Change in carbon stocks arising from land-use conversion to oil palm plantations

A science-for-policy paper for the Oil palm Research-Policy Partnership Network

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Key messages

1. **Peat soils** contain **very high carbon stocks** which are lost due to ongoing oxidation and increased fire risk when peat soils are drained to grow oil palm in addition to above-ground carbon lost from forest clearance. Conversion of natural habitats on peat soils to oil palm plantation results in **very high carbon loss**. HIGH CONFIDENCE

2. **Undisturbed tropical forest** contains **high carbon stocks**, and conversion of forest to oil palm plantations results in **high carbon loss** regardless of soil type. HIGH CONFIDENCE

3. **Degraded forest** (e.g. selectively logged forest) contains less carbon than undisturbed forest, but conversion of disturbed forest to oil palm results in **net carbon loss**, which is likely to be **substantial** in most cases even for conversion of highly degraded forest. REASONABLE CONFIDENCE

4. **Rubber and tree crop plantations** on mineral soils contain **similar or slightly higher carbon stocks** compared to oil palm. Conversion to oil palm is likely to incur a **small carbon loss**. REASONABLE CONFIDENCE

5. **Shrub land** contains **less carbon than oil palm** plantations, and conversion of these land cover types on mineral soils results in **no carbon loss or small net carbon gain**. REASONABLE CONFIDENCE

6. **Grassland and intensive mono-crop agriculture** contains **less carbon** than oil palm plantations, and conversion of these land cover types on mineral soils results in **no carbon loss or small net carbon gain**. HIGH CONFIDENCE

7. The **carbon stock** of a piece of land **should not be the only criterion** for deciding whether to convert to oil palm plantation and should be carefully **considered alongside other essential values** such as biodiversity, ecosystem goods and services food security (i.e. in the case of converting crop land), social and economic values or indirect land use change.

Scope of the report

The aim of this report is to synthesize current scientific information to help policy makers make decisions about land conversion to oil palm plantations. This report compares the carbon stocks (CS) of oil palm plantations with other land cover types to determine the change in stored carbon which will arise from converting these different land covers to oil palm plantations.

The report focuses on CS comparisons of different land cover types, and does not include other important values such as biodiversity, ecosystem goods and services (such as soil and water protection), food security (i.e. in the case of converting crop land), social and economic values or indirect land use change. Carbon stocks are not necessarily a good indicator of other values, and all these values should be considered alongside the evidence presented in this report when making decisions about land conversion.

The report focuses specifically on Malaysia and Indonesia. Many of the findings may also be broadly applicable to other regions, but land cover types may differ substantially in characteristics and carbon content, especially for Africa and Central/South America. Additional evidence should be obtained to inform policy decisions in these regions.

Carbon emissions from other aspects of land clearing and palm oil production, such as fossil fuel use or mill effluent emissions, are not considered in the report, but may be significant. Therefore, conversion of land cover types with similar CS to oil palm plantations may not equate to carbon neutral conversion, and companies should also address these other emissions to improve the carbon footprint of their plantations (see Chase et al. 2012).

Potential for carbon offsetting and compensatory mechanisms are not addressed in this report, but could be a useful tool in policy decisions. There may be benefits to converting some land with a slightly higher CS if increased protection and rehabilitation of land elsewhere could give greater overall carbon benefits. Other important values such as biodiversity and rural/smallholder livelihoods might also be considered in this context.

Rationale

In the industrial era (post 1750), and especially in the last few decades, global temperatures have risen at unprecedented rates (IPCC 2013) driven by anthropogenic emissions of greenhouse gases (IPCC 2013). The largest contribution to warming is from CO_2, but N_2O, CH_4, ozone and water vapour are also important (IPCC 2013). Climate change is predicted to present significant challenges to humanity, and mitigating further climate change by reducing greenhouse gas (GHG) emissions is essential for minimising negative impacts (IPCC 2014).

