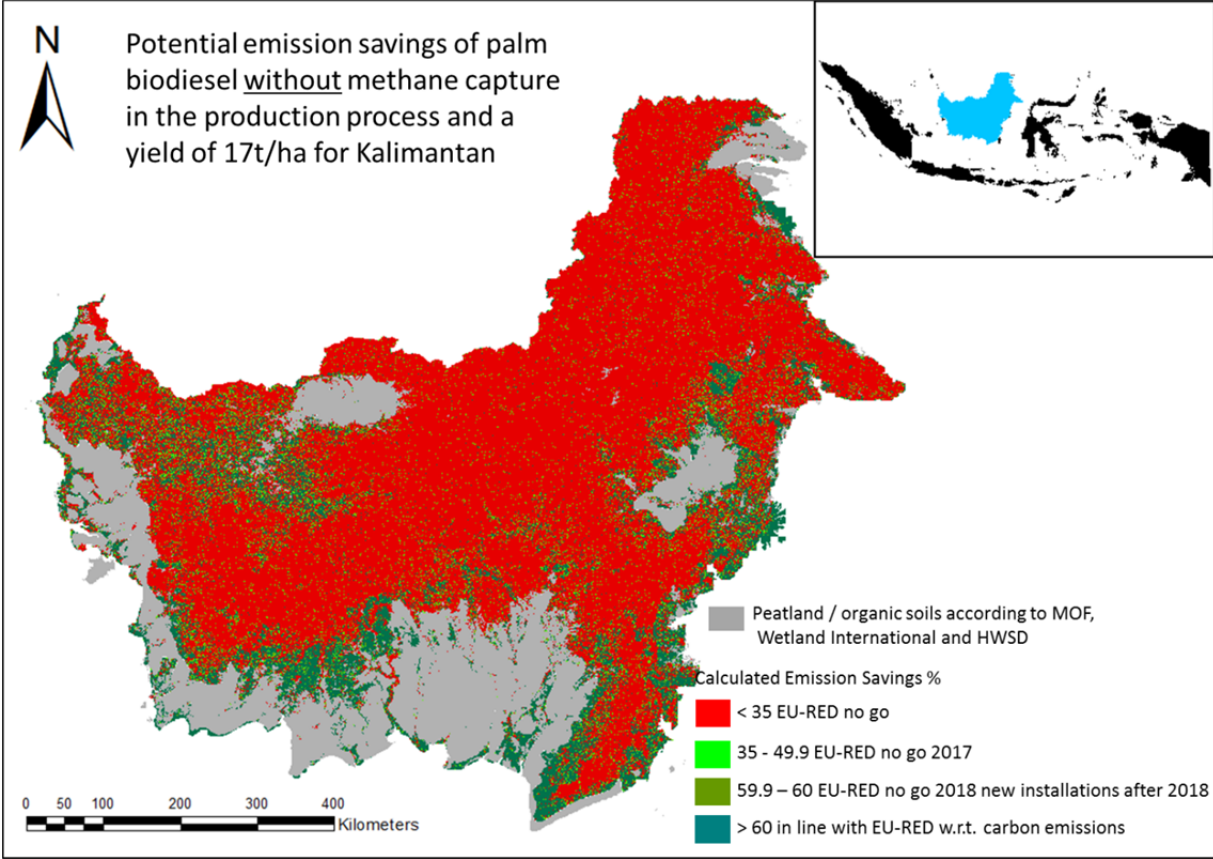
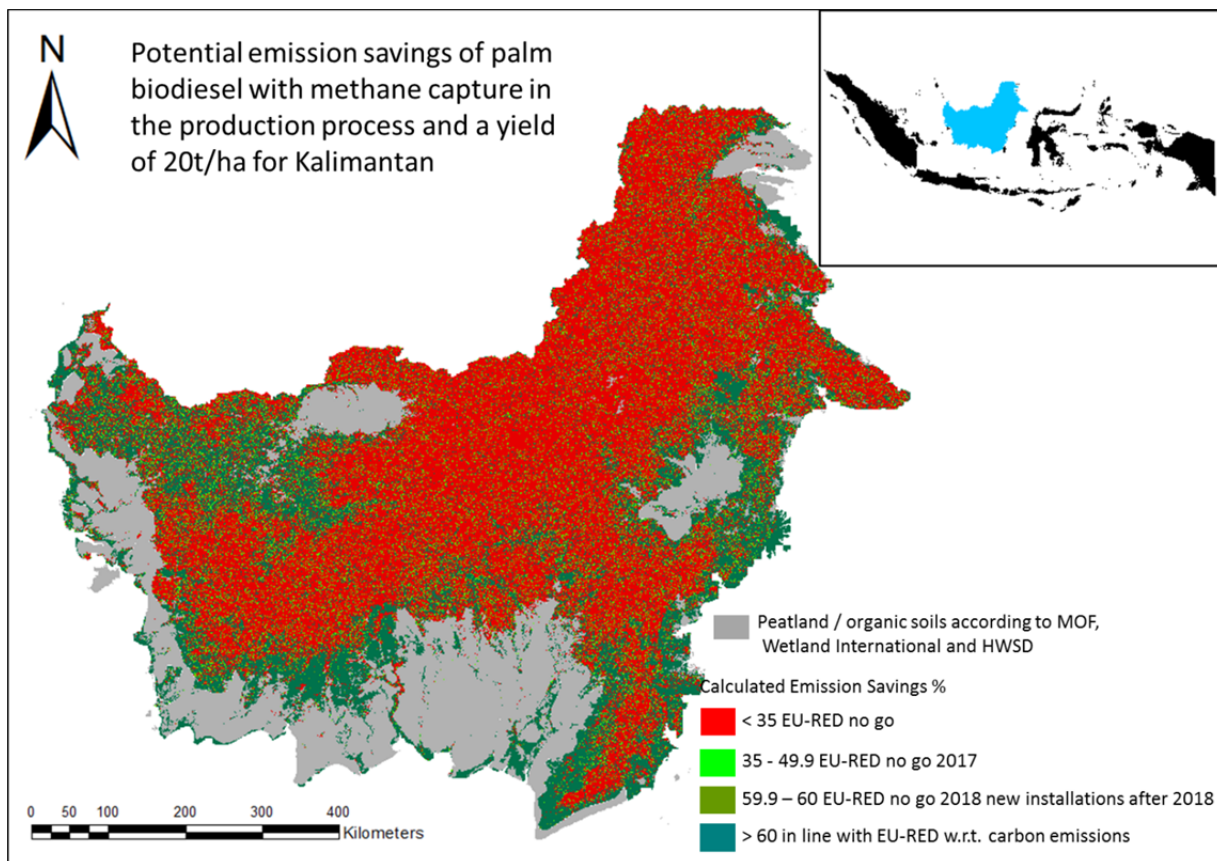


