Estimating CO_2 emissions associated with selective timber harvesting and oil palm conversion in Papua New Guinea

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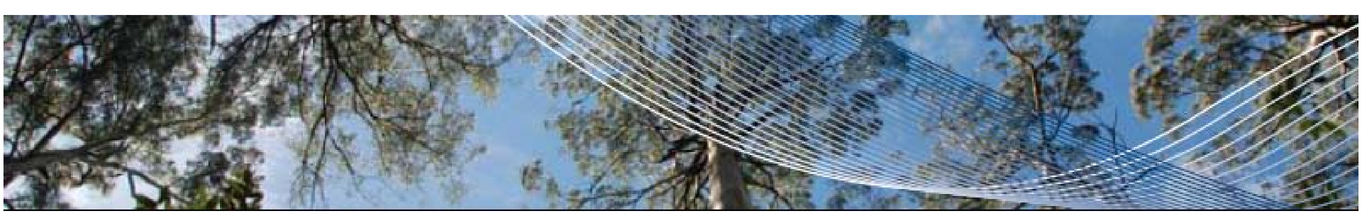

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Executive summary

A methodology is presented for estimating the CO_2 emissions associated with selective-harvesting and oil palm conversion in Papua New Guinea (PNG). This methodology is interim in the absence of explicit guidelines for Reducing Emissions from Deforestation and Degradation (REDD). Emissions are estimated based on an assumption of average timber volume extracted per hectare of selective-harvesting; this assumption was used in the absence of up to date spatial information on land cover and land cover change for PNG. It is recommended that this methodology and the resulting estimates be revised as REDD guidelines become available, and spatial information for PNG improves.

For each year from 1960 to 2008 the carbon (C) pools affected by selective-harvesting and oil palm conversion in PNG were estimated. Some pools decompose returning CO_2 to the atmosphere (harvesting and oil palm residues), some sequester, removing CO_2 from the atmosphere (regrowing forest and oil palm), some store CO_2 (wood products), while others release CO_2 through combustion (burning sawmill residue and fuel used in machinery), fertiliser use and effluent.

Estimated emissions from selective-harvesting fluctuate between 33 and 44 million tonnes of CO_2 emitted ($MtCO_2e$) for the period 1996 to 2008. Estimated emissions from oil palm conversion fluctuate between 2 and 6 $MtCO_2e$ for the same period. The methodology was applied to several land use scenarios (high, medium and low levels of selective-harvesting and oil palm conversion) for the period 2009 to 2020. Estimated emissions for a scenario of high activity fluctuate between 37 to 45 and 2 to 3 $MtCO_2e$ for selective-harvesting and oil palm respectively. For a scenario of low activity emissions fluctuate between 25 to 45 and 1 to 2 $MtCO_2e$ for selective-harvesting and oil palm respectively.

Aims – Terms of Reference

1) Estimate annual CO_2 emissions associated with selective timber harvesting for the period 1960 to 2008 for Papua New Guinea (PNG).
2) Estimate annual CO_2 emissions associated with oil palm conversion for the period 1996 to 2008 for PNG.
3) Estimate emissions associated with selective-harvesting and oil palm conversion for scenarios for the period 2009 to 2020.

Part 1 – Emissions associated with Selective timber harvesting

Methodology

In the absence of explicit guidelines for the REDD (UNFCCC 2006, 2009) mechanism, this methodology for estimating CO_2 emissions associated with selective timber harvesting in PNG is based on available literature as referenced such as published carbon book-keeping methods (e.g. Ramankutty *et al*. 2007, Blanc *et al*. 2009) and elements of the Voluntary Carbon Standard (VCS 2008a, 2008b, 2008c) and IPCC guidelines (IPCC 2003, 2006).

For each year over the period 1960 to 2008 the carbon (C) pools affected by selective-harvesting in PNG were estimated. Some pools decompose returning CO_2 to the atmosphere (harvesting residues) some sequester, removing CO_2 from the atmosphere (regrowing forest), some store CO_2 (wood products), while others release CO_2 through combustion (burning sawmill residue and fuel used in machinery). Most of these C pools will be aboveground, however, there will be an enhanced pool of belowground residue from dead biomass in roots and stumps. Other below ground carbon pools such as soil C were not considered because they are unlikely to change due to selective-harvesting in the considered time frames (Hughes *et al*. 1999, IPCC 2006, Yashiro *et al*. 2008).

Estimating CO_2 emissions associated with selective timber harvesting

Estimating selective-harvesting area

The annual (year *i*) area affected by selective-harvesting (selective-harvesting area; SHA_i) was estimated from the sum (TV_i; total volume) of round wood log export volume (EV_i) and the volume of locally processed timber (LPV_i), and an assumption of average removals per hectare (15 m^3/ha; Keenan *et al*. 2005, Keenan *et al*. 2009);

$$TV_i = EV_i + LPV_i$$

$$SHA_i = (TV_i/15)$$

EV_i, LPV_i, and TV_i are log export, locally processed, and total extracted volume from native forests in PNG for year *i*

The estimation of selective-harvesting area using the above methodology is an interim approach; it is envisaged that future approaches will use remote sensing data sources to more explicitly and accurately identify affected areas (e.g. Asner *et al*. 2002, Asner *et al*. 2004, Fox *et al*. 2009c). The above method is reliant on the generality of 15 m^3/ha as the average volume removed in selective-harvesting per hectare. Concession level analysis of net available area, net volume, and volumes of round wood export and locally processed timber to confirm that 15 m^3/ha is suitable for this purpose. Applying this figure to harvesting data from 1961–2008 results in a total selectively-harvested forest area of 3.7 million hectares. This is similar to the PNGFA estimate of selectively-harvested forest (upto 2002) of 3.4 million hectares. However, more analysis is recommended to test the generality of this assumption.