Agriculture and land use change together contribute around 26% of GHG emissions globally (agriculture, 13.8%, land use change, 12.2%, Herzog 2009). This compares to 14.3% from transport and 19% from industry (Herzog 2009). Reducing GHG emissions from agriculture and land use change is key for reducing GHG emissions in order to help mitigate climate change.

Oil palm is an important crop in SE Asia; Malaysia and Indonesia collectively produce 86% of the world's palm oil (USDA-FAS 2014). The largest sources of emissions from oil palm agriculture are from land use change and peat oxidation (Chase et al. 2012). Between 50% and 60% of oil palm expansion between 1990 and 2005 in Malaysia and Indonesia directly replaced forests (Koh and Wilcove 2008), and this trend is projected to continue (Carlson et al. 2013). Oil palm is responsible for 16% of the total emissions from land use change and peat oxidation in Indonesia, and 32% in Malaysia (Agus et al. 2013), and so reducing emissions in this sector would contribute significantly to national emissions reduction targets.

Carbon is stored in living and dead organic material in the environment. The land cover types with the greatest carbon stores in SE Asia are peat soils and natural forest. When these habitats are converted to oil palm plantations carbon is released into the atmosphere. Oil palms sequester and store some carbon, and since they are large, woody plants with a life cycle of 20-30 years they store substantially more carbon than annual crops, but substantially less carbon than natural forest. Peat soils store very large stocks of carbon, and when land on peat soils is converted to oil palm, drainage for cultivation causes oxidation of the peat and increased fire risk, which releases carbon into the atmosphere as CO_2. Therefore, to develop policy which will minimise emissions from converting land to oil palm plantation, scientific evidence is required to quantify the carbon content of different land cover types. This will enable identification of those land cover types that should be targeted for conversion because they contain similar or lower CS compared with oil palm, and those that should be avoided because they contain large amounts of carbon and for which conversion to oil palm would result in high carbon loss.

Carbon Stock Classification

Based on the available literature (see references for complete list of sources consulted) we allocated a Carbon Stock (CS) classification to common land cover types in Malaysia and Indonesia (see table 1, figure 1). Land cover types classified as *High* or *Medium*, are those on mineral soils which have higher above-ground carbon (AGC) stocks than the time-averaged CS of oil palm plantations (30-40 Mg C/ha, Agus et al. 2013). Land cover types classified as *Low* have equal or less AGC than oil palm plantations and occur on mineral soils. *High+* land cover types are all land cover types on peat soils. These land cover types contain very large stocks of soil organic carbon (SOC, at least 300 Mg C/ha, of which 270Mg C/ha might be expected to be lost over a single 25 year oil palm rotation), in addition to the AGC loss from clearing. Conversion of natural peat forest to oil palm potentially puts the entire CS of the peat at risk of oxidation if there is no restorative intervention. For deep peat this could amount to thousands of tonnes of carbon loss per hectare.

Table 1: Carbon Stock (CS) classification definitions.

	Carbon Stock classification	Carbon stock Mg C/ha	Annual C loss (peat only)Mg C/ha/yr	Land cover types	Change in carbon when converted to oil palm
Peat soils	**High+**	>300* SOC +AGC of land cover type (deep peat of >3m contains 1000s Mg C/ha)	10.8 (IPCC 2013) (=270Mg C/ha over one 25 yr oil palm rotation)	Peat soil (>50cm deep), any land cover type	Very Large loss
Mineral soils (AGC considered only)	**High**	>100	na	Most forest types	Large loss
	Medium	40-100	na	Most tree plantations, some very degraded forest	Small loss
	Low	<40	na	Oil palm, shrub land, monocrop agriculture, grassland	No loss or small gain

