World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

Palm oil series

The carbon footprint of Indonesian palm oil production

The Renewable Energy Directive (RED) of the European Union includes a commitment to substitute part of the Union's transport fuel with biofuels in order to reduce carbon dioxide emissions. The directive also takes partial responsibility for increases in emissions that may occur outside of the national accounting frameworks. Specifically, the RED defines a minimum level of net emissions reduction, also known as emissions savings. The directive implies that palm oil exporting countries, such as Indonesia, need to have reliable data on the carbon footprint of palm oil to be used for biofuel.
We applied the Biofuel Emissions Reduction Estimator Scheme (BERES) tool to 23 plantations in Indonesia, which abide by what is considered current 'good practice', and estimated whether the net emissions reduction of this 'good practice' was able to meet minimum EU standards. The estimation of the net emissions included oil palm life-cycle assessment.

Main findings	Implications
1. Ten of the 23 plantations converted more than 60% of their area from forests to oil palm.	These plantations have higher potential emissions from other land-use and land-cover conversions.
2. The ranges of time-averaged aboveground carbon stock of land cover other than oil palm were: a. 150–250 tonne of carbon per hectare (t C/ha) for forests, b. 50–150 t C/ha for tree-based systems and c. less than 50 t C/ha for non-tree-based systems.	Developing oil palm plantations from land-cover types with carbon stock higher than 40 t C/ha leads to a 'carbon debt' in the first plantation cycle.
3. The time-averaged aboveground carbon stock of oil palm, based on a typical replanting cycle of 25 years, is (35)–40–(45) t C/ha (implying a measured range of 35–45 and a mean of 40).	
4. Annual carbon dioxide emission rates from mineral soil were zero.	The potential change in belowground carbon pools can be ignored if adequate soil management practices in the use of fronds, cover crops and organic fertilizers are followed.
5. In 91% of the plantations assessed, oil palm had replaced vegetation of more than 40 t C/ha, thus incurring carbon debt. The average net emissions rate of all sampled plantations owing to land-use conversion ranged 0–36 tonne of carbon dioxide equivalent per hectare per year (CO_2eq/ ha/yr).	Conversion before 2008 is 'grandfathered' (current rules don't apply). But if the pattern persists after 2008, the companies will be held responsible for the carbon debt.
6. The average fresh fruit bunch (FFB) production in Indonesia is approximately 18.8 t/ha/yr, which translates into an application rate for nitrogen fertilizer of 141 kg N/ha/yr.	The higher the yield, the more rapidly carbon debt can be neutralized and net emissions savings earned. However, higher yields depend on more than proportionally higher nitrogen fertilizer use. The additional nitrous oxide (N_2O) emissions need to be accounted for. Net effects depend on the assumed fraction of nitrogen fertilizers lost as N_2O.
7. In 39% (first-cycle assessment) and 78% (second-cycle or subsequent assessment) of the plantations, palm oil used for biodiesel can lead to emissions savings (calculated per standard EU procedure) of at least 35%.	A substantial part of the current production of palm oil can meet the directive for minimum emissions savings.
8. Intensification and good management practices will increase emissions savings and decrease the product's carbon footprint.	

Introduction

The carbon footprint of a commodity that is traded internationally is the sum of a number of components that represent net emissions at different stages of the production cycle. A life-cycle assessment of palm oil includes three different stages of the production cycle.

A. The initial conversion of vegetation into a palm oil plantation, usually based on land clearing, leading to a 'carbon debt'.

B. The balance of emissions and absorption during the growth cycle of the oil palms, depending on growth rate, green manure and organic waste management and fertilizer practices, leading to time-averaged carbon stock that influences carbon debt and repayment time.

C. Transport to the refinery followed by processing and further transport: from crude palm oil (CPO) and kernel production, transesterification into biofuel, transportation to the end user.

Typically, the carbon footprint for stage A is expressed per unit area, for stage C per unit product, and for stage B as a combination of the two. The productivity per unit area is the unifying concept that allows all emissions to be expressed per unit product. Where the product is used as a biofuel source, the emissions caused (the carbon footprint) can be compared with the emissions that would be caused by an energetic equivalent amount of fossil fuel.

This comparison leads to a net emissions reduction or 'relative emissions savings' ratio, which has been the basis for EU rules about the types of biofuel that can be eligible for support under biofuel policies. Currently, the minimum emissions saving is set at 35%, with a gradual increase to 60% required by 2018. These new standards imply that palm oil exporting countries, such as Indonesia, need to have reliable data on the carbon footprint of palm oil to be used for biofuel.

Objective

The objective of the study was to estimate the carbon footprint of Indonesian palm oil production. It required several steps.

1) Analyzing land-use and land-cover changes and trajectories.

2) Estimating time-averaged aboveground carbon stock of existing land cover surrounding oil palm plantations, expressed in tonne of carbon per hectare (t C/ha) including trees, understorey vegetation, litter and necromass.

3) Estimating time-averaged aboveground carbon stock of oil palm plantations (in t C/ha), including oil palms, understorey vegetation, litter and necromass in different production environments (peat and mineral soil types) and management regimes (nucleus/company, plasma and independent).