Estimating emissions from selectively-harvested area

CO_2 emissions associated with the selective-harvesting area (CSH_i) in year *i* were estimated based on emissions from an accumulating pool of decomposing residue (DR_i), observed C sequestered in regrowth (CR_i), net C stored in harvested wood products ($NCWP_i$), C combusted during fuel consumption (EFC_i) and the stoichiometric conversion ratio from C to CO_2 equivalent of 44/12 (Blanc *et al*. 2009, VCS 2008b, VCS 2008c);

$$CSH_i = [DR_i - CR_i - NCWP_i + EFC_i] \times [44/12]$$

Observed reductions in above ground live biomass due to selective-harvesting

Fox *et al*. (2009b) found that, on average, selectively-harvested forest had 50 tC/ha less above ground live biomass (AGLB) then primary forest immediately after harvesting; primary forest average AGLB of 112 tC/ha minus selectively-harvested average AGLB of 62.2 tC/ha after harvesting. Therefore we can assume that the carbon fraction of AGLB displaced in selective-harvesting (RSH) is approximately 50 tC/ha.

A component of this 50 tC/ha will be moved off site as wood products. A larger component will become dead biomass including tree crowns, non-merchantable materials, and trees killed. Collectively we can refer to this pool as "collateral damage". This large component will become decomposing residue. We can estimate this large pool by subtracting the carbon fraction of the assumed timber volume removals of 15 m^3/ha. The carbon fraction of timber removals can be estimated from the average wood density for commercial timber species in PNG. This was calculated using an average of species wood density weighted by the annual volume of timber removed from the forest. The weighted average wood density of exported timbers was 0.58 kg/m^3. Therefore the contribution to decomposing residue from collateral damage after harvesting can be calculated as;

$$\Delta CD = 50 - [15 \times 0.50 \times 0.58]$$

Collateral damage resulting from selective-harvesting is therefore 45 tC/ha, and can be estimated from the selectively-harvested areas (SHA_i);

$$CD_i = SHA_i \times 45$$

As estimated above, selective-harvesting displaces a large component of aboveground living biomass to dead biomass (45 tC/ha). This is consistent with studies of the biomass dynamic after selective-harvesting; Keller *et al*. (2004) observed the deposition of 37.5 and 54 tC/ha of dead biomass after reduced impact and conventional selective-harvesting in the Brazilian Amazon. Other additions to the decomposing residue pool also need to be considered.

Other additions to the decomposing residue pool

The decomposing residue pool (DR_i) consists of a one off contribution from displaced living biomass (calculated above), as well as contributions from living biomass displaced from; areas deforested (AD_i); failed regeneration (FR_i); and belowground residue (BR_i).

Areas deforested

Areas are deforested during selective-harvesting due to road construction, log dumps, logging camps and other infrastructure. The ratio of total selectively-harvested area to deforested area has been estimated to be 15% in tropical selective-harvesting operations (Pulkki 1997). The average carbon fraction of AGLB in primary forest in PNG was estimated in Fox *et al*. (2009a, 2009b) to be 112 tC/ha. A component of this will be removed from the forest during selective-harvesting as wood products (estimated below), but a majority will remain in the forest as decomposing residue. Therefore the carbon fraction of biomass displaced from deforested areas and contributing to decomposing residue can be estimated as;

$$AD_i = [0.15 \times SHA_i \times 112] - [SHA_i \times 15 \times 0.50 \times 0.58]$$

Failed regeneration

Selectively-harvested areas that fail to adequately regenerate (Failed regeneration; FR_i) will annually contribute to the decomposing residual pool due to tree mortality. Analysis of forest recovery after selective-harvesting has indicated that 25% of areas in PNG fail to adequately recover due to poor harvesting practices, subsequent anthropogenic disturbance (shifting cultivation) and fire disturbance (Yosi *et al*. 2009). This component of selectively-harvested forest will accumulate annually, and will contribute to the decomposing residual pool due to ongoing tree mortality. An inverse of the sequestration rate (1.15 tC/ha/yr; see section *Estimating C sequestered in regrowth*) can be used to characterise mortality and to estimate the C lost to mortality in forests with failed regrowth. The area of failed regeneration (AFR_i) can be estimated as;

$$AFR_i = SHA_i \times 0.25$$

The total magnitude of this contribution in year *i* (FR_i) can be estimated as the sum of contributions from failed regrowth from previous years as well as the present year;

$$FR_n = \sum_{i=1961}^{n} \left[\left[62 - 50\left(e^{-16/t}\right) \right] \times AFR_i \right]$$

Where *t* is the time since selective-harvesting.

Belowground residue

Selective-harvesting will result in an enhanced pool of below ground residue in the root material of harvested trees. The component of total belowground biomass affected by selective-harvesting can be estimated from the amount of aboveground biomass affected, and the application of established ratios (Herald *et al*. 2008). The IPCC (2006) recommend a ratio for belowground to aboveground biomass of 0.37 for lowland tropical forests. By applying this ratio to the observed reduction in AGB due to selective-harvesting (RSH; 50 tC/ha; Fox *et al*. 2009b) we can estimate the amount of belowground residue (BR_i);

$$BR_i = SHA_i \times 50 \times 0.37$$

The decomposing residue pool in year *n* (DR_n) therefore consists of accumulating contributions from living biomass displaced from collateral damage CD_i, areas deforested (AD_i), failed regeneration (FR_i), and belowground residue (BR_i);

$$DR_n = \left[\sum_{i=1961}^{n} (CD_i + AD_i + FR_i + BR_i)\right]$$

When estimating decomposition rates it is important to separate the fine debris (FD_i) pool from the large wood (LW_i) pool as the two pools decompose at very different rates. The fine debris pool, which consists of leaves, twigs and small diameter branches, will decompose rapidly while large woody biomass will decompose at a much slower rate (Chambers *et al*. 2004, Keller *et al*. 2004, Blanc *et al*. 2009). The ratio of large wood to fine debris was estimated using Permanent Sample Plot (PSP) data for primary forests collected by PNG Forest Research Institute. The ratio (R_{LWFD}) was determined by first summing stem volumes (SV_i) (adjusted for wood density for species *T* (WD_T), and the carbon fraction of biomass; 0.5) for all trees (*i*) on the one hectare PSPs. This was then divided by the summed carbon fraction of AGB (Blanc *et al*. 2009);

$$R_{LWFD} = \frac{\sum_{i=1}^{n} SV_i \times WD_T \times 0.5}{\sum_{i=1}^{n} AGB_i}$$

