GHG emissions due to deforestation

Report

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Contents

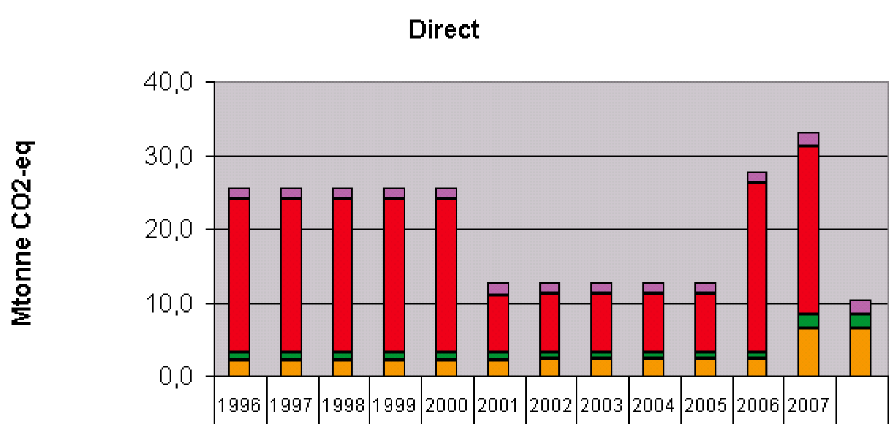
Summary

CE Delft assessed for Greenpeace Netherlands the magnitude of greenhouse gas emissions resulting from deforestation and forest degradation in tropical forests in Malaysia and Indonesia related to Dutch economic activities.

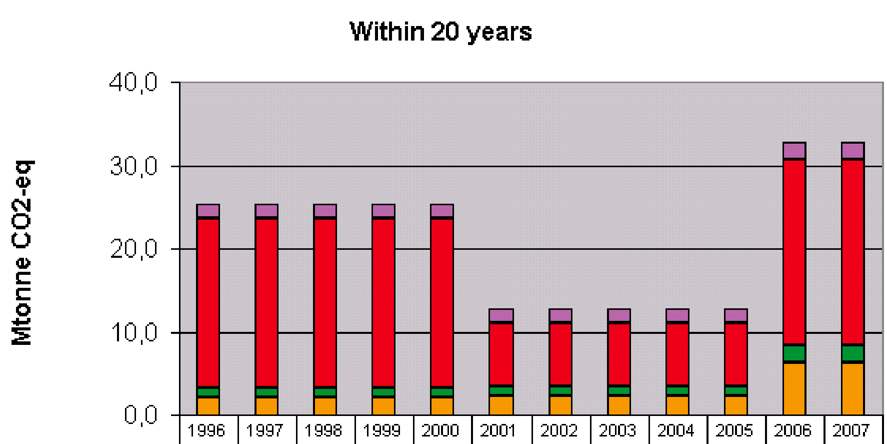
CE Delft has calculated greenhouse gas emissions (GHG) related to both:
- The emissions related to vegetation removal sec.
- The emissions related to removal and more long term effects related to assimilation of CO_2 in forest regrowth and changes in organic material in soils.

Emissions related to vegetation removal and aggregated emissions for both vegetation removal and long term effects are reported separately. Soil organic carbon stock changes are considered by Greenpeace as more uncertain, so the emphasis will be on the direct emissions.

Figure 1 **Annual GHG emissions due to forest degradation and deforestation allocatable to the Netherlands**



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Indonesia log	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,9	1,9
Indonesia palm	20,7	20,7	20,7	20,7	20,7	7,8	7,8	7,8	7,8	7,8	22,9	22,9	
Malaysia log	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,9	1,9
Malaysia palm	2,2	2,2	2,2	2,2	2,2	2,2	2,3	2,3	2,3	2,3	2,3	6,5	6,5



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Indonesia log	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	2,1	2,1
Indonesia palm	20,3	20,3	20,3	20,3	20,3	7,6	7,6	7,6	7,6	7,6	22,4	22,4
Malaysia log	1,2	1,2	1,2	1,2	1,2	1,1	1,1	1,1	1,1	1,1	2,1	2,1
Malaysia palm	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	6,3	6,3

The conducted assessment has been based mainly on IPCC (2006) methodology and default values.
Only for changes in carbon stocks in soil (or soil organic matter) due to forest degradation a different approach has been applied because IPCC (2006) does not provide a methodology for calculating these changes.
For forest degeneration due to logging and for GHG emissions related to oil palm plantation realization on mineral soils and on peat several scientific papers and reports have been used as information source.

In accordance with IPCC (2006) the net effects were determined for a time horizon of 20 years, meaning that net GHG emissions related to carbon assimilation due to regeneration of vegetation and gradual changes in soil organic carbon within a period of 20 years have been taken into account.

Deforestation associated with palm oil cultivation gives the highest contributions. The contribution by logging is limited mainly because for logging in South East Asia only a relatively small proportion can be attributed to the Netherlands – through the imports.

Total GHG emissions from deforestation and degradation that can be attributed to Dutch economy amounts to 12 - 25 Mtonnes per year for the period up to 2005. These emissions represent 5% - 10% of total Dutch domestic emissions.
In the last two years the high rate of deforestation and the intensive economic relation of the Netherlands with the deforestation makes the Netherlands accountable for an emission that represents 30 - 32 Mtonnes or 15% of total Dutch GHG emissions.

These figures concern a conservative estimation for several reasons:

- In the analysis the CO_2 assimilated in oil palm trees was discounted (as a CO_2 sink) – in accordance with the IPCC (2006) methodology.
  However it is uncertain that the oil palms will remain in place once the plantation has reached the end of its economic life and after the trees have become too high for fruit bunches harvesting.
  If the oil palms are cut down no net CO_2 assimilation will have taken place and net GHG emissions have been underestimated.
- We assumed that 25% of oil palm plantations have been or are realized on peat soils – in accordance with current average geological situation of oil palm plantations in South East Asia.
  However, the 2006 TU Delft and WUR study concerning CO_2 emissions from drained peat lands in South East Asia indicates that the percentage of newly realized plantations on peat soils is actually higher than the considered average 25%. The study unfortunately does not indicate which percentage has actually been realized on peat soils.
  Since plantations on peat soils generate far higher GHG emissions per hectare than plantations on mineral soils – due to peat oxidation - the probable underestimation of the percentage of plantations recently realized on peat also means that GHG emissions have probably been underestimated.