Figure 16



**Figure 17**



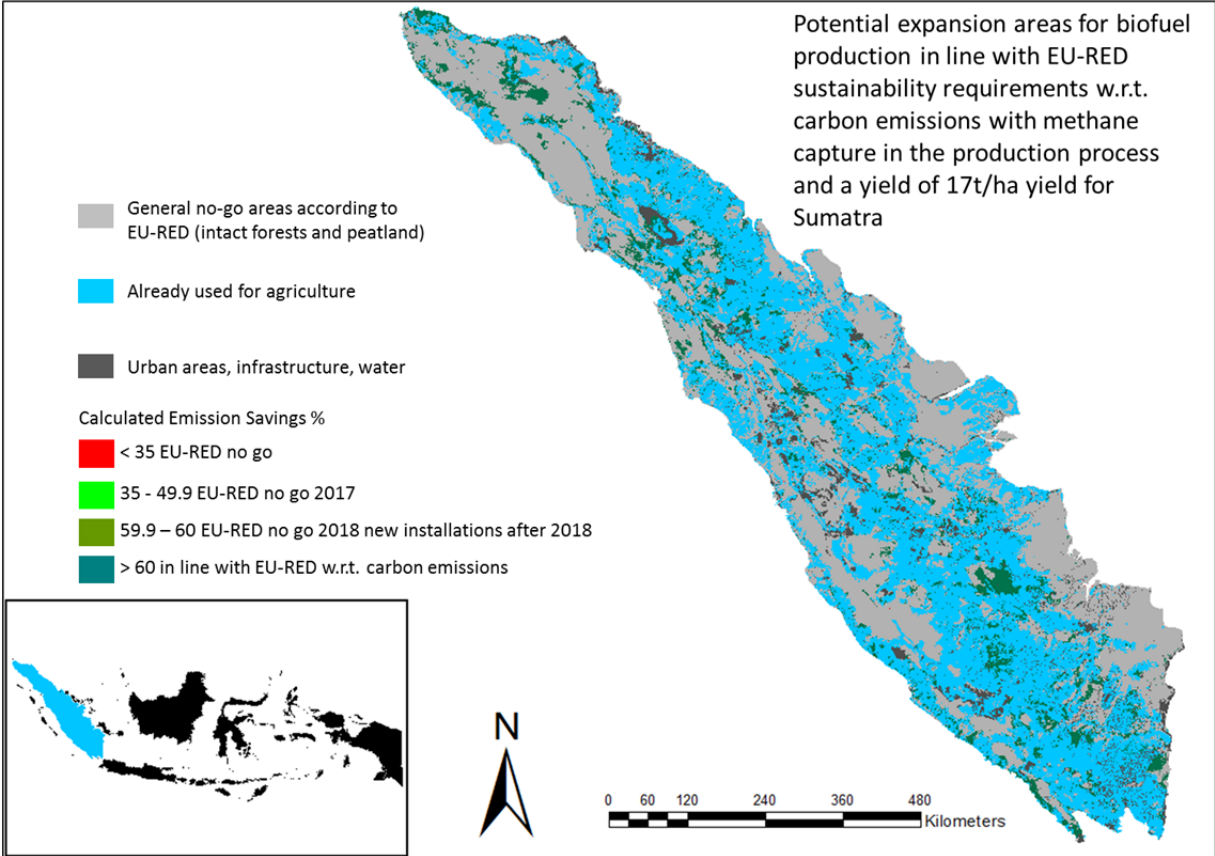
As a last step I want to raise the question of the overall implications of my results on possible land use change effects Indonesia. This is, first of all, a question on how much area for sustainable expansion still does exist which is not yet used for agricultural production. This is area where an expansion 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 indirect land use change 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.<sup>15</sup> 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.