This ratio was estimated for 12 primary forest plots which were averaged resulting in a ratio of 0.43. The proportion of decomposing residue attributable to the large wood (LW_i) pool is then;

$$LW_i = DR_i \times 0.43$$

The decomposition rate of the large wood and fine debris pools were based on reported values from the literature, using an exponential decay formula (Keller *et al*. 2004, Chambers *et al*. 2000, Blanc *et al*. 2009);

$$DR_i = DR_{i-1} e^{-kt}$$

Therefore the decomposing residue (DR_i) pool in year i is DR_{i-1} (decomposing residue in year $i-1$) multiplied by the exponent of the decay rate (k) multiplied by the time (t) since deposition.

Fine debris pools will decompose rapidly with a decay rate of 0.2 ($k_{FD} = 0.2$) which results in a half-life of about three years (Keller *et al*. 2004).

Large wood pools will decompose at a slower rate with a decay rate of 0.1 ($k_{FD} = 0.1$) which results in a half-life of about eight years.

Estimating C sequestered in regrowth

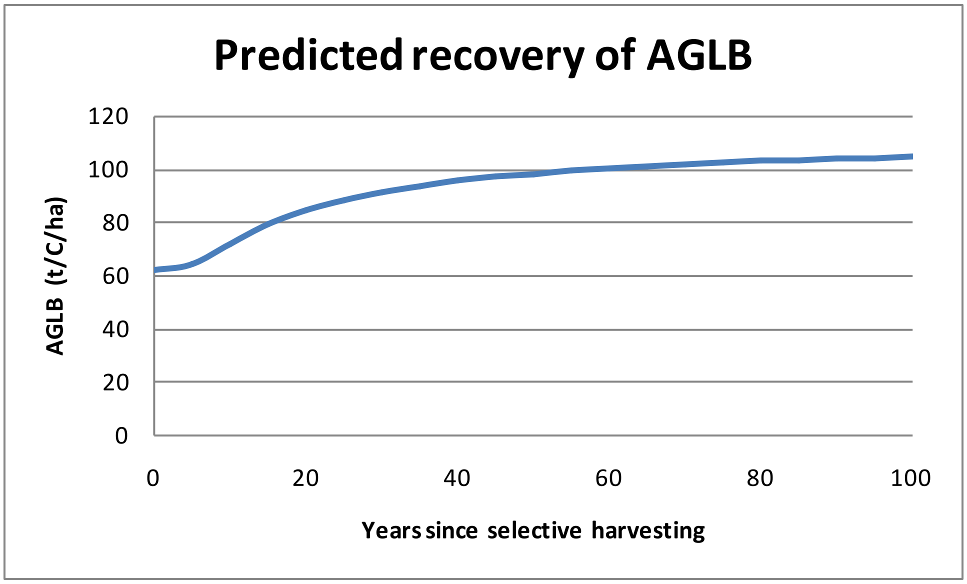
Yosi et al. (2009) found that 75% of selectively-harvested forest successfully regenerates. Therefore the area of successful regeneration in year *i* (ASR_i) can be estimated as;

$$ASR_i = SHA_i \times 0.75$$

C sequestered in regrowth in year *n* (CR_n) was estimated from the accumulative area of successful regeneration (ASR_i) and observed average C sequestration for selectively-harested forest (1.15 tC/ha/yr; Fox *et al*. 2009b). To realistically replicate tropical forest recovery a maximum C sequestration rate of 1.15 over a recovery period of 50 years were assumed. To replicate the sigmoidal tendency of forest recovery a simple model was adopted from the forest recovery function of Australia's National Carbon Accounting System. The function is appealing because the parameters are readily interpretable with the first parameter representing the upper asymptote (primary forest C; 112 tC/ha) and the second parameter representing the shape of the curve to this asymptote (Brack 2006) and was modified here for the addition of AGLB after selective-harvesting (62 tC/ha) and the acquisition of 50 tC/ha over the recovery period;

$$C_t = 62 + 50\left(e^{-k/t}\right)$$

Where C_t is the aboveground C, *t* years after selective-harvesting and k is the rate parameter. By assuming a recovery rate of 1.15 tC/ha/yr between 0 and 20 years after harvesting (measurement periods for PSPs; Fox *et al*. 2009b) and a recovery period of 50 years, k was estimated to be 16. This resulted in an average annual sequestration rate of 1.15 over the first 20 years of recovery which matches empirical data (Fox *et al*. 2009b).