4) Assessing carbon dioxide and other greenhouse gas emissions from palm oil production in Indonesia, including

   a. Carbon dioxide emissions from land conversion to oil palm plantations; and

   b. Carbon dioxide and other greenhouse gas emissions from management, oil processing and transportation.

Methodology

We applied the BERES tool (Box 1) to 23 plantations in Indonesia which abide by what is considered current 'good practice'. We did this in order to meet the

Box 1. Biofuel emissions reduction estimator scheme

BERES is an integrated assessment scheme for estimating carbon dioxide and other greenhouse gas emissions related to palm oil and other biofuel production. It includes three different phases (A, B and C[1,i,ii,iii,iv]) of the production process in line with EU-mandated calculations[v]. The three processes and their emissions components involved at least four units of analysis in the relationship between carbon dioxide (and other greenhouse gases) emissions and the production of palm oil, which can be a source of biofuel, among other uses.

1 A technical coefficient was used to estimate emissions due to the processing steps of palm oil production.

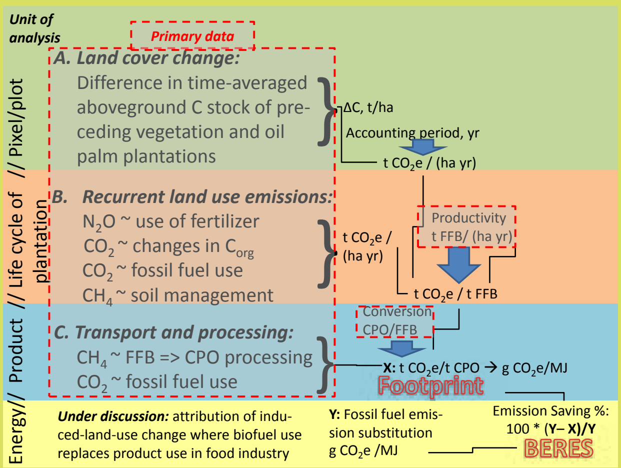

Figure 1. Four units of analysis in the relationship between carbon dioxide (and other greenhouse gases) emissions and the production of palm oil, which can be a source of biofuel, among other uses

above objectives and to find answers to the following questions:

1) Does current Indonesian palm oil production, on average, meet the standards for net emissions reductions when used as biofuel?

2) Does part of current Indonesian palm oil production meet the standards for net emissions reduction when used as a biofuel?

3) Can Indonesian palm oil production in the near future meet the standards for net emissions reduction when used as biofuel?

Sample profile

Selection of plantations for data collection followed a stepwise cluster approach, soliciting self-nomination of companies to be involved in learning the method while helping to collect data. The stepwise sampling design used three main criteria:

1) initial land use categorized into 'forest' and 'non-forest';

2) soil type categorized into 'peat' and 'mineral'; and

3) relative density of oil palm in the relevant province.

Based on these three main criteria, a total of 12 clusters (strata) were defined as a basis for a stratified sampling approach[2] (figure 2 and table 1). Based on nominations of study sites by plantation companies, the most important strata could be covered with replicate samples, but clusters such as 'peat, non-forest history' were not represented in the final selection of 23 plantations. The sample results across the strata reflect the range of conditions of oil palm plantations in Indonesia, and opportunities for change, rather then unbiased averages.

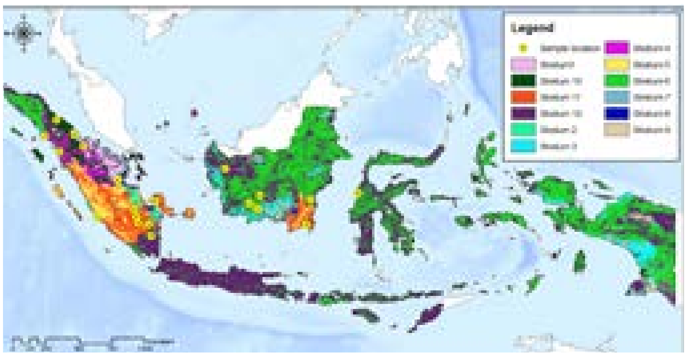

Figure 2. Sample distribution of oil palm plantations

2 Due to the voluntary nominations of plantations, this approach focuses on what can be done rather than the average of what is being done. Stratification helped to distinguish between the conditions found, but we don't yet have reliable "stratum weight" indicators to arrive at a weighted average at national scale.

Table 1. Sample distribution of oil palm plantations by cluster based on the parameters of former land use, soil and density of oil palm in the province

Sample parameters			Cluster name	Number of samples
Initial land use	Soil	Area density of oil palm		
Forest	Peat	Density 1	Cluster 1	2
		Density 2	Cluster 2	2
		Density 3	Cluster 3	1
	Non-peat	Density 1	Cluster 4	2
		Density 2	Cluster 5	3
		Density 3	Cluster 6	8
Non-forest	Peat	Density 1	Cluster 7	
		Density 2	Cluster 8	
		Density 3	Cluster 9	
	Non-peat	Density 1	Cluster 10	2
		Density 2	Cluster 11	3
		Density 3	Cluster 12	
Total sample plantations				23

Main Findings

1. Ten of the 23 plantations converted more than 60% of their area from forests to oil palm

The analysis of land-use[vi] changes and trajectories explored the dynamics of land-use systems before and after plantation establishment. The trajectories were divided into four classes:

1) forest converted to oil palm;

2) tree-based system converted to oil palm;

3) non-tree-based system converted to oil palm; and

4) non-vegetation converted to oil palm.