<sup>15</sup> 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 12-17, 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 12.-14.). 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 18 for Sumatra and Figure 19. for Kalimantan.

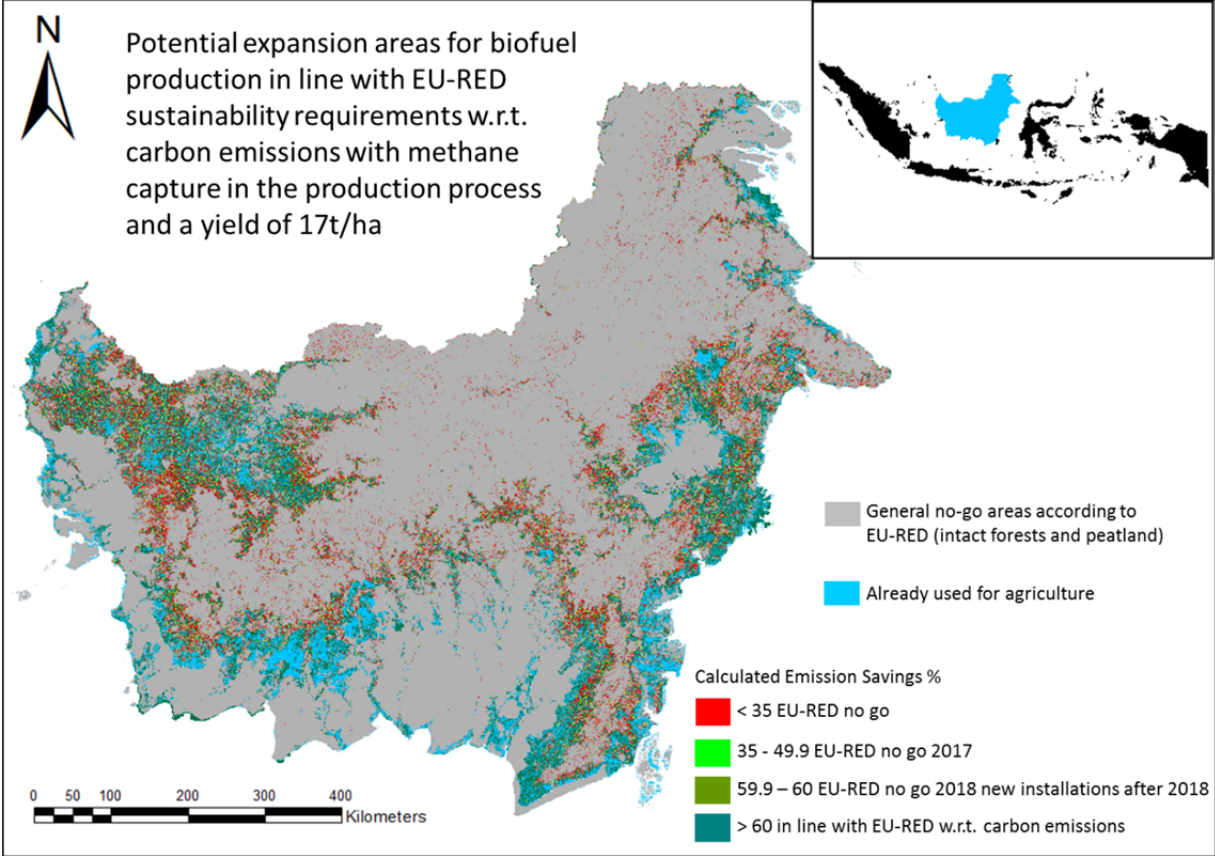
**Figure 18**



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. Sustainable expansion areas decrease to only 3.4 million ha (see Table 2). 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 no 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. In addition, one has to add that these maps do not include biodiversity factors and areas needed for other infrastructure, settlements etc. and general suitability for production which will further decrease suitable areas. Thus, even though it is tempting, these 10% will not be the whole available expansion are 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. This is unrealistic when considering that the OECD expects an increase in consumption of vegetable oils of 30% till 2021 compared to 2009 (OECD Agricultural Outlook) and that Indonesia has an increasing population.

**Figure 19**



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, if the EU wants to reduce the ILUC risk of its biofuel mandate, it should support a sustainable land use management that includes the reactivation of degraded areas.

However, the feasibility of such policy needs to be evaluated against the overall development in the country. When reviewing the complex socioeconomic drivers of deforestation in Indonesia, a successful implementation of such land use planning strategy is easier said than done. These drivers do not only refer to the international demand for palm oil and timber products but also to domestic drivers of deforestation that enable the elastic supply of cheap palm oil. Lange and Bertelmann 2013 summarize these domestic drivers based on a literature review. These are firstly the domestic demand for agricultural products due to economic growth, urbanization and an increasing population. Secondly, smallholders demand forest and agricultural land to improve their income security and/or to produce cash crops. Thirdly, all these direct drivers are only possible due to weak institutions that summarize problems of data availability, corruption, unclear property rights, poor law enforcement and legislative chaos (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 if producers fulfil the sustainability requirements for DLUC. 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.