Following this model, regrowth forest is still sequestering C after 100 years, albeit at a reduced rate. Therefore the C stock in successfully regenerating forest (SR_n) in year *n* can be estimated from the accumulating area of successful regeneration multiplied by the predicted recovery function;

$$SR_n = \sum_{i=1961}^{n} \left[\left[62 - 50\left(e^{-16/t} \right) \right] \times ASR_i \right]$$

Estimating C stored in wood products

CO_2 stored in harvested wood products CWP_i was calculated from accumulative round wood export and locally processed timber volumes, average recovery (33% recovery in tropical sawn timbers; Blanc *et al*. 2009), average wood density for utilised commercial timber species (WD; 0.58), the carbon fraction of dry timber (default is 0.5), the fraction of solid dry wood that decays annually, and the average life span of tropical timber in China (Industry advises that this is approximately 5 years). This approach is known as the stock change approach (Dias *et al.* 2009). Annual decay rates for solid tropical timbers have been estimated to 0.02 (Winjum *et al*. 1998, IPCC 2006), therefore a multiplier of 0.98 on the accumulated round wood carbon fraction is appropriate to estimate C stored in wood products. Average wood density of exported round wood was calculated using an average of species wood density weighted by the annual export quantity. The weighted average wood density was 0.58 kg/m^3. Stock change can calculated as the annual addition of C to the wood product pool less that amount that decays annually. The addition of C in year i can be calculated as;

$$CWP_i = TV_i \times 0.33 \times 0.58 \times 0.5 \times 0.98$$

Where TV_i is the total extracted volume from native forests in PNG for year *i*. The carbon fraction of round wood sawmill waste (66% of round wood) was assumed to be burned as is common practice in local processing and in export countries such as China and were immediately decomposed with the carbon fraction emitted.

The C emissions associated with harvested products in year *i* (EWP_i) from decay can be calculated as;

$$EWP_i = \left[\left[\sum_{i-4}^{i}(TV_i \times 0.33 \times 0.58 \times 0.5)\right] \times 0.02\right]$$

n is the number of years over which C accumulates in wood products (assumed to be 5 years based on industry advice on timber life span in China). The emitted quantity (EWP_i) needs to be subtracted from the C added (CWP_i) to estimate the net C change in C stock in year n ($NCWP_n$);

$$NCWP_n = CWP_n - EWP_n$$

The net amount of C stored in wood products can then be added as a C sink.

Estimating CO_2 emissions from fuel consumption

Emissions from fuel consumption in year *i* (EFC_i) associated with selective-harvesting is the summation of consumption from felling (FEL_i), preparation ($PREP_i$), loading (LD_i), transport (TR_i), and the emission factor for each fuel type ($E_{FEL}, E_{PREP}, E_{LD}, E_{TR}$);

$$EFC_i = (FEL_i \times E_{FEL}) + (PREP_i \times E_{PREP}) + (LD_i \times E_{LD}) + (TR_i \times E_{TR})$$

Fuel consumption (in kilolitres) due to felling and loading are a function of the total extracted volume (Klvac *et al*. 2003, Klvac and Skoupy 2009);

$$FEL_i = TV_i \times 0.0015$$

$$LD_i = TV_i \times 0.00105$$

Where TV_i is the total extracted volume from native forests in PNG for year *i*. Fuel consumption due to preparation is assumed to be equivalent to consumption for felling;

$$PREP_i = FEL_i$$

Fuel consumption associated with transport is a function of the extracted volume, the average volume carried on each truck (VT_i; 10m^3; Kinjo *et al*. 2005), the average haulage distance (HD_i; estimated to be 50km for PNG), and fuel efficiency (3000 km/kL; Kinjo *et al*. 2005);

$$TR_i = (TV_i/VT) \times (HD_i/FE)$$

The emission factor for petrol (felling and preparation) is 2.3 tCO_2/kL;

$$E_{FEL}, E_{PREP} = 2.3$$

The emission factor for diesel (loading and transport) is 2.7 tCO_2/kL;

$$E_{TR}, E_{LD} = 2.7$$

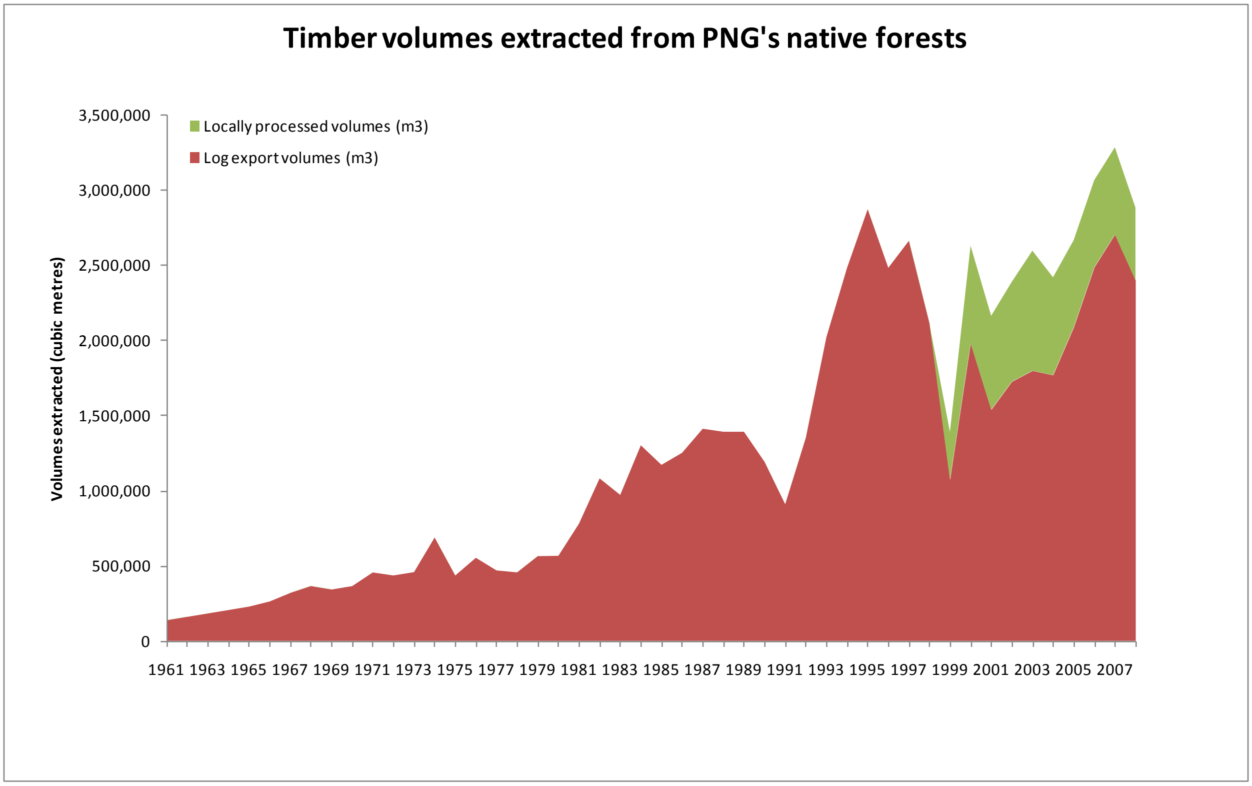
Both emission factors from the United States Environment Protection Agency (http://www.epa.gov/oms/climate/420f05001.htm, accessed Nov, 2009).