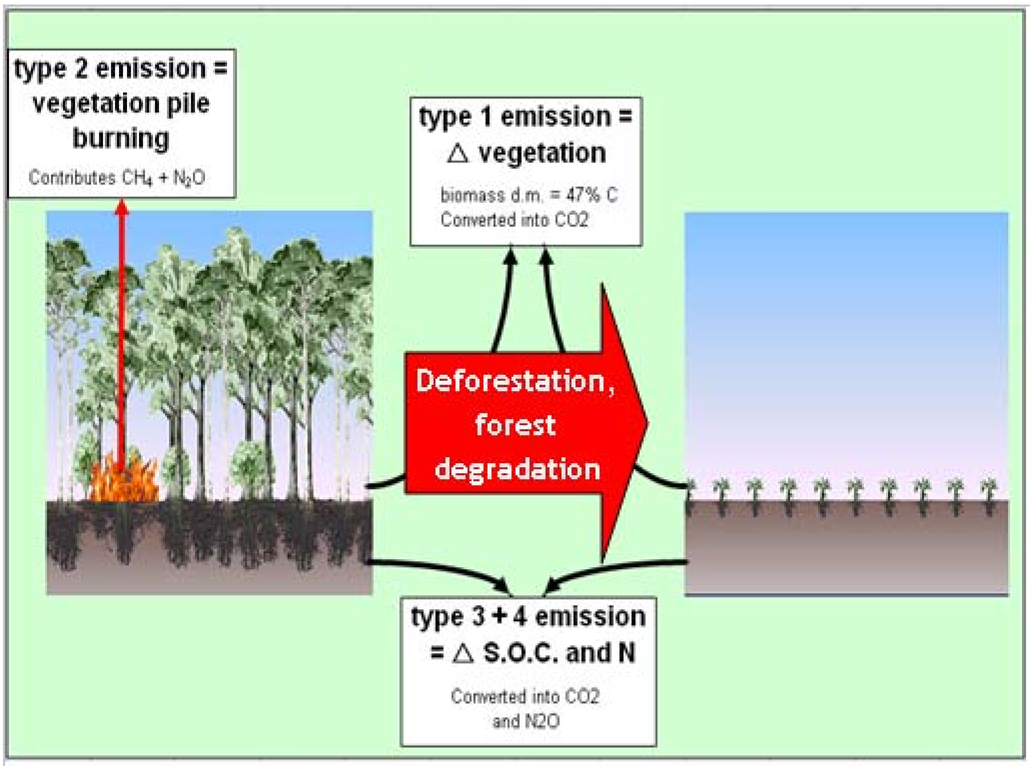
1 Methodology

1.1 Overview

Emissions due to land use change (LUC) are shown in Figure 2.

In general the net GHG emissions arising from LUC c.q. deforestation can be categorized in following categories (IPCC, 2006):
1. Change in aboveground vegetation and associated roots and dead organic matter (fallen leaves, branches, fruits, etcetera) and consequent changes in the amount of carbon stored in these pools, due to exploitation and regeneration processes.
2. Change in carbon stocks in soil.
3. N_2O emissions from soil.
4. Emissions related to removal of the vegetation originally present by pile combustion and dumping.

Figure 2 GHG emissions from LUC



Changes in carbon stocks and N_2O emissions and actually also changes in vegetation all are events that occur gradually, rather than immediately. Only removal of existing vegetation and possible burning of this vegetation and associated emissions related to both activities are immediate by nature. Carbon stocks and N_2O emissions change to a new level within several decades after deforestation or forest degradation. Removed vegetation can grow back or be replaced eventually by other vegetation, thereby changing the net greenhouse gas (GHG) emissions related to deforestation or forest degradation. Vegetation extracted for commercial purposes such as timber or pulp will also take years or decades to become waste and be converted into CO_2.

In IPCC and LCA's all these emissions are taken into account – or at least all emissions occurring within a period of 20 years, as required by IPCC.
Soil organic carbon stock changes are also considered by Greenpeace as more uncertain, so the emphasis will be on the direct emmissions

In order to meet both Greenpeace's needs to address deforestation and forest degradation utilizing emission figures that can be presented as annually and immediate by nature and the requirement for a scientific sound approach we calculated both and give them separately.

The different contributions are discussed below in more detail. In the subparagraphs the IPCC (2006) methodology for calculating these different contributions is also discussed broadly.

1.2 Changes in vegetation

Immediate changes in carbon stocks due to vegetation removal

The change in the aboveground vegetation can be obtained by comparing and subtracting the amount of carbon stored per hectare in the new vegetation from the amounts of carbon stored in the original vegetation.

The carbon content of pristine forests can be derived from the IPCC (2006) default values for aboveground biomass stocks and subsurface roots and their carbon content. Multiplying changes in carbon stocks with 44/12 – the ratio in mass between CO_2 and C - gives the concurrent CO_2 emissions. In formula:

$$CO_2\ (vegetation\ removal) = \frac{44}{12} \times 47\% \times \Delta\ M_{vegetation,d.m.}$$

In which 47% represents the average carbon content of dry vegetation. In practice carbon content can vary between ± 44% and ± 50% (see IPCC, 2006).

Regeneration of vegetation, cultivation of oil palms

In case of selective logging of natural forests, the forest may regenerate (partially) after being cut. In case of the establishment of oil palm plantation a totally new type of (oil palm plantation) vegetation will develop and will be maintained.

When calculating GHG emissions due to land use change the increased carbon storage in vegetation resulting from vegetation regeneration or new vegetation development should be taken into account according to UNFCCC calculation guidelines. This is taken into account in this study.

1.3 Changes in dead organic matter (D.O.M.)

Dead organic matter refers to fallen leaves and twigs and other vegetative debris. In case of palm oil plantation this also refers to the empty fruit bunches and other fruit residues returned to the plantation. For natural forests it refers the mentioned twigs, leaves and to fruits, nuts and anything else up to dead trees.
Amount of dead organic matter – trees that have died, died off leaves, fruits and twigs - will change when vegetation changes.

In IPCC (2006) default values for dead organic matter and litter are given for different climate zones (e.g. tropical and subtropical climate zones).
The disadvantage with this rather rough approach is that it does not take into account for example the level of degradation of a certain forest or does not take into account the relation with the actual annual net growth of biomass (NPP) in a region as function of precipitation and available solar radiation. It also does not take into account management practices in oil palm plantations, such as some who do return organic matter to the plantation. It also depends upon application of sustainable forest management techniques!

A more realistic approach calls for the utilization of a model which does take these parameters into account as applied in this study.

1.4 Changes in soil organic carbon (S.O.C.)

Change in soil carbon stocks is caused by:
- Changes in the amount of organic material falling on the earth and being converted into humus.
- The intensity of tillage and the duration of tillage.

Tillage and annual cropping mean disturbance of the soil structure and exposure of soil organic matter to oxygen and results in oxidation and degradation of the soil organic matter, releasing the carbon stored in the organic matter as CO_2.