## **5. 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 gap as Indonesia is the largest producer of palm oil, the most important vegetable oil in the world. Our maps can be used for a low carbon development policy of the agricultural sector in the region.

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. This further points out the importance of a sustainable land use planning and sustainability regulation for all production in the region. The impact of a regulation such as EU-RED is ineffective if all other production does not underlie any 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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Montane	Volcanic	Paddy Field	80	3	4	1.10	88	92	92	152	151.7	114.7	137.3
Tropical Montane	Volcanic	Plantation	80	60	82	1.15	92	92	174	152	20.2	-16.8	25.6
Tropical Montane	Volcanic	Primary Dryland Forest	80	277	379	1.00	80	92	459	152	-436.5	-473.5	-362.7
Tropical Montane	Volcanic	Savana	80	13	18	1.00	80	92	98	152	142.1	105.2	129.2
Tropical Montane	Volcanic	Secondary Dryland Forest	80	200	273	1.00	80	92	353	152	-267.1	-304.1	-218.6
Tropical Montane	Volcanic	Agriculture mixed Grass	80	21	29	0.74	59	92	89	152	157.7	120.7	142.4
Tropical Montane	Volcanic	Bush	80	30	41	1.00	80	92	121	152	105.4	68.4	98.0
Tropical Montane	Volcanic	Dryland farming	80	5	7	1.00	80	92	87	152	160.4	123.4	144.7
Tropical Montane	Volcanic	Forest Plantation	80	151	207	1.00	80	92	287	152	-161.2	-198.2	-128.7
Tropical Montane	Volcanic	Mixed Agriculture	80	5	7	0.69	55	92	62	152	199.7	162.7	178.1
Tropical Montane	Volcanic	Open Land	80	0	23	1.00	80	92	103	152	133.8	96.8	122.1
Tropical Wet	HAC	Paddy Field	44	3	4	1.10	48	51	53	110.6	148.8	111.8	134.9
Tropical Wet	HAC	Plantation	44	60	82	1.15	51	51	133	110.6	20.2	-16.8	25.6
Tropical Wet	HAC	Primary Dryland Forest	44	277	379	1.00	44	51	423	110.6	-445.2	-482.2	-370.0
Tropical Wet	HAC	Primary Mangrove Forest	44	159	218	1.00	44	51	262	110.6	-186.7	-223.7	-150.4
Tropical Wet	HAC	Savana	44	13	18	1.00	44	51	62	110.6	133.5	96.5	121.8
Tropical Wet	HAC	Secondary Dryland Forest	44	200	273	1.00	44	51	317	110.6	-275.7	-312.7	-226.0
Tropical Wet	HAC	Secondary Mangrove forest	44	91	124	1.00	44	51	168	110.6	-36.5	-73.5	-22.6
Tropical Wet	HAC	Agriculture mixed Grass	44	21	29	0.74	33	51	62	110.6	134.0	97.0	122.3
Tropical Wet	HAC	Bush	44	30	41	1.00	44	51	85	110.6	96.8	59.8	90.6
Tropical Wet	HAC	Dryland farming	44	5	7	1.00	44	51	51	110.6	151.7	114.7	137.3
Tropical Wet	HAC	Forest Plantation	44	151	207	1.00	44	51	251	110.6	-169.9	-206.9	-136.0
Tropical Wet	HAC	Mixed Agriculture	44	5	7	0.69	31	51	37	110.6	173.3	136.3	155.7