A necessary simplifying assumption is an average haulage distance of 50km. The actual haulage distance could be estimated on a concession basis using geographic information systems and network analysis of haulage routes (Healey *et al.* 2009). However, this spatial information is not currently available. If it were available it could be integrated with concession level extracted volumes to more accurately estimate the emissions associated with haulage.

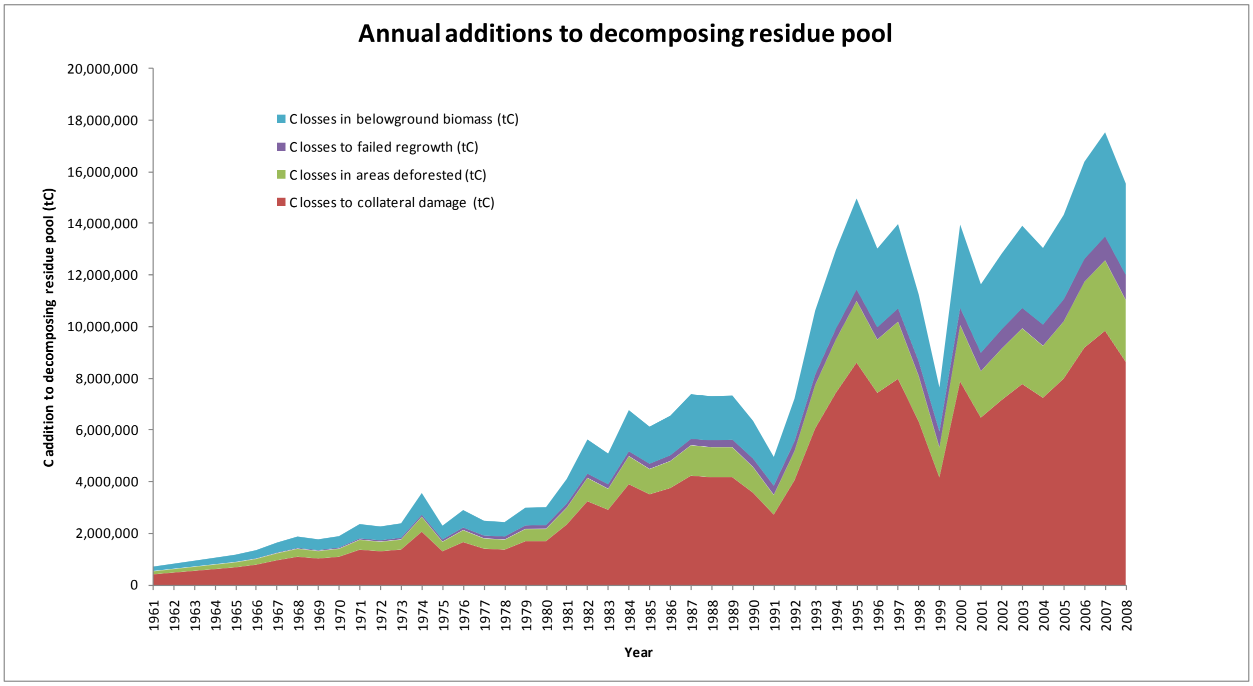
Fuel consumption associated with the shipping of round wood exports to overseas markets (principally China) was not included in the current analysis. However, this source of CO_2 may be significant and should be considered for inclusion in future work.