*Based on 60kg C/m^3 (Page et al. 2002, and definition of peat soil as >50cm depth of partially decomposed organic matter)

na= not applicable

Confidence levels

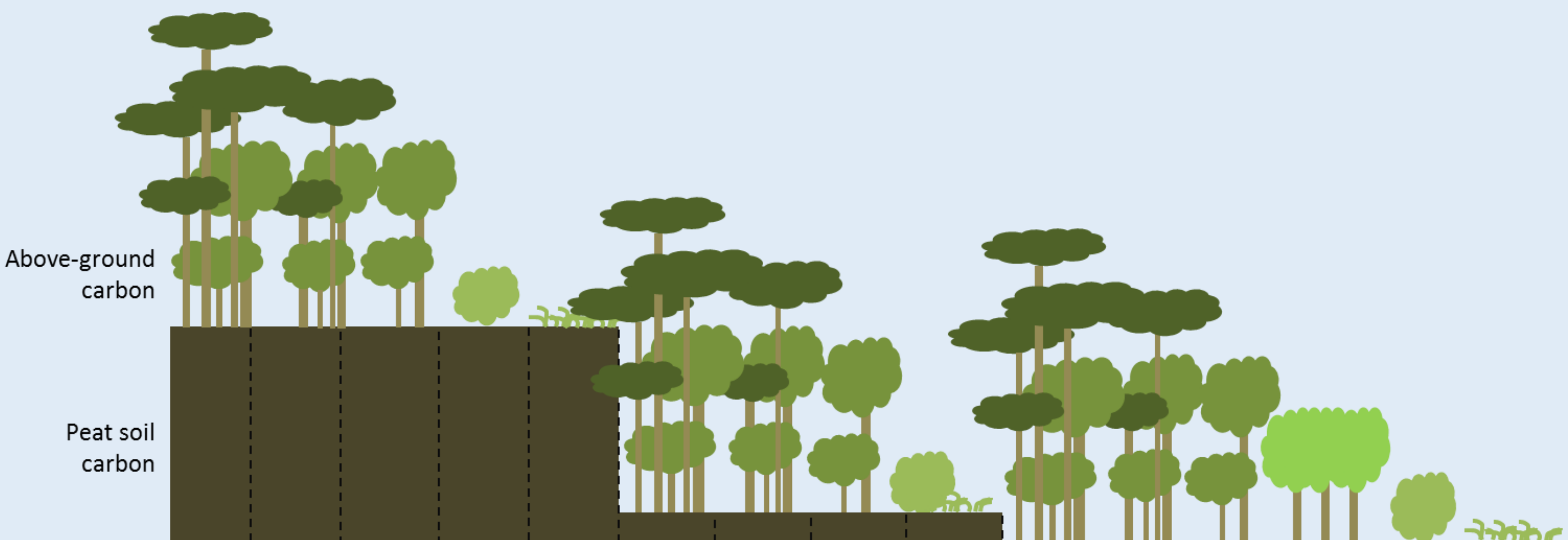
Confidence levels are assigned to the **estimated change in carbon** for each land cover type **when converted to oil palm.** This level indicates the confidence in the scientific evidence based on the amount of evidence (i.e. the number of published research studies), the variation in the evidence (i.e. how similar estimates are for a particular land cover type), and the size of the difference in the CS of the land cover type compared with that of oil palm.

The confidence level ***does not*** relate to the CS classification itself, but to the impact of conversion.

High confidence: the evidence is robust and provides a clear consensus: there is very little doubt about the expected change in carbon when this land cover type is converted to oil palm.

Reasonable confidence: The evidence is generally in agreement as to the expected change in carbon when this land cover type is converted to oil palm, but there is a small amount of uncertainty, either because there is some variation in CS within the land cover type or because there is only a small difference in CS compared with oil palm, therefore there is some uncertainty about the direction of the change.

Low confidence: The evidence is lacking and/or variation among estimates is very large and more research is needed.