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Wet	HAC	Open Land	44	0	23	1.00	44	51	67	110.6	125.1	88.2	114.7
Tropical Wet	LAC	Paddy Field	60	3	4	1.10	66	69	70	129	150.1	113.1	136.0
Tropical Wet	LAC	Plantation	60	60	82	1.15	69	69	151	129	20.2	-16.8	25.6
Tropical Wet	LAC	Primary Dryland Forest	60	277	379	1.00	60	69	439	129	-441.3	-478.3	-366.7
Tropical Wet	LAC	Savana	60	13	18	1.00	60	69	78	129	137.3	100.3	125.1
Tropical Wet	LAC	Secondary Dryland Forest	60	200	273	1.00	60	69	333	129	-271.9	-308.9	-222.7
Tropical Wet	LAC	Secondary Mangrove forest	60	91	124	1.00	60	69	184	129	-32.6	-69.6	-19.4
Tropical Wet	LAC	Agriculture mixed Grass	60	21	29	0.74	44	69	74	129	144.5	107.5	131.2
Tropical Wet	LAC	Bush	60	30	41	1.00	60	69	101	129	100.6	63.6	93.9
Tropical Wet	LAC	Dryland farming	60	5	7	1.00	60	69	67	129	155.5	118.5	140.6
Tropical Wet	LAC	Forest Plantation	60	151	207	1.00	60	69	267	129	-166.0	-203.0	-132.8
Tropical Wet	LAC	Mixed Agriculture	60	5	7	0.69	42	69	48	129	185.1	148.1	165.7
Tropical Wet	LAC	Open Land	60	0	23	1.00	60	69	83	129	129.0	92.0	118.0
Tropical Wet	other	Paddy Field	83	3	4	1.10	91	95	96	155.45	151.9	114.9	137.5
Tropical Wet	other	Primary Dryland Forest	83	277	379	1.00	83	95	462	155.45	-435.8	-472.8	-362.0
Tropical Wet	other	Savana	83	13	18	1.00	83	95	101	155.45	142.9	105.9	129.8
Tropical Wet	other	Secondary Dryland Forest	83	200	273	1.00	83	95	356	155.45	-266.4	-303.3	-218.0
Tropical Wet	other	Agriculture mixed Grass	83	21	29	0.74	61	95	91	155.45	159.6	122.7	144.1
Tropical Wet	other	Bush	83	30	41	1.00	83	95	124	155.45	106.1	69.1	98.6
Tropical Wet	other	Dryland farming	83	5	7	1.00	83	95	90	155.45	161.1	124.1	145.3
Tropical Wet	other	Forest Plantation	83	151	207	1.00	83	95	290	155.45	-160.5	-197.5	-128.1
Tropical Wet	other	Mixed Agriculture	83	5	7	0.69	58	95	64	155.45	201.9	164.9	180.0
Tropical Wet	other	Open Land	83	0	23	1.00	83	95	106	155.45	134.5	97.5	122.7
Tropical Wet	sandy	Paddy Field	66	3	4	1.10	73	76	77	135.9	150.6	113.6	136.4

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Wet	sandy	Plantation	66	60	82	1.15	76	76	158	135.9	20.2	-16.8	25.6
Tropical Wet	sandy	Savana	66	13	18	1.00	66	76	84	135.9	138.8	101.8	126.3
Tropical Wet	sandy	Secondary Dryland Forest	66	200	273	1.00	66	76	339	135.9	-270.4	-307.4	-221.5
Tropical Wet	sandy	Agriculture mixed Grass	66	21	29	0.74	49	76	78	135.9	148.5	111.5	134.6
Tropical Wet	sandy	Bush	66	30	41	1.00	66	76	107	135.9	102.0	65.1	95.1
Tropical Wet	sandy	Dryland farming	66	5	7	1.00	66	76	73	135.9	157.0	120.0	141.8
Tropical Wet	sandy	Forest Plantation	66	151	207	1.00	66	76	273	135.9	-164.6	-201.6	-131.5
Tropical Wet	sandy	Mixed Agriculture	66	5	7	0.69	46	76	53	135.9	189.5	152.5	169.4
Tropical Wet	sandy	Open Land	66	0	23	1.00	66	76	89	135.9	130.4	93.4	119.2
Tropical Wet	Spodic	Primary Dryland Forest	124	277	379	1.00	124	143	503	202.6	-425.9	-462.9	-353.7
Tropical Wet	Spodic	Secondary Dryland Forest	124	200	273	1.00	124	143	397	202.6	-256.5	-293.5	-209.6
Tropical Wet	Spodic	Dryland farming	124	5	7	1.00	124	143	131	202.6	170.9	133.9	153.7
Tropical Wet	Spodic	Forest Plantation	124	151	207	1.00	124	143	331	202.6	-150.6	-187.6	-119.7
Tropical Wet	Spodic	Open Land	124	0	23	1.00	124	143	147	202.6	144.4	107.4	131.1
Tropical Wet	Volcanic	Paddy Field	130	3	4	1.10	143	150	147	209.5	155.7	118.7	140.7
Tropical Wet	Volcanic	Plantation	130	60	82	1.15	150	150	232	209.5	20.2	-16.8	25.6
Tropical Wet	Volcanic	Primary Dryland Forest	130	277	379	1.00	130	150	509	209.5	-424.5	-461.5	-352.4
Tropical Wet	Volcanic	Savana	130	13	18	1.00	130	150	148	209.5	154.2	117.2	139.4
Tropical Wet	Volcanic	Secondary Dryland Forest	130	200	273	1.00	130	150	403	209.5	-255.0	-292.0	-208.4
Tropical Wet	Volcanic	Agriculture mixed Grass	130	21	29	0.74	96	150	126	209.5	190.6	153.6	170.4
Tropical Wet	Volcanic	Bush	130	30	41	1.00	130	150	171	209.5	117.4	80.5	108.2
Tropical Wet	Volcanic	Dryland farming	130	5	7	1.00	130	150	137	209.5	172.4	135.4	154.9
Tropical Wet	Volcanic	Forest Plantation	130	151	207	1.00	130	150	337	209.5	-149.2	-186.2	-118.4
Tropical Wet	Volcanic	Mixed Agriculture	130	5	7	0.69	90	150	97	209.5	236.3	199.3	209.3
Tropical Wet	Volcanic	Open Land	130	0	23	1.00	130	150	153	209.5	145.8	108.8	132.3