Results 1961 to 2008

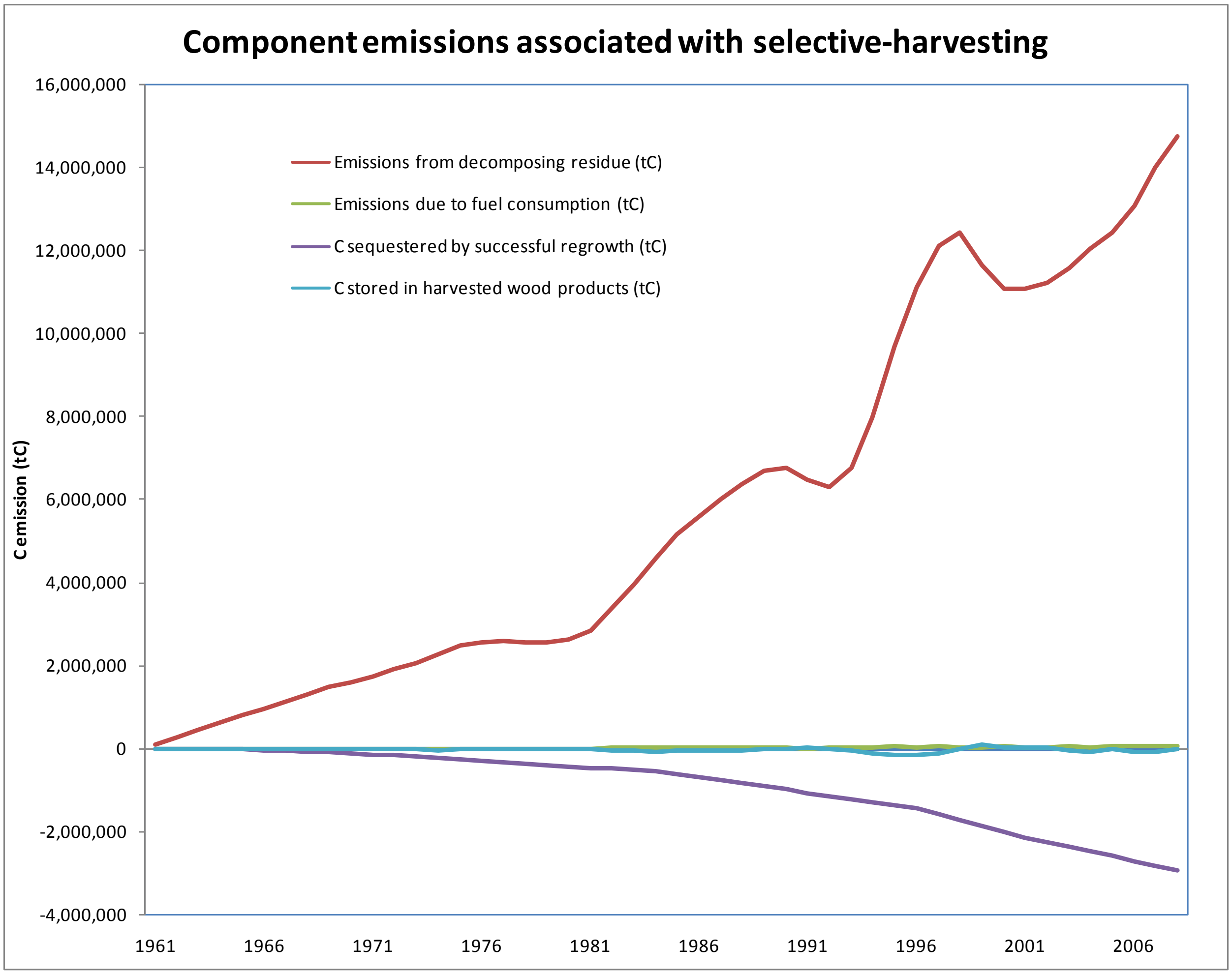
National log export data (excluding plantation logs) and locally processed volumes are available for Papua New Guinea from 1961 to 2008 (various sources). The trend in log export data is depicted below;



Using the methodology described above, the C and CO_2 emission contributions from various sources can be estimated and examined.