Land cover type	Primary forest on deep peat	Medium-high density forest on deep peat	Highly degraded forest on deep peat	Shrub and degraded deep peat	Grassland, annual crops on deep peat	Primary forest on shallow peat	Medium-high density forest on shallow peat	Highly degraded forest on shallow peat	Highly degraded peat soils e.g. due to drainage for agriculture	Primary forest on mineral soil	Medium to high density forest on mineral soil	Highly degraded forest on mineral soil	Tree plantation on mineral soil	Shrub on mineral soil	Grassland and annual crops on mineral soil
Carbon Stock Classification	High+	High+	High+	High+	High+	High+	High+	High+	High+	High	High	Medium-High	Medium	Low	Low
Confidence in the evidence base for predicting change in stored carbon when land cover type is converted to oil palm	HIGH	HIGH	HIGH	REASONABLE	REASONABLE	HIGH	HIGH	HIGH	LOW	HIGH	REASONABLE	LOW	REASONABLE	REASONABLE	HIGH

Figure 1: **Diagram of landcover types and associated carbon stock (CS) classification**. Conversion of land cover types with High+ or High CS classifications should be avoided even if the confidence level is Low (e.g. for highly degraded peat soils) because of the very large stores of carbon which are at risk. Confidence levels relate to the evidence for *change* in stored carbon when a land cover type is converted to oil palm and not the CS classification itself.

Areas of high confidence

Peat soils contain very high carbon stocks and conversion of natural forest on deep peat soils to oil palm plantations will result in very high carbon loss.

Tropical peat soils contain extremely large amounts of carbon, often an order of magnitude higher per unit area than the above ground carbon (AGC) stores in undisturbed forest. Drainage is necessary to grow oil palm, and this causes irreversible carbon loss through oxidation of the peat and increased fire risk. Unlike the clearing of forest or emissions from fires, oxidation occurs progressively over time, and is not a one-off loss. The amount of time it would take for all the peat to oxidise is not well understood, nor is it known how future landuse will affect further oxidation of peat. Many estimates predict carbon losses of 450-735 Mg C/ha over a 25 year oil palm life cycle (e.g. Page et al. 2011; Hooijer et al. 2012; Couwenbeg & Hooijer 2013). However, even based on the most conservative emissions estimates of 40 Mg CO_2/ha/yr or 10.8 Mg C/ha/yr (IPCC 2013), this would result in a loss of over 200Mg/C/ha within one oil palm rotation: the equivalent of the AGC lost in clearing primary rainforest. This is in addition to the AGC lost from any forest cleared from the area, and puts the entire carbon store at risk of oxidation unless the peat is re-wetted at some point in the future (Verwer et al. 2008). Thus there is high confidence that conversion of peat land will incur very high carbon losses.

Undisturbed tropical forest in SE Asia contains high carbon stocks, and conversion of undisturbed forest to oil palm plantations will result in high carbon loss.

AGC stocks of undisturbed lowland (<500m elevation) forest are an order of magnitude higher (as much as 400 Mg C/ha, Zeigler et al. 2012, Agus et al. 2013) than those of oil palm (30-40 Mg C/ha) and there is high confidence that conversion will incur high carbon losses.

Grassland and annual crops on mineral soils contain less carbon than oil palm plantations and conversion of this land will be carbon neutral, or result in a small carbon gain.

Grassland and annual crops on mineral soils contain much less carbon (<20 Mg C/ha) than oil palm which has a 20-30 year lifecycle and large woody stems. There is high confidence that conversion of grassland and annual crop land will result in no direct net loss of carbon.

Areas of reasonable confidence

Disturbed and degraded forests (e.g. selectively logged forest) have high carbon content and conversion to oil palm plantations will incur substantial carbon losses.

The AGC of most degraded forest is over twice as high as oil palm at the time of conversion. There is reasonable confidence that conversion of disturbed forest, even if heavily degraded, will incur a substantial carbon loss. There is some uncertainty about forest which has been degraded to the extent that it resembles scrubland, however, detecting the presence of dipterocarp species in SE Asia will help to determine whether highly degraded forest is able to recover naturally from disturbance. Levels of forest degradation and the amount of carbon they contain need to be better defined in order to help companies and governments identify which areas to avoid, and which to convert. Conversion of medium-high quality logged forest should be avoided, and it is recommended that a precautionary approach is taken to avoid all degraded forest until better guidelines become available.

Conversion of rubber and other tree plantations will incur small carbon losses.