On the other hand returning crop residues to the soil and application of manure and green manure all mean organic material is added to the soil organic matter. A small part of the organic material added to the soil will not be degraded and will instead accumulate in the soil, thus resulting in soil c.q. humus generation.

In the IPCC (2006) methodology changes in soil organic carbon stocks can be calculated by multiplying the carbon stock originally present with the three change factors:

$$SOC_2 = SOC_1 \cdot f_{land\ use} \cdot f_{tillage} \cdot f_{input}$$

In which SOC_1 represents the amount of soil carbon originally present before degradation or deforestation and SOC_2 represents the amount remaining after these types of interferences.

This approach is applicable for situations in which land use is changed permanently, e.g. from forest into agricultural field. For such permanent changes default factors can be determined. In this study the IPCC (2006) will be applied for land use change from forest into agricultural area for oil palm cultivation.

But the approach is less suitable for situations in which the forest is degraded by repetitive activities, such as regular wood cutting for construction wood or pulp wood or regular undergrowth clearing for livestock grazing. In such situations frequency of occurrence of the repetitive activity and intensity of the individual activities may vary. The IPCC (2006) approach would require estimating different possible combinations of frequency and intensity. For such situations a model based approach is more suitable.

In this study a model is utilized for forest systems, IPCC for land use change resulting in creation of agricultural land and perennial crop systems (oil palm plantation).

1.5 N_2O emissions

N_2O emissions from soil oxidation have been estimated in accordance with IPCC (2006):
- Assuming a 15 ÷ 1 ratio between C in soil and N in soil.
- Assuming that 1% of the N in soil will be emitted as N_2O in case of S.O.C. oxidation.

1.6 Emissions from fires

These emissions include CH_4 and N_2O emissions from biomass burning or CH_4 emissions from pile dumping of cleared vegetation that is not utilized usefully.

These emissions can be estimated by application of the emission factors per tonne of biomass given in IPCC 2006 and estimating the amount of biomass per hectare that is burned or dumped.

For burning of biomass in tropical forests emission factors in IPCC (2006) amount to:
- 0,2 kg N_2O/tonne dry biomass.
- 6,8 kg CH_4/tonne dry biomass.

Combustion efficiency is 90% according to IPCC (2006), meaning that 90% of the biomass will actually be combusted.

2 Basic assumptions

2.1 Activities

An overview of activities resulting in deforestation or forest degradation and of potentially affected soils and types of vegetation in the considered different countries and regions is given in Table 1. Forest degradation for construction wood for example may be limited to tropical forests, because of higher concentrations and wider variety of premium hard wood species existing in this forest type.

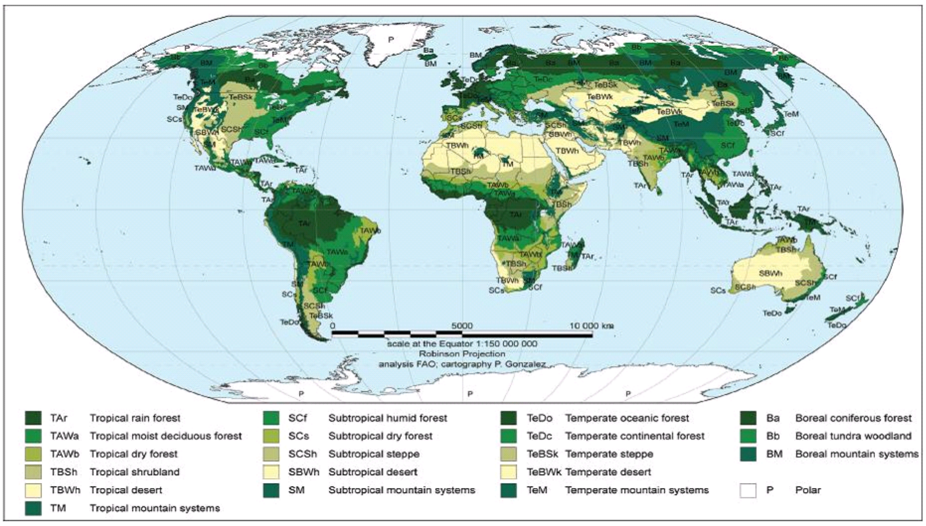
Table 1 Overview of forest - soil - activity combinations to be considered[1]

		Soil vegetation combinations				Reason for deforestation, degradation		
		HAC	LAC	Volcanic	Histosol	Wood	Pulp	Palm oil
South East Asia	Indonesia							
	Tropical rainforest		X	X	X	X	X	X
	Malaysia							
	Tropical rainforest		X		X	X	X	X

HAC = unweathered soil, LAC is weathered soil, histosol = peat.

Relevant – and affected - forest types and soil types have been deducted from respectively IPCC (2006) and FAO World Soil map (see Figure 2). A close up of the considered regions is included.

Figure 3 World vegetation cover map



[1] The term HAC in Table 2 refers to Highly Active Clay soils and means soils only slightly weathered and still containing high concentrations of nutrients. The term LAC soil refers to Low Activity Clay and refers to a highly weathered with a relative low concentration of nutrients because these have been leached from the soil under influence of precipitation and temperature.

Figure 4 **Close-up of considered region**

2.2 Specifications of pristine forests and soils

Specifications of undisturbed forests and forest soils are given in Table 2. The amount of carbon in vegetation refers to both above ground and below ground biomass.

Relevant forest types and soil types have been deducted from respectively IPCC (2006) and FAO World Soil map (see Figure 5).
The given default specifications for the different forest types and soil types are averages and actual amounts of biomass present as vegetation and amounts of soil organic carbon (SOC) may vary significantly within the same type.

For example aboveground biomass in insular tropical rainforests in Asia may in practice vary between 120 and 680 tonnes d.m./ha (IPCC, 2006), a significant deviation from the average value of 280 tonnes d.m./ha given by IPCC and applied in this study.
Variations occur because soil composition, ground water availability and other parameters can differ significantly even within small distances of several meters.

However the IPCC (2006) are generally accepted as an acceptable estimation of average values of the considered specifications and these are therefore applied in this study.