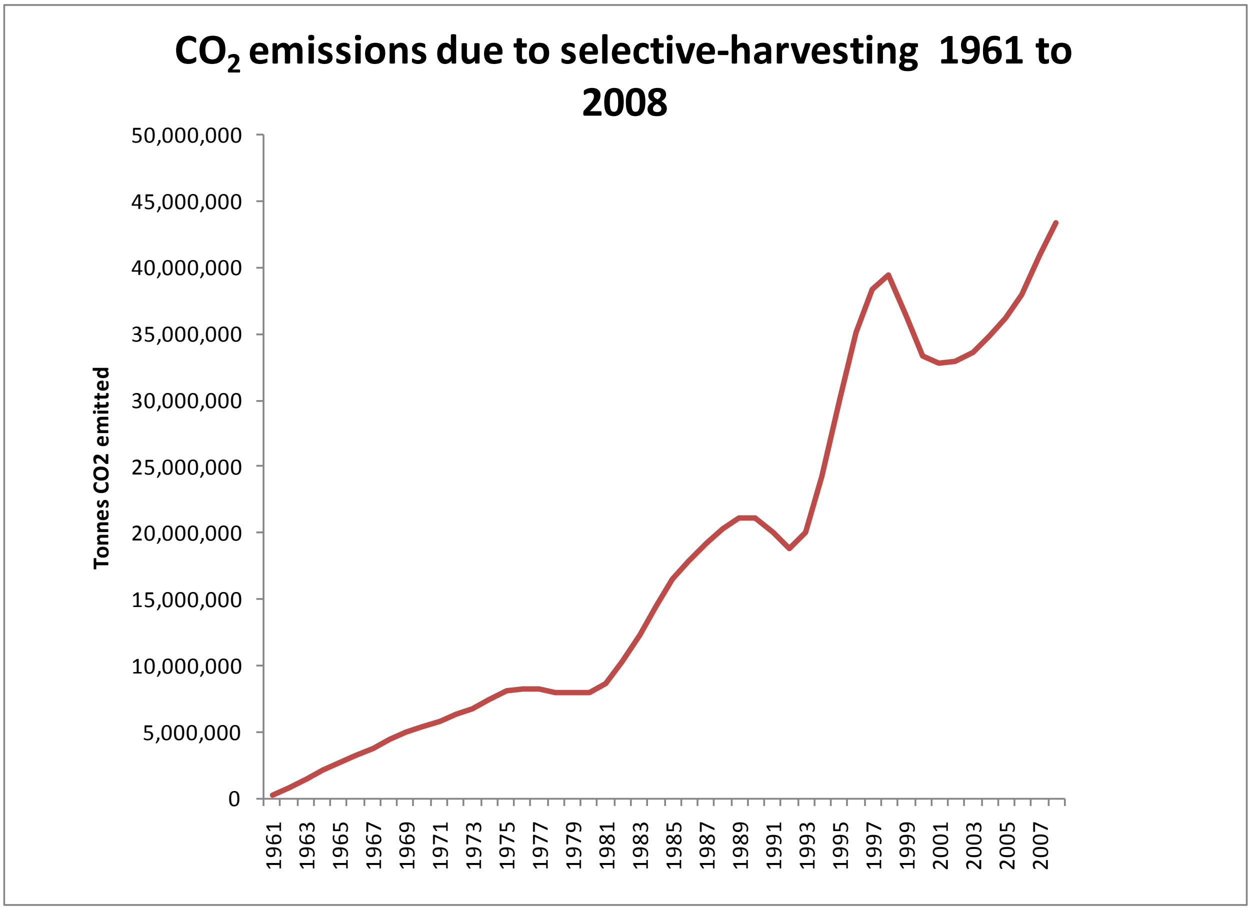


The graph above depicts annual additions to the decomposing residue pool. Collateral damage is the largest addition to decomposing residue.



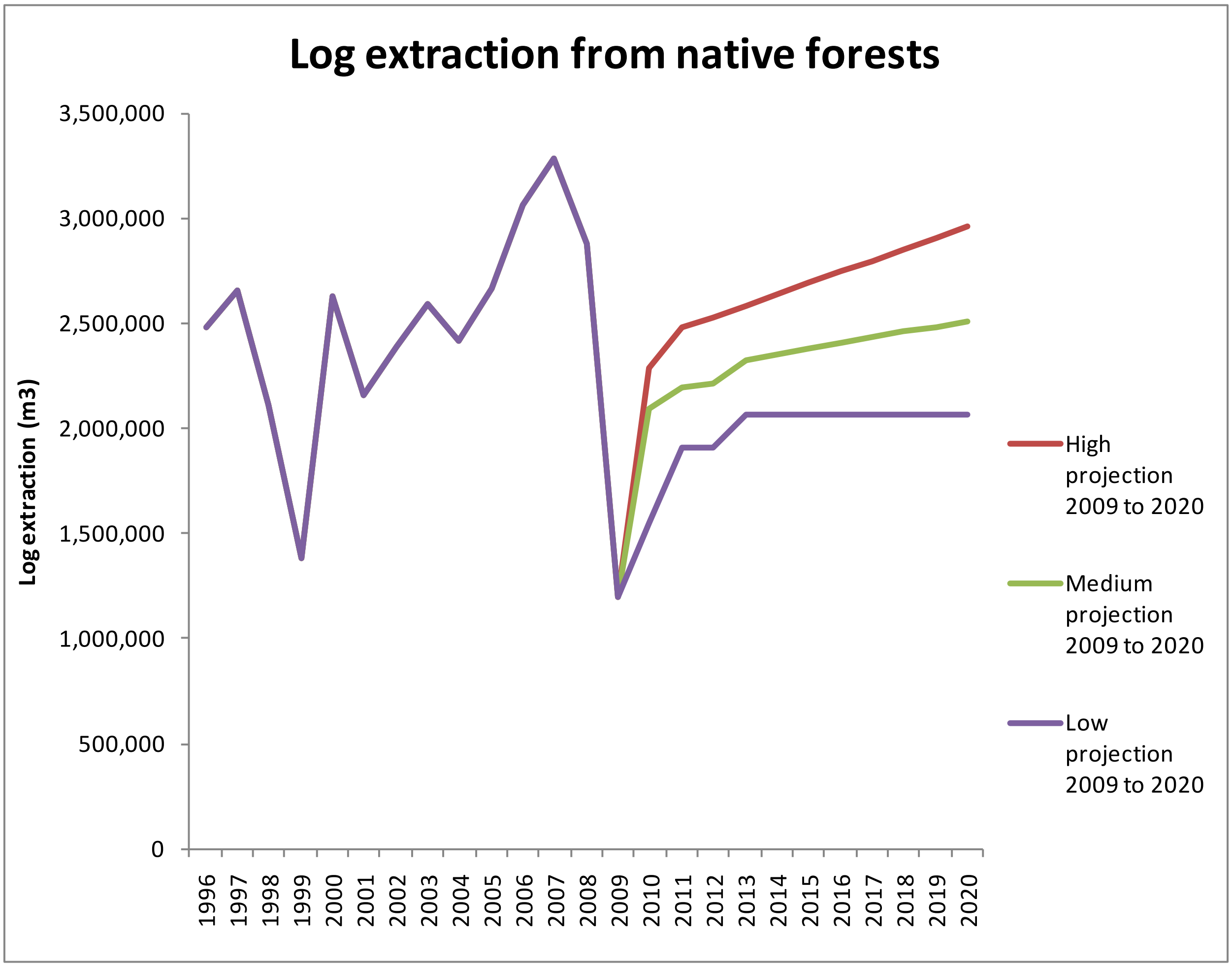
The graph of component emissions indicates the relative contributions of decomposing residue, fuel consumption, regrowth sequestration, and C storage in harvested wood products. Note that negative emission is C sequestration. It can be observed that emissions from decomposing residue is the single most important source, while regrowth sequestration is increasing as this pool accumulates. C emissions due to fuel consumption and C storage wood products are relatively insignificant.