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Wet	wetland	Paddy Field	86	3	4	1.10	95	99	99	158.9	152.2	115.2	137.7
Tropical Wet	wetland	Plantation	86	60	82	1.15	99	99	181	158.9	20.2	-16.8	25.6
Tropical Wet	wetland	Primary Mangrove Forest	86	159	218	1.00	86	99	304	158.9	-176.6	-213.6	-141.8
Tropical Wet	wetland	Savana	86	13	18	1.00	86	99	104	158.9	143.6	106.6	130.4
Tropical Wet	wetland	Secondary Dryland Forest	86	200	273	1.00	86	99	359	158.9	-265.6	-302.6	-217.4
Tropical Wet	wetland	Secondary Mangrove forest	86	91	124	1.00	86	99	210	158.9	-26.4	-63.4	-14.0
Tropical Wet	wetland	Agriculture mixed Grass	86	21	29	0.74	64	99	93	158.9	161.6	124.6	145.8
Tropical Wet	wetland	Bush	86	30	41	1.00	86	99	127	158.9	106.9	69.9	99.2
Tropical Wet	wetland	Dryland farming	86	5	7	1.00	86	99	93	158.9	161.8	124.8	145.9
Tropical Wet	wetland	Forest Plantation	86	151	207	1.00	86	99	293	158.9	-159.8	-196.8	-127.4
Tropical Wet	wetland	Mixed Agriculture	86	5	7	0.69	60	99	66	158.9	204.1	167.1	181.9
Tropical Wet	wetland	Open Land	86	0	23	1.00	86	99	109	158.9	135.2	98.3	123.3
Warm Temperate Moist	HAC	Primary Dryland Forest	88	277	379	1.00	88	101	467	161.2	-434.6	-471.6	-361.0
Warm Temperate Moist	HAC	Savana	88	13	18	1.00	88	101	106	161.2	144.1	107.1	130.8
Warm Temperate Moist	HAC	Secondary Dryland Forest	88	200	273	1.00	88	101	361	161.2	-265.2	-302.1	-217.0
Warm Temperate Moist	HAC	Agriculture mixed Grass	88	21	29	0.74	65	101	94	161.2	162.9	125.9	146.9
Warm Temperate Moist	HAC	Bush	88	30	41	1.00	88	101	129	161.2	107.3	70.3	99.6
Warm Temperate Moist	HAC	Dryland farming	88	5	7	1.00	88	101	95	161.2	162.3	125.3	146.3
Warm Temperate Moist	HAC	Mixed Agriculture	88	5	7	0.69	61	101	68	161.2	205.6	168.6	183.1
Warm Temperate Moist	HAC	Open Land	88	0	23	1.00	88	101	111	161.2	135.7	98.7	123.7
Warm Temperate Moist	LAC	Primary Dryland Forest	63	277	379	1.00	63	72	442	132.45	-440.6	-477.6	-366.1

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Warm Temperate Moist	LAC	Savana	63	13	18	1.00	63	72	81	132.45	138.1	101.1	125.7
Warm Temperate Moist	LAC	Secondary Dryland Forest	63	200	273	1.00	63	72	336	132.45	-271.2	-308.2	-222.1
Warm Temperate Moist	LAC	Agriculture mixed Grass	63	21	29	0.74	47	72	76	132.45	146.5	109.5	132.9
Warm Temperate Moist	LAC	Bush	63	30	41	1.00	63	72	104	132.45	101.3	64.3	94.5
Warm Temperate Moist	LAC	Dryland farming	63	5	7	1.00	63	72	70	132.45	156.3	119.3	141.2
Warm Temperate Moist	LAC	Forest Plantation	63	151	207	1.00	63	72	270	132.45	-165.3	-202.3	-132.1
Warm Temperate Moist	LAC	Open Land	63	0	23	1.00	63	72	86	132.45	129.7	92.7	118.6
Warm Temperate Moist	Spodic	Paddy Field	124	3	4	1.10	136	143	141	202.6	155.2	118.2	140.3
Warm Temperate Moist	Spodic	Secondary Dryland Forest	124	200	273	1.00	124	143	397	202.6	-256.5	-293.5	-209.6
Warm Temperate Moist	Spodic	Bush	124	30	41	1.00	124	143	165	202.6	116.0	79.0	107.0
Warm Temperate Moist	Spodic	Dryland farming	124	5	7	1.00	124	143	131	202.6	170.9	133.9	153.7
Warm Temperate Moist	Spodic	Forest Plantation	124	151	207	1.00	124	143	331	202.6	-150.6	-187.6	-119.7
Warm Temperate Moist	Spodic	Open Land	124	0	23	1.00	124	143	147	202.6	144.4	107.4	131.1
Warm Temperate Moist	Volcanic	Paddy Field	80	3	4	1.10	88	92	92	152	151.7	114.7	137.3
Warm Temperate Moist	Volcanic	Plantation	80	60	82	1.15	92	92	174	152	20.2	-16.8	25.6
Warm Temperate Moist	Volcanic	Primary Dryland Forest	80	277	379	1.00	80	92	459	152	-436.5	-473.5	-362.7
Warm Temperate Moist	Volcanic	Savana	80	13	18	1.00	80	92	98	152	142.1	105.2	129.2
Warm Temperate Moist	Volcanic	Secondary Dryland Forest	80	200	273	1.00	80	92	353	152	-267.1	-304.1	-218.6
Warm Temperate Moist	Volcanic	Agriculture mixed Grass	80	21	29	0.74	59	92	89	152	157.7	120.7	142.4