Figure 5 FAO world soil map

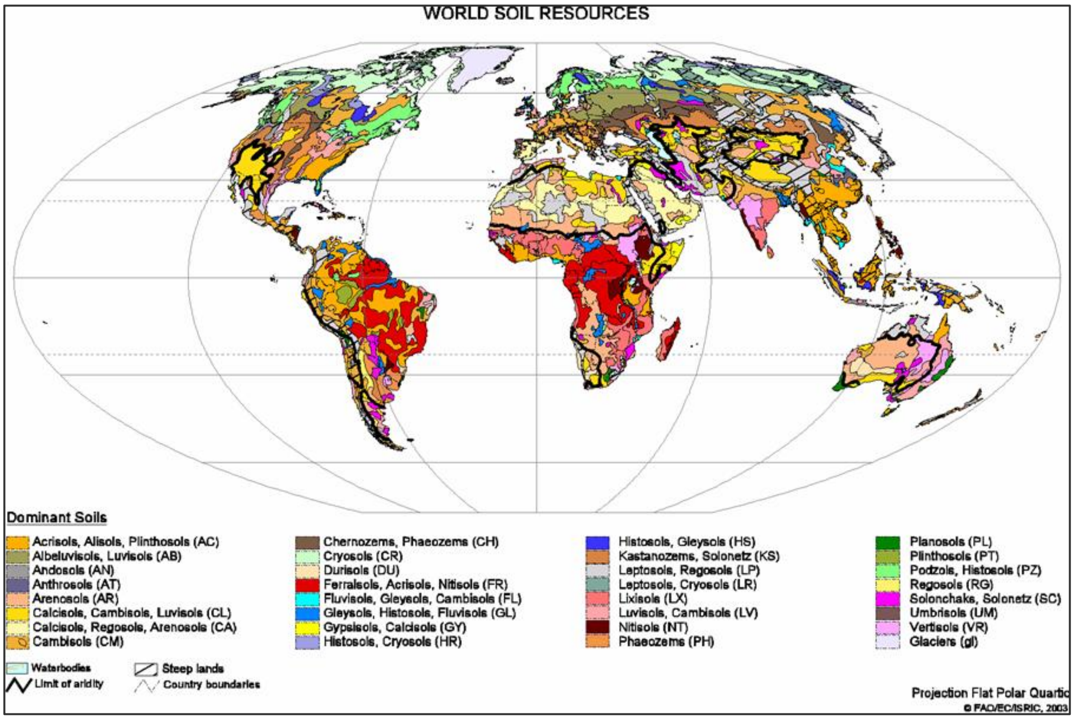


Table 2 **Specifications of pristine forests considered in this study**

		Soil Organic Carbon (tonne/ha) (IPCC, 2006)				Biomass specifications (undisturbed forests) (IPCC, 2006)			C vegetation (tonne/ha)	NPP (g C/m²/year)
						Aboveground vegetation (tonne d.s./ha)	Percentage roots	C vegetation		
		HAC	LAC	Volcanic	Histosol					
South East Asia	Indonesia									
	Tropical rainforest	44	60	130		350	37%	47%	225	1,100
	Malaysia									
	Tropical rainforest		60			350	37%	47%	225	1,200

HAC = Un weathered soil, LAC is weathered soil, histosol = peat.

NPP = Net primary production, the amount of biomass produced each year.

Source: IPCC, 2006.

2.3 Aid Environment report output used in this study

For calculation of total GHG emissions due to deforestation and forest degeneration that can be allocated to Dutch economy the following areas have been adopted from the Aid Environment report.

Table 3 Overview of areas deforested and degraded in the countries considered in this study

		Deforested and degraded area's allocated to the Netherlands (in 1.000 ha) in the considered periods:		
		Period 1995 - 2000	Period 2001 - 2005	Period 2006 and 2007
Indonesia	Wood	26	31	12
	Pulp			
	Soy			
	Palm	120	54	53
Malaysia	Wood	11	13	8
	Pulp			
	Soy			
	Palm	13	16	15

For estimation of GHG emissions related to forest degeneration in case of logging for timber following volumes of extracted logs were adopted from the Aid Environment report:
- Indonesia: 40 m^3/ha.
- Malaysia: 60 m^3/ha (average over considered period).

2.4 Specifying deforestation and degradation applied in this study

In Table 5 an overview is given of the percentage of vegetation that is removed by each of the activities considered in this study. The frequency with which the activity takes place and the destination of the removed vegetation (litter, burning, removal from area) are also specified.
- Forest degradation:
  The figures for forest degradation due to timber logging have been adapted from Brown (2008) and Putz (2008).
- Deforestation:
  For the other, deforestation activities in which the application c.q. use of the land changes from natural forest into plantation or field the level of vegetation removal is obviously 100%. We assumed that logging also takes place when forest is cleared to make way for oil palm or pulpwood areas. Why leave commercial opportunities unutilized?

For logging for timber the percentages of removed vegetation have been based on the Aid Environment deforestation report which gives information concerning volumes of round wood removed and fate of vegetation in case of land clearing. The calculations upon which the percentages are based are illustrated in Table 4. The calculations are elucidated in the text frame below.

Calculating forest degradation levels from extracted volumes of logs

Level of degradation due to logging was calculated as described below:
In the Aid Environment report concerning deforestation estimates are given for the volume of round wood removed per hectare degraded (see table, column named m^3 round wood/ha). Based on Brown (2008) and Putz (2008) these volumes were translated into amounts of biomass removed.

1. First m^3 of round wood have been converted into tonne C/ha of removed vegetation by multiplication with the density of the wood (625 kg/m^3 – see Aid Environment report) and by multiplying the resulting amount of dry wood with the average carbon content for wood in general (47%; see IPCC, 2006).
2. Then the removed amount of round wood was multiplied with a number of ratios representing the ratio between the weight of the commercial timber log (as round wood) and three other categories of wood removed, logged or otherwise damaged:
   a The fraction of the tree not removed from the forest as commercial log, in essence the tree crown.
   b Trees damaged by the felling of the timber tree.
   c Vegetation removed during logging road construction.

The different ratio's are given in the left columns of the table and have been extracted from Brown (2008).
Multiplying of the amount of timber log removed per hectare with these ratio's gives the total amount of aboveground biomass removed.

Total amount of above and belowground biomass were calculated using the ratio's of root to aboveground biomass given by IPCC (2006).

The calculations described above refer to conventional selective logging. For Reduced Impact Logging (RIL) emissions are 35% lower (see Putz, 2008).

Table 4 Calculation of commercial log weight to total removed vegetation ratio

	Indonesia: extracted volume = 40 m^3/ha (Aid Environment) equals 26 tonnes dry biomass		Malaysia: extracted volume = 60 m^3/ha (Aid Environment) equals 39 tonnes dry biomass	
	Tonne wood damaged or removed per tonne extracted timber log	tonne C/ha	Tonne wood damaged or removed per tonne extracted timber log	tonne C/ha
Extracted as timber log / round wood	1,0	11,9	1,0	17,8
Tree residue	1,0	11,9	1,0	17,8
Damaged trees	2,3	27,2	2,3	41
Logging road	1,0	11,9	1,0	17,8
Total	5,3	62,9	5,3	94,4

Results:
- For Indonesia: 40 m^3 log corresponds to 63 tonne C/ha removed, this is 38% of total vegetation (see also Table 2);
- For Malaysia: 60 m^3 log corresponds to 94 tonne C/ha removed, this is 57% of total vegetation (see also Table 2).