There is reasonable confidence that the AGC of rubber and other tree plantations, including mixed tree plantations, have slightly higher carbon stocks than oil palm plantations, and conversion of these areas will result in a small loss of carbon. There is some uncertainty as to whether conversion would incur slight overall loss or gain because carbon stocks are similar to those of oil palm. Less intensive and mixed tree plantations may contain more carbon than intensive monocrop plantations, but usually less than highly degraded natural forest.

Areas of low confidence and key knowledge gaps

There are low levels of certainty in determining the impact of conversion on carbon storage for land cover types which are border line between CS classifications, and for highly degraded peat soils. We have identified six key topic areas (listed in order of importance) where information is lacking, and we have assessed the likelihood that filling these knowledge gaps will have an impact on policy development:

The impacts of converting degraded peat soils, and how conversion impacts on nearby peat lands outside of the concession area, are not well understood.

The continuous process of peat oxidation is complex compared to the one-off events of forest clearance and fires. There is a need for better understanding of the processes and factors involved, particularly in relation to conversion of peat soils which are already degraded (e.g. because they have already been partially drained for agriculture), and distances over which conversion could affect peat soils beyond the conversion area, for example if the water table is altered leading to peat subsidence outside the plantation. This may also pose increased fire risk for drained peat outside concessions areas if there is no fire control provision as there may be within concessions. There is a high likelihood that filling this knowledge gap will affect policy development depending on how much conversion to oil palm exacerbates carbon loss from already degraded peat soils, and if it is found that buffer zones around peat land are required in order to prevent the destabilisation of peat soils outside of plantation areas. This should be a high priority for research because of the large carbon stocks which are at risk in these areas. Companies and governments wishing to reduce carbon losses should avoid conversion of any peat land.

There is considerable variation in estimates of above-ground carbon stocks for natural forest.

Measures of AGC are the best studied component of total carbon stock for different land-use types (other components include below-ground live biomass carbon, dead organic matter and soil organic carbon). AGC is likely to be the most useful component of the total carbon stock for allocating CS classifications to land cover types on mineral soils since it is the easiest component to measure, a reliable indicator of overall carbon stored in the environment and remote sensing techniques are a promising tool for efficient monitoring of AGC. However, there is still large variation in measurements of AGC within the same land cover types. A few studies have attempted to consolidate the estimates from the literature (Agus et al. 2013, Zeigler et al. 2012), but they nonetheless report wide ranges in estimates of AGC; such variation might be reduced with new, more selective and detailed analyses. Other sources of variation include the choice of mathematical equations used to derive carbon estimates from field measurements, and the components of the above-ground biomass included in the field measurements (for example, whether dead vegetation, leaf litter, lianas, saplings or just trees were included, whether forest gaps were surveyed, and the accuracy of wood density estimates). More stringent categorisation of forest types and degradation would reduce the range of AGC estimates, improving confidence in estimates and thus producing more reliable guidelines for assessment. There is a high likelihood that filling this knowledge gap will impact on CS classification of degraded forests on mineral soils because of the current uncertainty in this land cover type, but there is a low likelihood that further clarification of above ground carbon will impact on CS classification of primary forest and forested peat land, where there is already high confidence that these areas contain high or very high carbon stocks.

Definitions of land cover types need to be improved, and tools developed to identify them.

Based on current carbon stock estimates, the category of "disturbed forest" is classified as High CS, whereas "scrubland" is Low CS. However, these vegetation types can be difficult to distinguish where forest is extremely degraded, or where severe degradation is spatially variable. Vegetation definitions need to be more clearly related to carbon stocks and tools such as remote sensing (Murdiyarso et al. 1995; Defries et al. 2002; Singh et al 2014), or efficient field measures of trees/ ha must be developed so that these land cover types are easily identifiable. There is a high likelihood that filling this knowledge gap will impact on CS classifications of different land cover types, and subsequent policy decisions.

Inconsistencies in the way carbon stocks are reported for different land cover types make it difficult to compare the impacts of conversion.