In connection with the potential greenhouse gas emissions from land-use conversion, a plantation which has converted a large proportion of its area from forest to oil palm will have higher emissions compared to a plantation that converted tree-based, non-tree-based or non-vegetation land uses.

A total of ten of the 23 plantations had converted more than 60% of their area from forest to oil palm (figure 3). These plantations have higher potential emissions from land-use conversion. Another ten plantations had a slightly lower forest to oil palm conversion rate, which ranged 10–20% of the total conversion area in the plantation. Only three of the 23 plantations converted from purely non-forest areas.

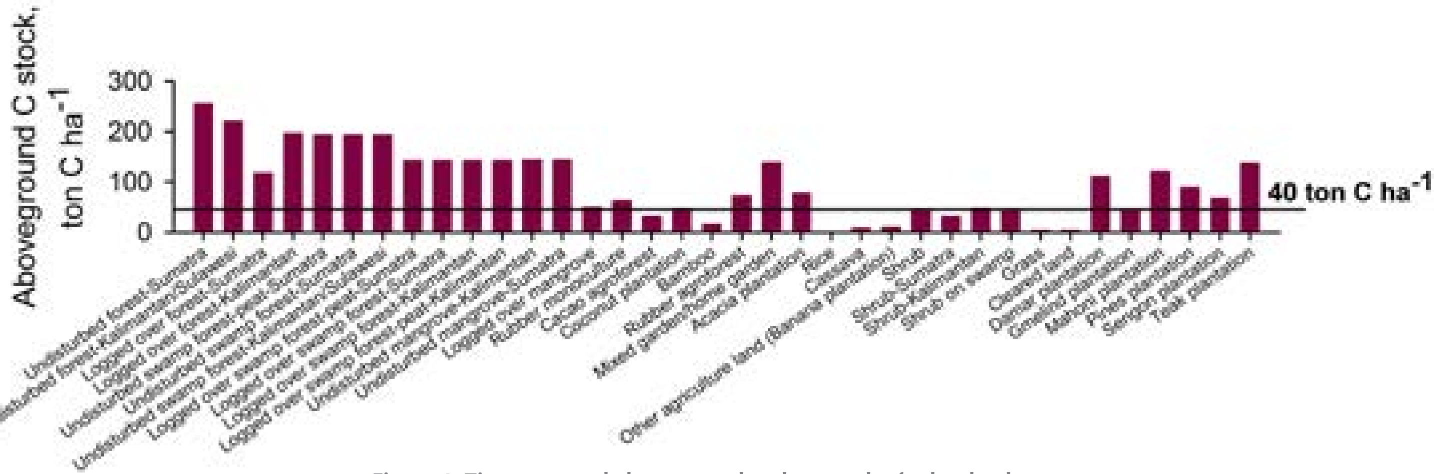

Figure 4. Time-averaged aboveground carbon stock of other land uses

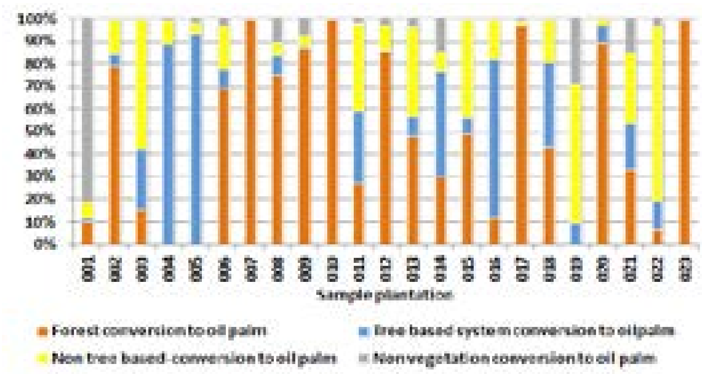

Figure 3. Land-use trajectories of all sample plantations

2. The ranges of time-averaged aboveground carbon stock were a) 150–250 t C/ha for forests; b) 50–150 t C/ha for tree-based systems; and c) less than 50 t C/ha for non-tree-based systems

To estimate emissions caused by land-cover change at landscape level, we used time-averaged carbon stock at 'land-use system' level[vii]. We found 21 types of land-use systems surrounding the 23 oil palm plantations, which were further classified into three larger categories of 'forest', 'tree-based systems' and 'non-tree-based systems'. The ranges of time-averaged carbon stock was 150–250 t C/ha for 'forest', 50–150 t C/ha for 'tree-based systems' and less than 50 t C/ha for non-tree-based systems[3,viii] (figure 4). These figures were derived from 924 measured plots, 800 of which came from the ICRAF database of earlier studies in Indonesia

3. The time-averaged aboveground carbon stock of oil palm, based on a typical replanting cycle of 25 years, is (35)–40–(45) t C/ha (implying a measured range of 35–45 and a mean of 40)

Similar to other land uses, time-averaged aboveground carbon stock of oil palm, based on a typical replanting cycle of 25 years, is also used to estimate emissions caused by land-cover changes at landscape level. The time-averaged aboveground carbon stock of oil palm was estimated for different production environments (peat and mineral soil types) and management regimes (nucleus/company, plasma and independent).