Table 5 **Specifications of forest degradation and deforestation activities**

	Activity	Frequency (years)	Percentage of vegetation removed	Fate of removed biomass		
				Burned	Litter	Removed from area
Indonesia	Wood	30	38%		86%	14%
	Pulp		100%	95%		5%
	Palm		100%	95%		5%
Malaysia	Wood	30	57%		86%	14%
	Pulp		100%	92%		8%
	Palm		100%	92%		8%

2.5 Model

As indicated in Chapter 2 a model was developed in order to be able to take into account the effects of forest degradation on the amount of carbon stored in the S.O.C. pool. For estimating such impacts the IPCC methodology is too crude.

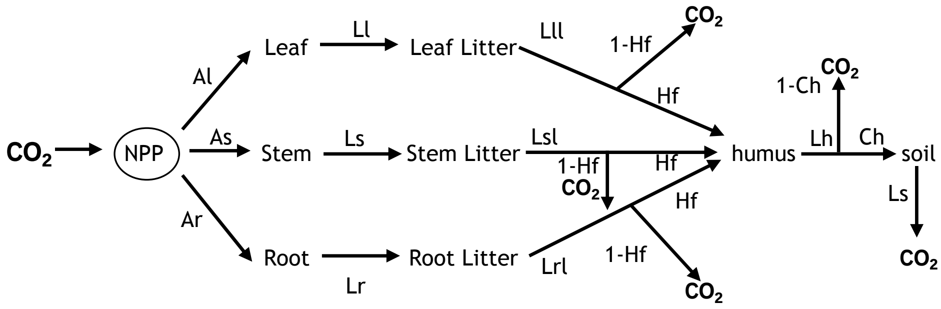
The backbone of the model is the assumption that the fixed carbon in biomass can be partitioned into separate pools: living, litter and soil. The pools together form the total carbon fixed in the biomass and soil. Then the carbon model is defined by the following parameters:

NPP	The rate at which atmospheric carbon is being fixed per year, per m^2.
Ax:	The partitioning of NPP into the biomass for leaf, stem and root.
Lx	The lifetimes of the carbon in pool x.
Hf	The rate at which carbon is being returned to the atmosphere.
Ch	The rate at which carbonization of humus to stable soil appears.

The way in which the parameters interact is shown in Figure 6. This interaction is described in literature (e.g.Roxburgh, 2005), and Bergkvist (2003) and is commonly accepted to show the general dynamics. In these dynamics an equilibrium can be reached, when the amount of carbon being fixed in the system is equal to the amount that flow out[2].

[2] Recent literature mentions a system without equilibrium where the amount of fixed carbon keeps increasing. Whereas these new findings have not been commonly accepted yet, we have not used them in this study. All parameters give a proportion, which gives the model a statistical nature.

Figure 6 **Model structure**



Calculations made using the model are:

– Equilibrium.
  For all situations the equilibrium has been taken as the initial state of the forest before degradation of deforestation.
– S.O.C. pool size as a function of degradation.
  Humus/soil: The influence of carbon fixed in the stable soil has not been taken into account, because the report focuses on short term impacts. Because the lifetime of stable soil is proven to be very long, though hard to quantify, a pool size can grow enormous in centuries (very little outflow, therefore called ‘stable’). The partition of the humus that carbonizes (Ch) is small, about 5% only. Because of these characteristics, the pool size of stable soil is not influenced much on short term when forest is being degraded or deforested. The long term influence though is unmistakable there, and potentially huge when seriously disturbed.
– NPP increase after forest degradation.
  The NPP is calculated dynamically until it reaches its maximum. The estimated increase storage in vegetation assuming a sigmoid function for vegetation growth and use this approach for estimating the amount of carbon stored in vegetation during a certain period to be considered:

$$NPP_{new} = \frac{NPP_{current} * sr}{1 + (sr - 1) * NPP_{current} / NPP_{\max}}$$

  In which sr is the succession rate, the rate at which the NPP recovers and NPPmax = maximum Net Primary Productivity.
– Degradation.
  When degradation takes place the living pools and NPP are degraded with the given percentage. Where the living carbon is allocated, is also asked as input. When not to litter (left on the ground), it is allocated to atmosphere. Where used, burned or else, after all the carbon will flow to the atmosphere.

The model input includes:

NPPmax	: Varies per region, deducted from NPP chart.
Al/As/Ar	: 20% / 50% / 30% taken from Roxbury (2005).
Lll=Lsl=Lrl=1	: All litter has a lifetime of 1 year.
Ls/Lr /Lh	: Deducted from the IPCC figures and determined region.
Lleaf = 2	: From Roxbury (2005).
Hf = 40%	: The part of the litter that turns to humus is set stable.

Applied figures are given Table 6.

Table 6 Model input

	Carbon pool sizes (tonne/ha)						Lifetime of material in pool							
	Cleaf	Croot	Cstem	C_lit_leaf	C-lit_root	C_lit_stem	Lleaf	Lroot	Lstem	Llitter	Lhumus			
											HAC	LAC	Volcanic	Histosol
Indonesia	7	61	158	3,3	2,2	5,5	2	28	29	1	10	14	30	
Malaysia	7	61	157	3,6	2,4	6,0	2	25	26	1		13		

L = lifetime, number of years the carbon remains in the pool.

3 Results per hectare

3.1 Direct impact

The immediately occurring GHG emissions related to removal of aboveground vegetation and burning of removed vegetation are given in Table 7. Emissions are given per activity and per region.

Table 7 Immediate emissions of GHG (tonne CO_2 eq./ha) due to vegetation removal and burning of removed vegetation

		Vegetation removal	Burning of vegetation	Total
Indonesia	Wood	316		316
	Pulp	826	36	863
	Palm	826	36	863
Malaysia	Wood	474		474
	Pulp	826	36	863
	Palm	826	36	863

The emissions due to vegetation removal refer to removal of all vegetation fractions, including roots.
Emissions related to burning have been calculated applying the emission factors for CH_4 and N_2O per tonne of burned biomass as given in IPCC (2006). It is assumed only litter and aboveground biomass is burned and that the commercially interesting trees are removed for sale first.

3.2 Direct emissions and long term effects

An overview of is given in Table 8.

Table 8 Overview of total of GHG emissions

		Direct emissions (tonne of CO_2/ha)	Emissions within period of 20 years (tonne of CO_2/ha)	Deforested and degraded area's allocated to the Netherlands (in 1.000 ha) in the considered periods (see Table 3):		
				Period 1995 - 2000	Period 2001 - 2005	Period 2006 and 2007
Indonesia	Wood	316	349	26	31	12
	Pulp	863	845			
	Palm	863	845	120	54	53
Malaysia	Wood	474	528	11	13	8
	Pulp					
	Palm	863	835	13	16	15

The size of degraded and deforested areas are also given in order to make the final results at the end of this chapter reproducible.