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Warm Temperate Moist	Volcanic	Bush	80	30	41	1.00	80	92	121	152	105.4	68.4	98.0
Warm Temperate Moist	Volcanic	Dryland farming	80	5	7	1.00	80	92	87	152	160.4	123.4	144.7
Warm Temperate Moist	Volcanic	Mixed Agriculture	80	5	7	0.69	55	92	62	152	199.7	162.7	178.1
Warm Temperate Moist	Volcanic	Open Land	80	0	23	1.00	80	92	103	152	133.8	96.8	122.1
Tropical Moist	HAC	Paddy Field	65	3	4	1.10	72	75	76	134.75	150.5	113.5	136.3
Tropical Moist	HAC	Plantation	65	60	82	1.15	75	75	157	134.75	20.2	-16.8	25.6
Tropical Moist	HAC	Primary Mangrove Forest	65	159	218	1.00	65	75	283	134.75	-181.7	-218.7	-146.1
Tropical Moist	HAC	Savana	65	13	18	1.00	65	75	83	134.75	138.5	101.5	126.1
Tropical Moist	HAC	Secondary Dryland Forest	65	200	273	1.00	65	75	338	134.75	-270.7	-307.7	-221.7
Tropical Moist	HAC	Secondary Mangrove forest	65	91	124	1.00	65	75	189	134.75	-31.4	-68.4	-18.3
Tropical Moist	HAC	Agriculture mixed Grass	65	21	29	0.74	48	75	77	134.75	147.8	110.8	134.0
Tropical Moist	HAC	Bush	65	30	41	1.00	65	75	106	134.75	101.8	64.8	94.9
Tropical Moist	HAC	Dryland farming	65	5	7	1.00	65	75	72	134.75	156.7	119.8	141.6
Tropical Moist	HAC	Forest Plantation	65	151	207	1.00	65	75	272	134.75	-164.8	-201.8	-131.7
Tropical Moist	HAC	Open Land	65	0	23	1.00	65	75	88	134.75	130.2	93.2	119.0
Tropical Moist	LAC	Paddy Field	47	3	4	1.10	52	54	56	114.05	149.0	112.1	135.1
Tropical Moist	LAC	Plantation	47	60	82	1.15	54	54	136	114.05	20.2	-16.8	25.6
Tropical Moist	LAC	Primary Dryland Forest	47	277	379	1.00	47	54	426	114.05	-444.5	-481.4	-369.4
Tropical Moist	LAC	Savana	47	13	18	1.00	47	54	65	114.05	134.2	97.2	122.5
Tropical Moist	LAC	Secondary Dryland Forest	47	200	273	1.00	47	54	320	114.05	-275.0	-312.0	-225.4
Tropical Moist	LAC	Agriculture mixed Grass	47	21	29	0.74	35	54	64	114.05	136.0	99.0	124.0
Tropical Moist	LAC	Bush	47	30	41	1.00	47	54	88	114.05	97.5	60.5	91.2
Tropical Moist	LAC	Dryland farming	47	5	7	1.00	47	54	54	114.05	152.4	115.4	137.9



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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Moist	LAC	Forest Plantation	47	151	207	1.00	47	54	254	114.05	-169.2	-206.2	-135.4
Tropical Moist	LAC	Open Land	47	0	23	1.00	47	54	70	114.05	125.9	88.9	115.4
Tropical Moist	Volcanic	Paddy Field	70	3	4	1.10	77	81	81	140.5	150.9	113.9	136.6
Tropical Moist	Volcanic	Savana	70	13	18	1.00	70	81	88	140.5	139.7	102.7	127.2
Tropical Moist	Volcanic	Secondary Dryland Forest	70	200	273	1.00	70	81	343	140.5	-269.5	-306.5	-220.7
Tropical Moist	Volcanic	Agriculture mixed Grass	70	21	29	0.74	52	81	81	140.5	151.1	114.1	136.8
Tropical Moist	Volcanic	Bush	70	30	41	1.00	70	81	111	140.5	103.0	66.0	95.9
Tropical Moist	Volcanic	Dryland farming	70	5	7	1.00	70	81	77	140.5	157.9	121.0	142.6
Tropical Moist	Volcanic	Forest Plantation	70	151	207	1.00	70	81	277	140.5	-163.6	-200.6	-130.7
Tropical Moist	wetland	Paddy Field	86	3	4	1.10	95	99	99	158.9	152.2	115.2	137.7
Tropical Moist	wetland	Savana	86	13	18	1.00	86	99	104	158.9	143.6	106.6	130.4
Tropical Moist	wetland	Agriculture mixed Grass	86	21	29	0.74	64	99	93	158.9	161.6	124.6	145.8
Tropical Moist	wetland	Bush	86	30	41	1.00	86	99	127	158.9	106.9	69.9	99.2
Tropical Moist	wetland	Dryland farming	86	5	7	1.00	86	99	93	158.9	161.8	124.8	145.9
Tropical Moist	wetland	Open Land	86	0	23	1.00	86	99	109	158.9	135.2	98.3	123.3
Tropical Montane	HAC	Paddy Field	88	3	4	1.10	97	101	101	161.2	152.3	115.3	137.9
Tropical Montane	HAC	Plantation	88	60	82	1.15	101	101	183	161.2	20.2	-16.8	25.6
Tropical Montane	HAC	Primary Dryland Forest	88	277	379	1.00	88	101	467	161.2	-434.6	-471.6	-361.0
Tropical Montane	HAC	Savana	88	13	18	1.00	88	101	106	161.2	144.1	107.1	130.8
Tropical Montane	HAC	Secondary Dryland Forest	88	200	273	1.00	88	101	361	161.2	-265.2	-302.1	-217.0
Tropical Montane	HAC	Agriculture mixed Grass	88	21	29	0.74	65	101	94	161.2	162.9	125.9	146.9
Tropical Montane	HAC	Bush	88	30	41	1.00	88	101	129	161.2	107.3	70.3	99.6
Tropical Montane	HAC	Dryland farming	88	5	7	1.00	88	101	95	161.2	162.3	125.3	146.3
Tropical Montane	HAC	Forest Plantation	88	151	207	1.00	88	101	295	161.2	-159.3	-196.3	-127.0
Tropical Montane	HAC	Mixed Agriculture	88	5	7	0.69	61	101	68	161.2	205.6	168.6	183.1