The aboveground accumulation of oil palm biomass under company (nucleus) management was estimated to be 6.0 t/ha/yr and 5.6 t/ha/yr on mineral and peat soils respectively (figure 5). The aboveground accumulation in oil palm biomass on mineral soils under plasma and independent types of management was estimated to be 5 t/ha/yr or 15% lower than nucleus management (figure 6).

3 The carbon stock of each pool was estimated by multiplying biomass with the corresponding carbon concentration.

Table 2. Time-averaged aboveground carbon stock of oil palm plantations

Soil type	Plantation management	Initial land cover	Oil palm	Understorey	Litter	Necromass	Total
			T C/ha				
Mineral	Nucleus	Forest	38.60 ± 1.28	0.51 ± 0.42	2.36 ± 2.40	3.60 ± 2.68	45.05 ± 1.28
		Other than forest				-	41.46 ± 1.28
	Plasma	Forest	33.78 ± 1.55		1.83 ± 1.21	3.60 ± 2.68	39.71 ± 1.55
		Other than forest				-	36.12 ± 155
	Independent	Other than forest			0.96 ± 0.49	-	35.25 ± 1.55
Peat	Nucleus	Forest	34.00 ± 3.27		2.36 ± 2.40	3.60 ± 2.68	40.46 ± 3.27
		Other than forest				-	36.86 ± 3.27

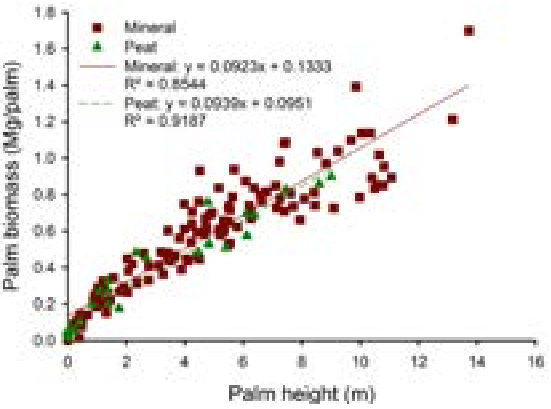

Figure 5. Correlation between palm height (m) and palm biomass (tonne/palm) on peat and mineral soils

By adding other components of carbon stock and assuming a 25-year oil palm production cycle, the time-averaged carbon stock of oil palm was estimated to be around 40 t C/ha in the phase 1 pilot study[ix,x]. Some differentiation in values was found across the 25 plantations (two plantations from phase 1 study), with values ranging from 35.25 ± 1.55 t C/ha to 45.05 ± 1.28 t C/ha (table 2). As a first estimate, a value of 40 t C/ha (+ or - 5) can be used, with more refined estimates per class available, depending on length of life cycle, management regime (smallholding or nucleus plantation) and mineral or peat soils[4,xi].

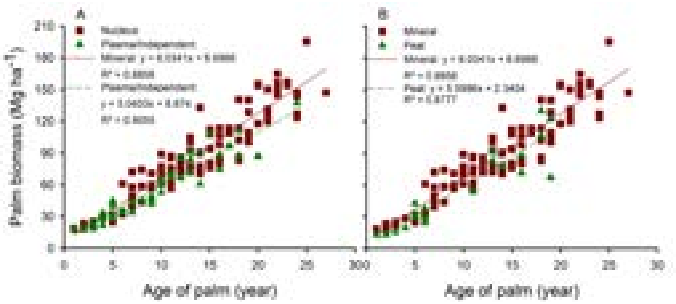

Figure 6. Correlation between age of palm and palm biomass (tonne/ha). A) palm growth on mineral soil under different management regimes; B) palm growth under nucleus management on different soil types.

4. Annual carbon dioxide emission rates from mineral soil were zero

Carbon dioxide emission from soil is one of the accounted emissions when estimating the carbon footprint by life cycle. Belowground carbon stocks in mineral soil, in the top 30cm of soil depth, did not show statistically significant changes with time, suggesting that annual emission rates from mineral soil were zero (figure 7). Depending on the details of plantation management in the use of fronds, cover crops and organic fertilizers, some zones showed enrichment reduction of bulk density, and others depletion and compaction, but the net effect was neutral. As shoot:root ratios of the vegetation formerly on the sites were approximately equal to those of oil palm, the 40 t C/ha threshold can apply to expected belowground, as well as aboveground emissions. Literature suggests both net gains and net losses are possible depending on details of conversion history. Further research can help clarify conditions where net gains or net losses are expected.