The presented figures are discussed in the subparagraphs below.

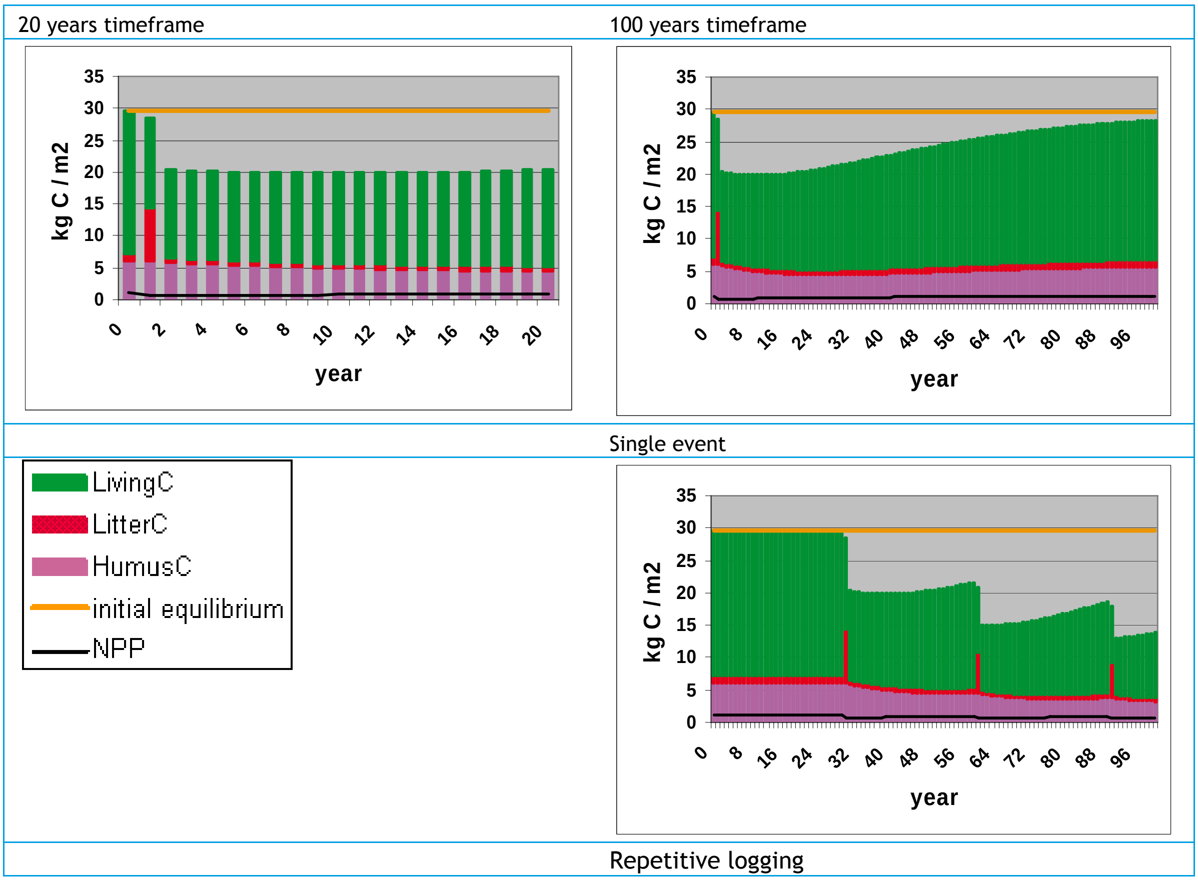
3.2.1 Forest degradation for timber logging

Effects of forest redevelopment and impacts on soil organic carbon pool size of temporarily limited influx of litter due to reduced vegetation level have been calculated with the model presented in paragraph 2.5. Calculation results are illustrated for Indonesia in Figure 7.

The figures also illustrate the effect of repetitive logging and redevelopment of forest on carbon pool sizes.

For Indonesia average decrease in total carbon pools in 20 years amounts to 9,2 kg C per m^2 in those 20 years - equivalent with a CO_2 emission of 9,2 x 44/12 x 10 = 349 tonnes of CO_2. Although vegetation has grown back to some extent, partly neutralizing emissions of CO_2 due to the original vegetation removal, the total amount of carbon stored in vegetation, litter and soil organic carbon is still smaller than directly after logging because of reduction of carbon in the soil. Soil carbon has been reduced because the reduced vegetation cover produced less litter in these twenty years as in the pristine situation.

Figure 7 Carbon pool development for logging in Indonesia



In case of a single logging the initial equilibrium will be reached almost again after a period of 100 years and the average decrease of fixed carbon is only 1,3 kg C/m^2.

In case of repetitive logging with a 30 years interval base, the initial equilibrium goes out of sight. The decrease of fixed carbon is 15,8 kg C/m^2.

In this analysis we only considered the total sequestered carbon 20 years after logging. Because of regrowth of trees this amount is higher than directly after logging.

3.2.2 Oil palm plantations

Oil palm plantations will accumulate biomass in the shape of oil palms. According to IPCC (2006) the accumulated amount of carbon in the oil palms amounts to:

$$118 \times (100\% + 22\%) \times 40\% = 57 \text{ tonne C/ha}$$

in which 118 refers to the accumulated aboveground biomass (d.s.), 22% to the relative amount of the roots (compared to the aboveground biomass) and 40% to the carbon content of dry biomass.
The sequestered 57 tonnes of C is equivalent to a reduction in atmospheric CO_2 of 57 x 44/12 = 212 tonne per hectare.

Main question is whether the palm trees and associated sequestered carbon will be maintained or whether the trees are cut down at the end of their economical live. In the latter case the effectively sequestered amount of CO_2 is much lower than the maximum sequestered amount – the amount sequestered in the tree just before cutting.

Concerning GHG emissions from dead organic material (D.O.M.) and soil an inconsistent view is given in various available reports, indicating that effects depend largely on soil type:

- For mineral soils changing land use from forest to oil palm plantation gives a limited emission of 19 - 41 tonnes of CO_2 (and 0,8 tonnes CO_2 eq as N_2O) (Ecofys, 2008). But given the high NPP per hectare and the high percentage of NPP attributed to canopy and fruit bunches, effect of land use change could equally likely be neutral or positive (sequestration of carbon in soil). It is likely that for an oil palm plantation the amount of organic material ending up as litter is comparable or larger compared to a natural forest. Because of this uncertainty emissions from soil stocks have been neglected.
- In case the oil palms are exploited on drained peat soils, there will be an emission of CO_2 and N_2O from decomposed and oxidized peat. Below we briefly discuss the emission factor applied in this study:
  - IPCC (2006) gives an annual emission of up to 20 tonnes of C per hectare per year, depending on drainage depth. This would be equivalent to a total emission over a period of 20 years of 1,467 + 124 tonnes of CO_2 eq. per hectare.
  - However, according to Germer (2008) in practice CO_2 emissions do not reach maximum value and amount to 31,4 ± 14,1 tonnes CO_2/ha/year. This value has been applied in current study.