The first inconsistency is in the reporting of degraded forest. When carbon stocks of undisturbed forest are estimated, it is assumed that carbon stocks will vary little over time because the ecosystem is in equilibrium (although they may in fact be accumulating carbon, Berry et al. 2010). When carbon stocks for oil palm or other agricultural crops are calculated, they are time-averaged to account for the accumulation of carbon over the crop life cycle. Estimates of carbon for logged and degraded forest are generally given as a measurement at a specific point in time, with no accounting for recovery of forest and associated accumulation of carbon over time. For example, if, after selective logging, a natural forest is allowed to recover, the carbon stock of the land may eventually approach that of primary forest. If the forest is designated as production forest and managed sustainably it may retain a consistent and relatively high carbon stock over multiple logging rotations. This implies that a time-averaging approach across logging rotations is required, similar to that used for crops. There is medium likelihood that using improved estimates which account for future carbon accumulation could impact on CS classification of disturbed forests. This is because there is already reasonable confidence that the carbon content of most logged forest is several times higher than that of oil palm plantations, and thus is classified as High CS, however, improved estimates which take account of potential future carbon content could affect CS classification for areas of very heavily degraded forest or scrubland which are less clearly defined.

The second inconsistency is in the reporting of carbon losses from conversion of peat soils versus AGC losses from land clearance. This is because carbon from peat is lost through oxidation gradually over time, whereas above-ground carbon losses are one-off events. Therefore, peat carbon loss is often reported as emissions per ha per year, whereas AGC loss is usually reported as the entire AGC of the previous land cover type minus the AGC of the new land cover type (in this case oil palm). It is difficult to quantify the overall impact of converting land cover types on peat to oil palm because it is affected by how long peat takes to completely decompose, and how long the land is managed as oil palm. However, filling this knowledge gap is unlikely to impact on policy decisions because carbon loss from peat oxidation over one oil palm rotation of 25 years is equivalent to the AGC loss from converting primary forest based on conservative estimates of annual carbon loss (IPCC 2013). This puts all peat land into the High CS category before AGC is taken into account which raises it to High+ CS category (see table 1).

Mapping of peat depth and associated carbon stocks is poor.

The depth of peat varies greatly and this has a large impact on carbon storage capacity. A source of discrepancy in estimates of carbon stocks depends on assumptions of average peat depth used in calculations. Peat depth is poorly mapped across SE Asia, and this is a key knowledge gap which needs to be filled in order to determine carbon stocks in peat land areas more accurately. However, the impact on policy decisions is likely to be small, because even shallow peat lands of 50cm depth contain as much or more carbon than the AGC of primary rainforest. All peat areas should already be classified as High+ CS and companies and governments wishing to reduce carbon losses should avoid conversion of all peat areas. Better mapping of peat depths across SE Asia would help to target better protection of peat.

The below-ground carbon stocks of mineral soils are poorly quantified.

Below-ground carbon stocks of mineral soils are poorly quantified due to the large area over which mineral soils occur, the variation in soil carbon across this area, and the difficulties of surveying carbon below-ground. It is possible to estimate below ground living biomass based on root:shoot ratios, however, there is uncertainty relating to soil organic carbon (SOC) which is likely to vary greatly among different land cover types and with conversion. Studies quoted in Agus et al. (2013) indicate a reduction in SOC in oil palm plantations compared with undisturbed forest, but no change or an increase in SOC when compared to disturbed forest. Although there is little information on this topic, filling this knowledge gap is unlikely to impact greatly on CS classifications because SOC in mineral soils is likely to vary much less than AGC or peat as a result of conversion to oil palm.

References

References refer to studies in wet aseasonal tropical climates at elevations below 500m in Malaysia, Indonesia and Papua New Guinea. The exception is for topics where there is a lack of evidence from these countries, for example, studies comparing soil carbon across different land cover types. References may be listed more than once if they are relevant to multiple land cover types.

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Glossary of Acronyms

AGC	Above-ground carbon
BGC	Below-ground carbon
CH_4	Methane
CO_2	Carbon dioxide
CS	Carbon stock
IPCC	Intergovernmental Panel on Climate Change
Mg C/ha	Million grams carbon per hectare
N_2O	Nitrous oxide
SOC	Soil organic carbon