4 The carbon stock of each pool was estimated by multiplying biomass with the corresponding carbon concentration.

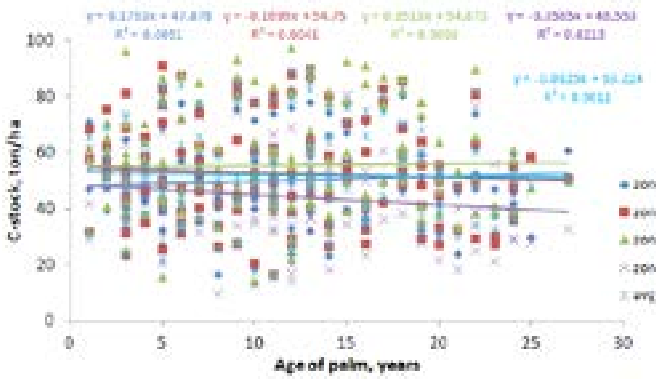

Figure 7. Soil carbon stock in mineral soil at 0–30cm depth at different oil palm ages

5. The average net emissions rate of all sampled plantations owing to land-use conversion ranged 0–36 tonne of carbon dioxide equivalent per hectare per year (CO_2eq/ ha/yr)

The data from plot-level carbon calculations and the time-series land-cover map and its trajectories were integrated to estimate the amount of carbon dioxide emissions caused by converting other land uses to oil palm plantations. The average net emissions rate caused by land-use conversion from all sample plantations ranged 0–36 t CO_2eq/ha/yr. One plantation showed a negative emissions rate, which meant that the plantation had larger carbon sequestration from land-use conversion compared to their emissions (figure 8).

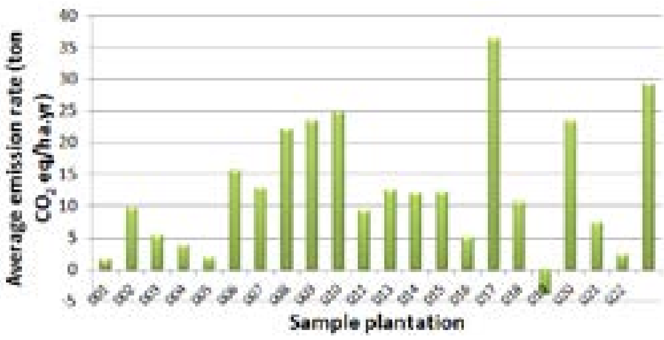

Figure 8. Average carbon dioxide emissions caused by land-use conversion

6. The average FFB production in Indonesia is approximately 18.8 t ha/yr, which translates into an application rate for nitrogen fertilizer of 141 kg ha/yr

BERES requires data of the time-averaged carbon stock (t C/ha) of the former land cover before oil palm was planted and the time-averaged carbon stock (t C/ha) of the oil palm plantation itself. It also requires data of fertilizer (nitrogen) levels (kg N/ha/yr) and the production levels of FFB (t/ha/yr) as well as the oil extraction rate.

The minimum and maximum FFB production over the life cycle is about 12.3 t/ha/yr and 24.4 t/ha/yr respectively. The minimum and maximum FFB production translated to the application of 67 kg N/ha/yr and 257 kg N/ha/yr of nitrogen fertilizer respectively (table 3 & figure 9).

We found that this equates to an average FFB production in Indonesia of about 18.8 t/ha/yr and 141 kg N/ha/yr of nitrogen fertilizer application.

7. The carbon footprint of Indonesian palm oil production

The EU-mandated minimum of 35% emissions savings for biofuel use cannot be achieved by palm oil from peat soils.

Table 3. Time-averaged nitrogen fertilizer application, yield levels and oil extraction rates per plantation

Plantation ID	N fertilizer[1)], kg N/ha/yr	FFB[2)], t/ha/yr	Kernel[3)], %	OER or CPO[3)], %	Palm kernel oil[4)], fraction
001	144.96	18.30	5.16	23.63	0.5
002	121.87	19.43	4.24	24.07	0.5
004	199.36	21.35	6.03	24.18	0.5
005	110.49	18.16	4.97	23.97	0.5
006	91.09	15.64	4.29	20.36	0.5
007	251.87	23.01	4.75	22.48	0.5
008	124.31	16.71	4.75	20.54	0.5
010	66.98	12.31	4.87	19.92	0.5
011a	153.61	19.38	5.31	22.31	0.5
011b	151.76	18.84			0.5
013	127.83	16.51	5.73	23.02	0.5
014	139.55	18.70	5.74	24.01	0.5
015	127.91	19.47			0.5
016	113.65	15.32	4.86	23.15	0.5
017	104.39	18.49	4.80	23.99	0.5
018	257.38	24.41	4.90	23.62	0.5
019	109.84	17.76	3.87	22.49	0.5
020	163.52	22.22			0.5
021a	126.52	14.59			0.5
021b	137.07	15.30			0.5
022	76.75	14.76	4.35	22.86	0.5
023	178.45	20.25	4.24	21.68	0.5

1) *Time-averaged nitrogen fertilizer rates (over the life cycle. No available data for plantation ID 003, 009 and 012, default data used (141 kg N/ha/yr) for these plantations.*
2) *Time-averaged production rates (over the life cycle). No available data for plantation ID 003, 009 and 012, default data used (18.8 t/ha/yr) for these plantations.*
3) *No available data for plantation ID 003, 009, 012, 015, 020 and 021, default data used (23% for the oil extraction rate (OER) or CPO and 5% for kernel) for these plantations. The carbon content of CPO was estimated by multiplying CPO with the corresponding carbon concentration[xii].*
4) *Corley and Thinker 2003[xiii]. The carbon content of PKO was estimated by multiplying PKO with the corresponding carbon concentration[xiv].*