Approximately 25% of palm oil plantations is situated on peat soil[3]

Averaging over the different types of soil per country gives the specific emissions within a 20 year period per hectare given in the table below.

At plantations not situated on peat soil there will be a net assimilation of carbon in the shape of palm trees within this period of 20 years, only limited negated due to soil carbon oxidation.
Plantations situated on peat soil will produce a very significant emission during this period of 20 years, exceeding the emission related to the removal of the originally present vegetation.

[3] http://www.wldelft.nl/cons/area/rbm/PEAT-CO2.pdf

Averaging over the different types of soils the fact that 25% of the oil palm plantations is located on peat[4] and the subsequent emissions from peat soils more than counterbalance the net assimilation of CO_2 in oil palms, resulting in a net average assimilation of 18 - 26 tonnes of CO_2 eq./ha.

Table 9 **Calculation of net long term GHG effects in case of deforestation for oil palm plantation realization**

	Malaysia		Indonesia		
A. SOC stocks in original soil (tonne/ha)					
Soil organic matter (see IPCC, 2006)	60	n.g.	60	130	n.g.
	LAC	Histosol	LAC	Volcanic	Histosol
B. SOC stock change factors for LUC to crop land - decline in soil carbon (see IPCC, 2006)					
- F land use	100%		100%	100%	
- F tillage	100%		100%	100%	
- F input	92%		92%	92%	
CO_2 emission per hectare due to LUC					
Tonne CO_2 eq./ha					
CO_2 from SOC oxidation (A x (1 – fl x ft x fi))	18	631[5]	18	38	631[5]
N_2O-emissions from SOC oxidation	1	53	1	3	53
Total emissions from soil over period of 20 years	19	684	19	41	684

Net effect of assimilation of CO_2 in oil palm trees and emissions from soil gives the net long term effects given in Table 10.

Table 10 **Calculation of net long term GHG effects in case of deforestation for oil palm plantation realization**

	Malaysia		Indonesia		
Oil palm vegetation CO_2 capture	-212	-212	-212	-212	-212
Total emissions from soil over period of 20 years	19	684	19	41	684
Net CO_2 effect	-192	472	-192	-170	472
Percentage of oil palms on this soil type:	75%	25%	38%	38%	25%
Average per country	-26		-18		

The results presented in the table are included in Table 8 (this subparagraph describes the in-depth discussion of the realization of the figures included in Table 8).

The result can be somewhat artificial since the oil palms may be cut down again after the plantation has reached its economic end of life after 25 – 30 years. In that case the CO_2 assimilated in the trees will be released again and no net assimilation will have occurred.

4 See http://www.wldelft.nl/cons/area/rbm/PEAT-CO2.pdf.

5 See Germer, 2008.

4 Global emissions from deforestation and forest degradation allocated to Dutch economy

Combining the emissions per hectare calculated in chapter 3 with the deforested and degraded area's determined by Aid Environment (see Table 3 and Table 8) gives the global annual emissions that can be allocated to the Netherlands:

- From Table 3 we took the Aid Environment sizes of the area that have been deforested or degenerated within a certain period and translated those into an average annual deforestation/degradation ratio.

  For example, deforested area for oil palm plantation realization in Indonesia from 1996 to 2000 amounted to 120,000 hectares, an average deforestation ratio of 120,000 ÷ 5 =24 ,000 hectares annual.
- From Table 8 specific emissions per hectare were taken.

  For Indonesia the specific direct emission due to deforestation has been estimated as amounting to 863 tonnes CO_2 eq/hectare
- Multiplication of both values gives the annual emissions related to Dutch economic activities.

  Multiplication yields a direct emission of 863 x 24,000 ≈ 20,700,000 tonnes or 20.7 Mtonnes CO_2 eq.

As can be deducted from Table 8 net long term emissions are relatively small, so that the contribution of these emissions is not very explicit when comparing the left and right side of the figure.

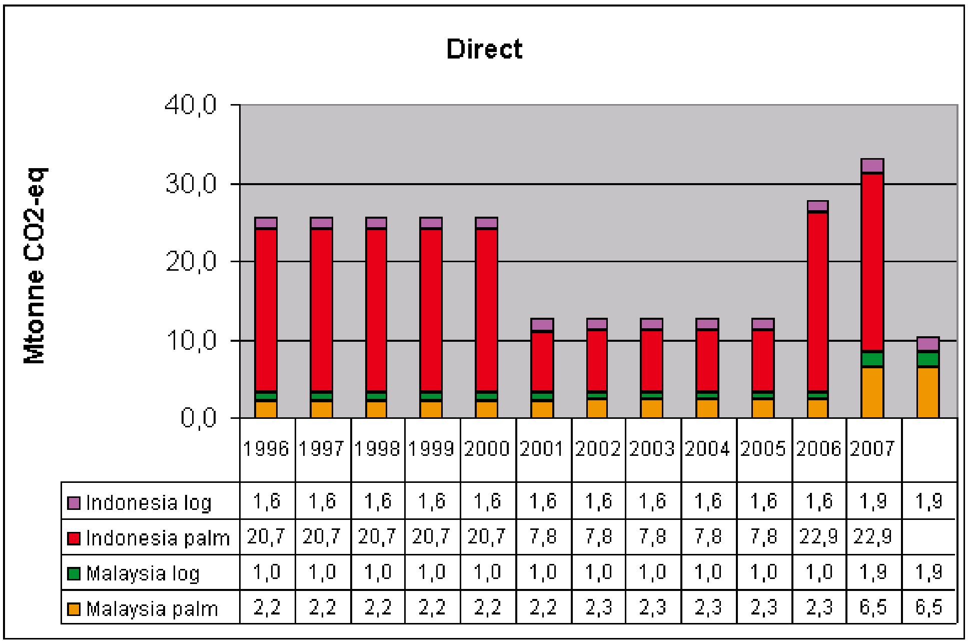
Oil palm cultivation gives the highest contribution. Logging contributes little to the total emissions because for logging in South East Asia little of the degraded area can be contributed to the Netherlands.

The figures thereby also illustrate where the core of Dutch economic involvement in the considered countries lays.