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Montane	HAC	Open Land	88	0	23	1.00	88	101	111	161.2	135.7	98.7	123.7
Tropical Montane	LAC	Paddy Field	63	3	4	1.10	69	72	74	132.45	150.3	113.3	136.2
Tropical Montane	LAC	Plantation	63	60	82	1.15	72	72	155	132.45	20.2	-16.8	25.6
Tropical Montane	LAC	Primary Dryland Forest	63	277	379	1.00	63	72	442	132.45	-440.6	-477.6	-366.1
Tropical Montane	LAC	Savana	63	13	18	1.00	63	72	81	132.45	138.1	101.1	125.7
Tropical Montane	LAC	Secondary Dryland Forest	63	200	273	1.00	63	72	336	132.45	-271.2	-308.2	-222.1
Tropical Montane	LAC	Agriculture mixed Grass	63	21	29	0.74	47	72	76	132.45	146.5	109.5	132.9
Tropical Montane	LAC	Bush	63	30	41	1.00	63	72	104	132.45	101.3	64.3	94.5
Tropical Montane	LAC	Dryland farming	63	5	7	1.00	63	72	70	132.45	156.3	119.3	141.2
Tropical Montane	LAC	Forest Plantation	63	151	207	1.00	63	72	270	132.45	-165.3	-202.3	-132.1
Tropical Montane	LAC	Mixed Agriculture	63	5	7	0.69	44	72	51	132.45	187.3	150.3	167.5
Tropical Montane	LAC	Open Land	63	0	23	1.00	63	72	86	132.45	129.7	92.7	118.6
Tropical Montane	other	Paddy Field	83	3	4	1.10	91	95	96	155.45	151.9	114.9	137.5
Tropical Montane	other	Secondary Dryland Forest	83	200	273	1.00	83	95	356	155.45	-266.4	-303.3	-218.0
Tropical Montane	other	Agriculture mixed Grass	83	21	29	0.74	61	95	91	155.45	159.6	122.7	144.1
Tropical Montane	other	Bush	83	30	41	1.00	83	95	124	155.45	106.1	69.1	98.6
Tropical Montane	other	Dryland farming	83	5	7	1.00	83	95	90	155.45	161.1	124.1	145.3
Tropical Montane	other	Forest Plantation	83	151	207	1.00	83	95	290	155.45	-160.5	-197.5	-128.1
Tropical Montane	other	Open Land	83	0	23	1.00	83	95	106	155.45	134.5	97.5	122.7
Tropical Montane	Spodic	Paddy Field	124	3	4	1.10	136	143	141	202.6	155.2	118.2	140.3
Tropical Montane	Spodic	Secondary Dryland Forest	124	200	273	1.00	124	143	397	202.6	-256.5	-293.5	-209.6
Tropical Montane	Spodic	Agriculture mixed Grass	124	21	29	0.74	92	143	121	202.6	186.6	149.6	167.0
Tropical Montane	Spodic	Bush	124	30	41	1.00	124	143	165	202.6	116.0	79.0	107.0
Tropical Montane	Spodic	Dryland farming	124	5	7	1.00	124	143	131	202.6	170.9	133.9	153.7
Tropical Montane	Spodic	Forest Plantation	124	151	207	1.00	124	143	331	202.6	-150.6	-187.6	-119.7

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***
			tC/ha	tC/ha	tC/ha		tC/ha	tC/ha	tC/ha	tC/ha	%	%	%
Tropical Montane	Spodic	Open Land	124	0	23	1.00	124	143	147	202.6	144.4	107.4	131.1

\* 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 calculations 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 tC/ha	Source
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 calculations I assume 4.5 kg biomass per 1 l fuel and a heating value of 32.65 MJ/l biodiesel (FNR 2012)