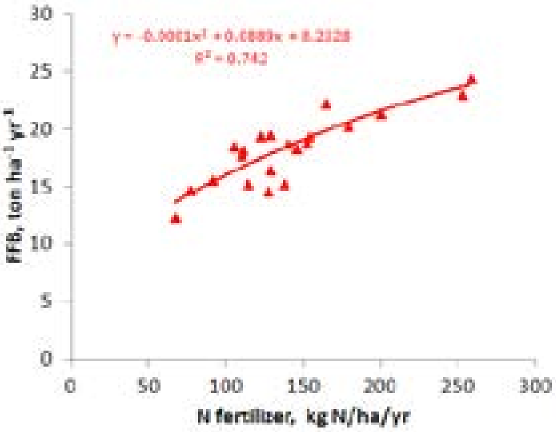

Figure 9. Correlation between two properties assessed over the life cycle (from Table 3): average yearly application of nitrogen fertilizer and average yearly FFB production on mineral soils

If more than 5% of the palm oil in a plantation is planted on peat soils, the average for the plantation is likely to be below the EU standard. The standard also cannot be achieved on mineral soils if the carbon debt caused by conversion is larger than 60 t C/ha, if the N_2O–N/N–fertilizer ratio is 1%, and when it is larger than 20 t C/ha if this ratio is 4%. The 1% estimate is an Intergovernmental Panel on Climate Change default value[xv], the 4% ratio is based on more recent research, but oil-palm specific data is lacking.

Oil palm produced on mineral soils derived from a former non-forest land use (clusters 10 and 11) can, in nearly all cases, meet the standard 35% emissions reduction target, with some already meeting the 60% emissions reduction target without installing methane capture in the mill (table 4).

Oil palm produced on mineral soils that have a forest conversion history (clusters 4–6) have a negative emissions savings result, which implies that more emissions are caused than are saved in biofuel use (table 4).

With oil palm on peat land as more than 5% of the total plantation area there tends to be an emissions savings ratio that is substantially below -100%, implying that use of such palm oil for biodiesel would not only not provide emissions savings but actually more than double global emissions. In these cases, methane capture at the mill is not sufficient to reach the emissions savings targets.

Of the studied samples, 39% (first-cycle assessment) and 78% (second-cycle or subsequent assessment) had emissions savings of more than 35% and could thus qualify under the EU directive (figure 10 & figure 11). This fraction exceeds the fraction of Indonesian palm oil exported to the EU and it may be possible to source all exports to the EU from plantations that meet the standard, even though a weighted average of all palm oil has no net saving in the first rotation.

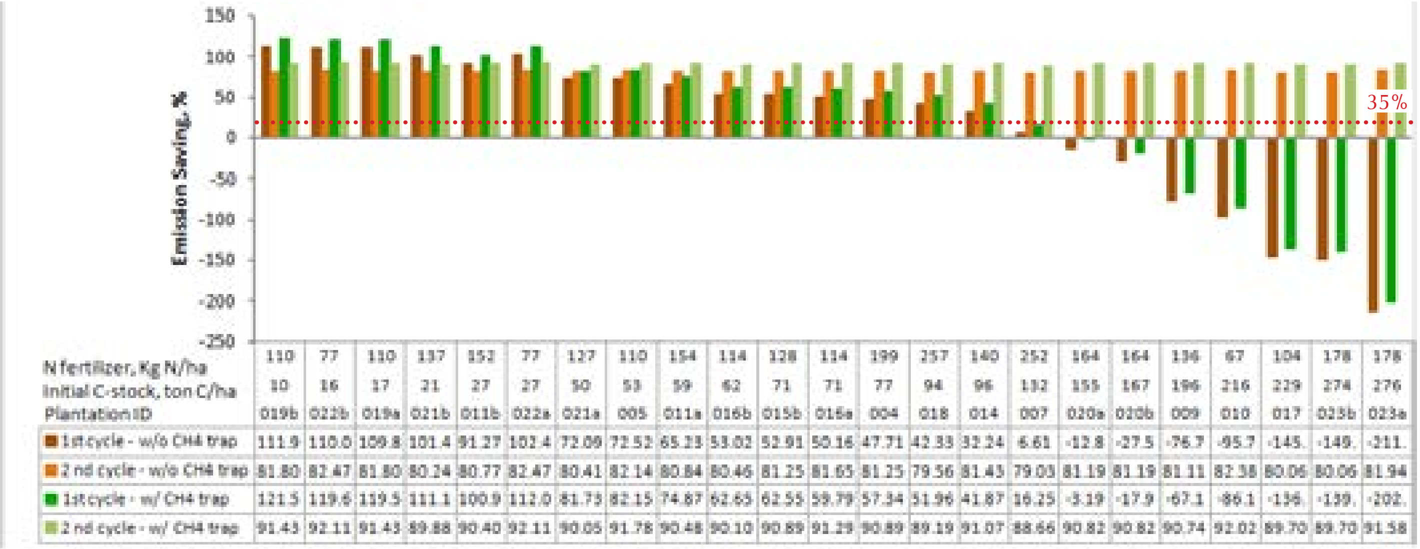

Figure 10. Attributable emissions savings in relation to former carbon stock and nitrogen fertilizer application. For plantations established on mineral soil and nitrogen loss as N_2O is 1%. (Plantation ID with a = nucleus; b = plasma)