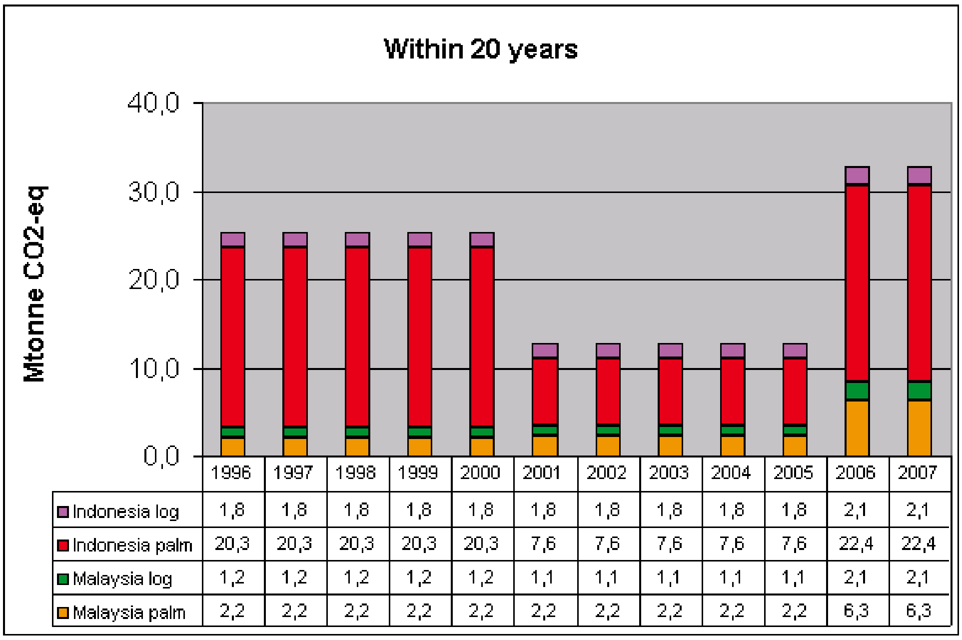
As illustrated in Figure 8 total GHG emissions from deforestation and degradation that can be attributed to Dutch economy amounts to 12 - 25 Mtonnes per year for the period up to 2005. These emissions represent 5% - 10% of total Dutch domestic emissions.

In the last two years the high rate of deforestation and the intensive economic relation of the Netherlands with the deforestation makes the Netherlands accountable for an emission that represents 30 - 32 Mtonnes or 15% of total Dutch GHG emissions.

Figure 8 **Annual GHG emissions due to forest degradation and deforestation allocatable to the Netherlands**



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	
Indonesia log	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,9	1,9
Indonesia palm	20,7	20,7	20,7	20,7	20,7	7,8	7,8	7,8	7,8	7,8	22,9	22,9	
Malaysia log	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,9	1,9
Malaysia palm	2,2	2,2	2,2	2,2	2,2	2,2	2,3	2,3	2,3	2,3	2,3	6,5	6,5



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Indonesia log	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	2,1	2,1
Indonesia palm	20,3	20,3	20,3	20,3	20,3	7,6	7,6	7,6	7,6	7,6	22,4	22,4
Malaysia log	1,2	1,2	1,2	1,2	1,2	1,1	1,1	1,1	1,1	1,1	2,1	2,1
Malaysia palm	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	6,3	6,3

These figures concern a conservative estimation for several reasons:

– In the analysis the CO_2 assimilated in oil palm trees was discounted (as a CO_2 sink) - in accordance with the IPCC, 2006 methodology.
  However it is uncertain that the oil palms will remain in place once the plantation has reached the end of its economic life and after the trees have become too high for fruit bunches harvesting.
  If the oil palms are cut down no net CO_2 assimilation will have taken place and net GHG emissions have been underestimated.

– We assumed that 25% of oil palm plantations have been or are realized on peat soils – in accordance with current average geological situation of oil palm plantations in South East Asia.
  However, the 2006 TU Delft and WUR study concerning CO_2 emissions from drained peat lands in South East Asia indicates that the percentage of newly realized plantations on peat soils is actually higher than the considered average 25%. The study unfortunately does not indicate which percentage has actually been realized on peat soils.
  Since plantations on peat soils generate far higher GHG emissions per hectare than plantations on mineral soils – due to peat oxidation - the probable underestimation of the percentage of plantations recently realized on peat also means that GHG emissions have probably been underestimated.

Literature

Berkkvist and Jarvis, 2004
P. Bergkvist, N. Jarvis
Modeling Organic Carbon Dynamics and Cadmium Fate in Long-Term Sludge-Amended Soil
In: Journal of Environmental Quality, vol. 33, (2004); p.181-191
http://jeq.scijournals.org/cgi/content/abstract/33/1/181c

Brown et al., 2008
S. Brown, T. Pearson, N. Moore, A. Parveen, S. Ambagis, D. Shoch
Impact of selective logging on thecarbon stocks of tropical forests:Republic of Congo as a case study - Deliverable 6: Logging impacts on carbon stocks
Arlington (USA) : Winrock International, 2008
http://carpe.umd.edu/resources/Documents/rpt_carbon_congo_3_2005_winrock.pdf/view

Ecofys, 2008
C. Hamelinck, Hamelinck, C., K. Koop, H. Kroezen, M. Koper, B. Kampman, G. Bergsma
Technical specifications greenhouse gas calculator for biofuels
Utrecht ; Delft : Ecofys ; CE Delft, 2008

Germer, 2008
J. Germer , J. Sauerborn
Estimation of the impact of oil palm plantation establishment on greenhouse gas balance
In : Environment, Development and Sustainability , 10 (2008) ; p. 697–716

IPCC, 2006
J. Penman et al
2006 IPCC guidelines for national greenhouse gas inventories
Paris : IPCC/OECD/IEA, 2006

Putz et al., 2008
Francis E. Putz, Pieter A. Zuidema, Michelle A. Pinard, Rene G. A. Boot, Jeffrey A. Sayer,Douglas Sheil, Plinio Sist, Elias, Jerome K. Vanclay
Improved Tropical Forest Management for Carbon Retention
In : PLoS Biology journal, 2008
http://www.cifor.cgiar.org/publications/pdf_files/polex/Putz%20et%20al%20%202008%20PLOS%20Biology%20Improved%20Forest%20Management%20(2).pdf

Roxbury, 2005
Stephen Roxburgh
The CASS Terrestrial Carbon Cycle Model v. 1.2 - User guide and tutorial exercises
CRC for Greenhouse Accounting
Canberra (AUS) : S.n., 2004

Wicke, et al., 2007
B. Wicke
A Greenhouse Gas Balance of Electricity Production from Co-firing Palm Oil Products from Malaysia
Utrecht : University of Utrecht, Copernicus Institute, 2007