Figure 11. Attributable emissions savings in relation to former carbon stock and nitrogen fertilizer application. For plantations established on mixed peat and mineral soils and nitrogen loss as N_2O is 1%. (Plantation ID with a = nucleus; b = plasma)

Table 4. Emissions savings if palm oil is used as the basis for biodiesel production for palm oil derived from the various strata distinguished in oil palm plantations in Indonesia

Sample stratification parameters			Cluster name	Emissions saving when CPO is used as feedstock for biodiesel (%)[1]					
				Min.		Max.		Avg.[2]	
Initial land use	Soil	Area density of oil palm		1st cycle	2nd cycle[3]	1st cycle	2nd cycle	1st cycle	2nd cycle
Forest	Peat	Density 1	Cluster 1	-369.8	-250.2	-199.2	-188.1	-284.5	-219.1
		Density 2	Cluster 2	-375.2	-191.5	26.3	63.6	-181.5	-68.5
		Density 3	Cluster 3	-178.5	-95.8	-178.5	-95.8	-178.5	-95.8
	Non- Peat	Density 1	Cluster 4	6.6	79.0	6.6	79.0	6.6	79.0
		Density 2	Cluster 5	-211.8	81.1	32.2	81.9	-85.4	81.5
		Density 3	Cluster 6	-149.0	74.6	111.9	82.4	12.1	80.3
Non-Forest	Peat	Density 1	Cluster 7	No examples were found, emissions saving is almost certainly negative					
		Density 2	Cluster 8						
		Density 3	Cluster 9						
	Non- Peat	Density 1	Cluster 10	53.0	80.5	72.5	82.1	62.8	81.3
		Density 2	Cluster 11	47.7	80.8	110.0	82.5	78.3	81.5
		Density 3	Cluster 12	No examples were found					

1) Emissions savings under a scenario without a methane trap in the mill and assuming 1% nitrogen loss as N_2O (IPCC default value)
2) The EU Renewable Emissions Directive requires a minimum 35% emissions saving
3) Second or subsequent cycle

8. Intensification and good management practices will increase emissions saving and decrease the product's carbon footprint

Fertilizer use increases crop yields and greenhouse gas emissions at plot level, but may reduce forest conversion. The net effect on potential emissions per unit yield is debated, especially for biofuels. The fertilizer level that minimizes net attributable emissions may be below (as in the 'Borlaug hypothesis': subsidize fertilizers) or above (as in the 'Ecological Agriculture hypothesis': tax fertilizers) the economically optimum level, depending on the context.

When net emissions per unit yield are minimized for plantations without carbon debt, fertilizer rates of 74–277 kg N/ha are indicated for a N_2O–N/N-fertilizer ratio of 4–1% respectively. At a carbon debt of 30 t C/ha, these values are 192 and 340 kg N/ha respectively. The current level of use of nitrogen fertilizer in Indonesia may be remarkably close to a level that minimizes net emissions per unit product. Intensification efforts beyond this would be unlikely to reduce the net emissions per unit product. Analysis of options to modify fertilizer prices (by subsidy or taxation) as part of policies to reduce emissions shows that a 'sustainable weighting of ecology and economic tradeoffs' (SWEET) would require a fertilizer/yield price ratio (p_{SWEET}) that is interdependent on carbon debt. Price policies for fertilizer alone then cannot align private and social optimization (figure 12a & figure 12b).

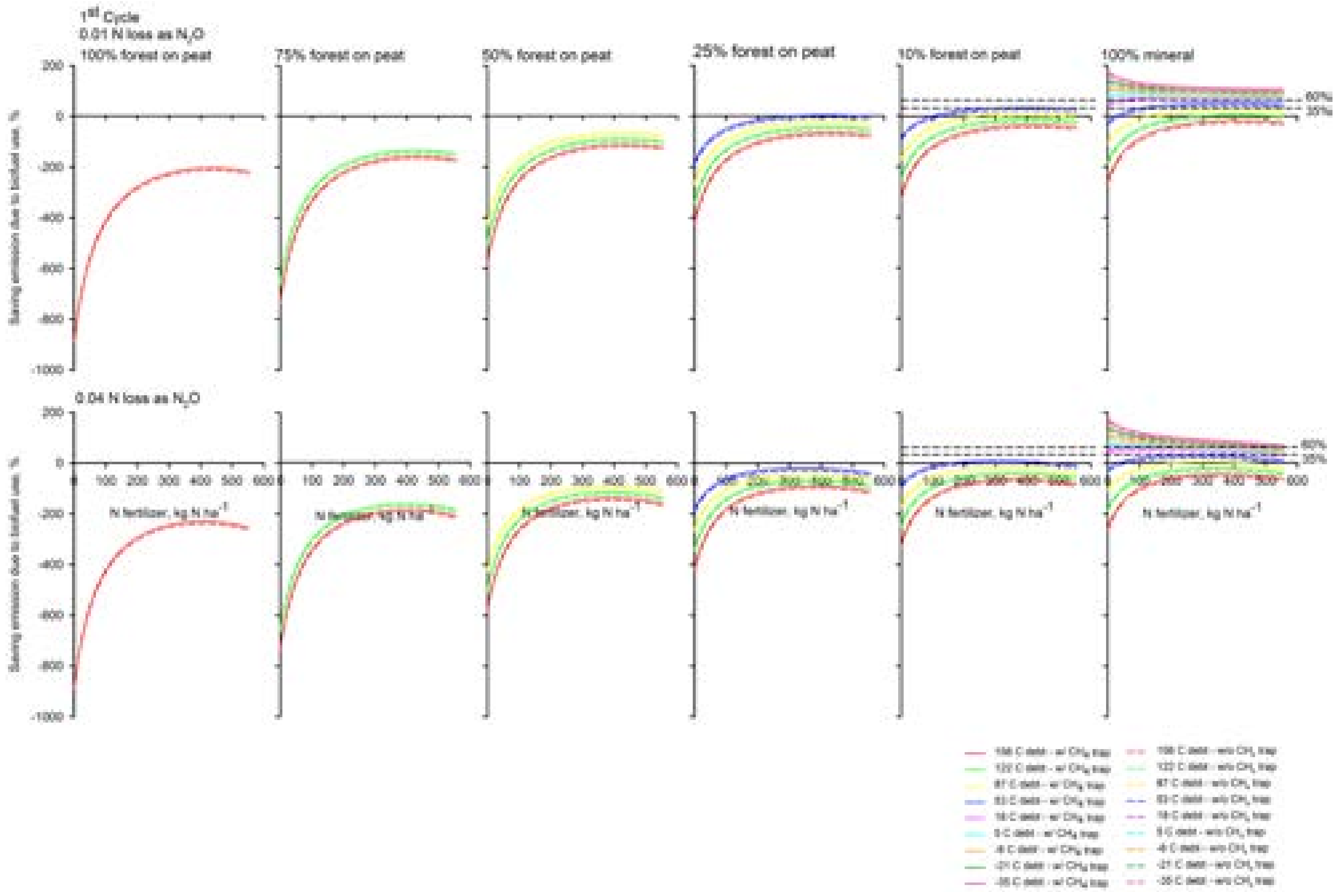

Figure 12 a. Results of BERES simulation of 1st cycle oil palm plantation under different scenarios

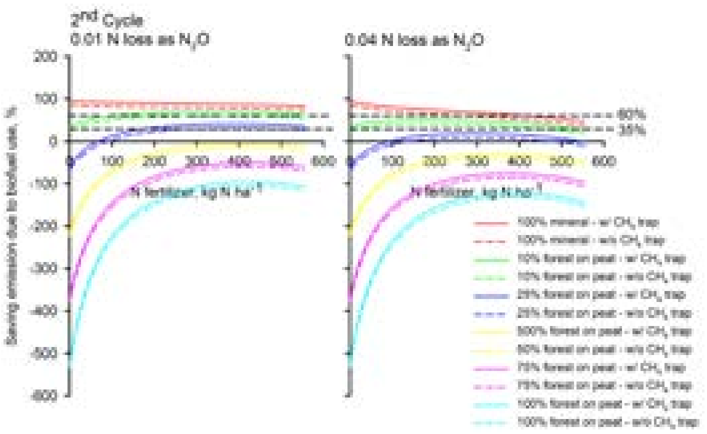

Figure 12b. Results of BERES simulation of 2nd cycle oil palm plantation under different scenarios

Conclusion and recommendations

There are several changes that would, in practice, increase emissions saving.

1) The current proportion of peat area to fulfill EU directive is 5% maximum; however this threshold should be revised downwards, for other environmental reasons, as well as considering future stringent EU conditions.
2) Avoid establishing new plantations on land that contains more than 40–60 t C/ha, as such land would invoke a carbon debt of more than 20 t C/ha and make it difficult to meet the 35% emissions saving standard.
3) Improve residue and soil carbon management to ensure a net positive effect on soil carbon (especially if plantations are on non-forest soils with reduced C_{org} content).
4) Improve the efficiency of use of nitrogen fertilizers to ensure N_2O-N/N-fertilizer emission rates of 1% or less by adopting best practices for N fertilizer management..
5) Improve oil yields without increasing emissions by improving access for smallholders and plantations to reliable, high-quality planting materials and continued selection to increase yield potential. Also incorporate good post-harvest management and processing facilities that can increase both FFB per unit emissions of plantation establishment/management and oil yield per unit FFB.
6) Install CH_4 (biogas) traps in mills will results in an increase of 9.6% of emission savings.

Several major uncertainties remain in assessment of carbon footprints.

1) The emissions factors for the use of peat land in relation to drainage, but this will not affect the conclusion regarding negative emissions savings.
2) The N_2O emissions factor needs more empirical data for oil palm on mineral and peat soils.
3) Opportunities for increasing the efficient use of fertilizers (better placement and timing) can reduce the emission characteristics of palm oil as well as increase profitability.
4) The scale at which standards and rules are to be applied, including responsibility for 'indirect land-use change', needs to be re-evaluated.

photos: Kurniatun Hairiah

photo: Kurniatun Hairiah

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