Based on the methodology described above, the total CO_2 emissions associated with selective-harvesting can be estimated as depicted below;

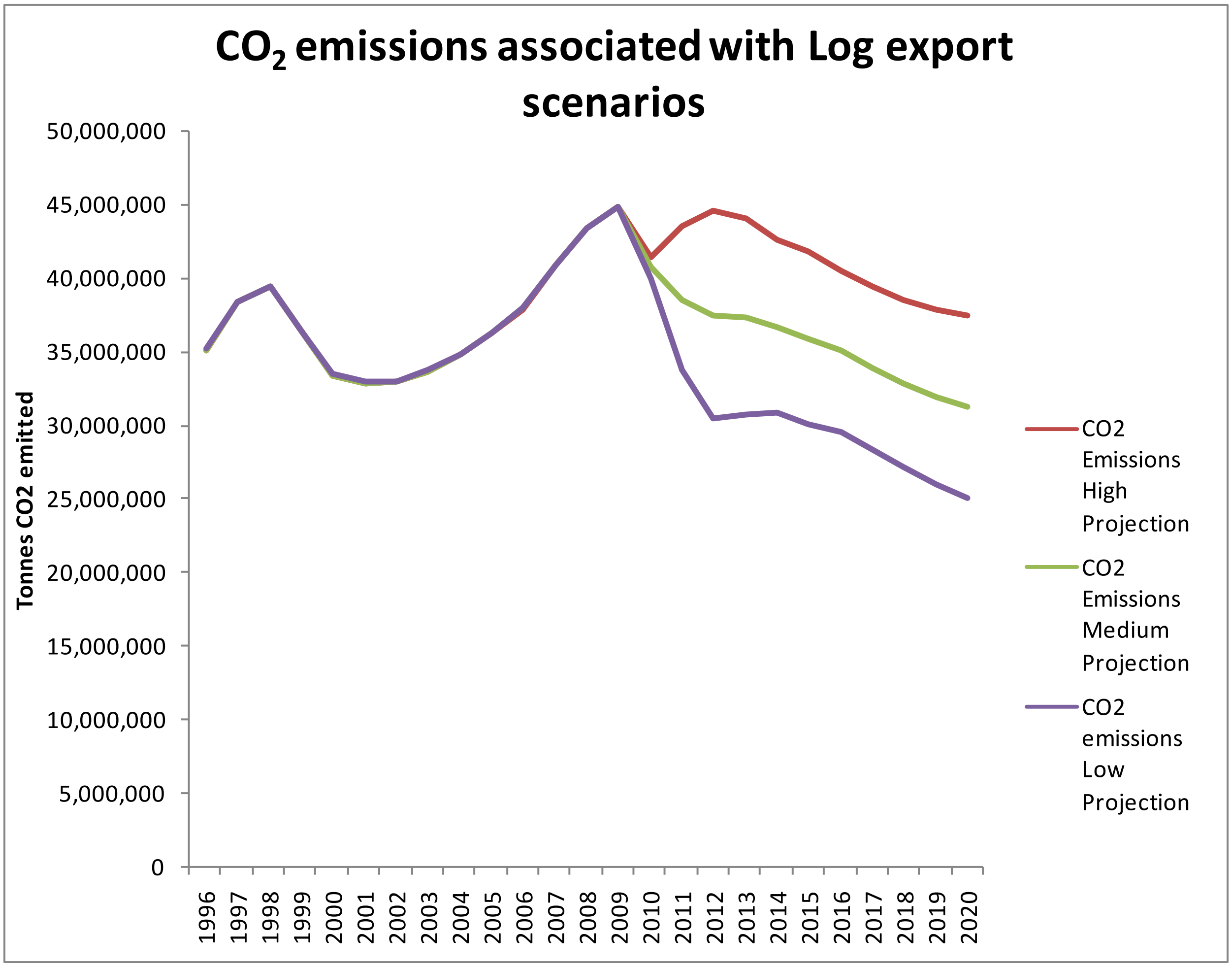


Results 1996 to 2020

The period 1996 to 2008 has been identified as a baseline period for more detailed study. Log extraction data is available for Papua New Guinea from 1996 to 2008. This has been projected from 2009 to 2020 under three scenarios; Low projected increase in exports; Medium projected increase in exports; and High projected increase in exports (Hunt 2009a). The following graph depicts Log export data under the three scenarios;



We can estimate the CO_2 emissions associated with these scenarios;



It can be noted in the graph above that emissions tend to fall away after peaking in 2014. This is because extraction rates are lower than the peak of 2006, which results in a lagged peak in emissions in 2008.

Part 2 – Emissions associated with oil palm conversion

Methodology

Emissions due to secondary forest conversion

Forest converted to oil palm is generally secondary forest that has already been subject to selective-harvesting. From Fox *et al*. (2009a, 2009b) we know the average C stock in AGLB for selectively-harvested forest in PNG; 62 tC/ha. We can also estimate the C stock in below ground live biomass (BGLB) using the IPCC (2006) ratio for belowground to aboveground biomass for lowland tropical forests of 0.37. Therefore, during the process of land conversion 85 tC/ha of living biomass will be displaced to non-living biomass which will decompose.

Contributions to the Residue (R_i) pool in year *i* can be estimated as the sum of above- and below-ground living biomass displaced in the process of land conversion (85 tC/ha) multiplied by the annual area converted in year *i* (AC_i);

$$R_i = AC_i \times 85$$

Germer and Sauerborn (2008) estimate that 40% of the biomass residue resulting from forest clearance for oil palm establishment is combusted resulting in the instantaneous release of stored C. Therefore the CO_2 emission resulting from residue combustion (RC_i) can be calculated as;

$$RC_i = 0.4 \times R_i \times [44/12]$$

60% of biomass becomes decomposing residue (DR_i). The CO_2 emissions associated with decomposition can be estimated using an exponential decay formula (Keller *et al*. 2004); as described for selective-harvesting above;

$$DR_i = 0.6 \times R_{i-1} e^{-k \times n}$$

Where *k* is 0.2 for fine debris component ($0.57 \times DR_i$) and 0.1 for the large wood component.

Emissions associated with palm oil production

Emissions associated with palm oil production in year *i* (EP_i) consist of CO_2 emissions from fuel consumption in transport and machinery (FC_i), fertilizer use (FZ_i), mill effluent (ME_i), minus C sequestered in the growing palms (S_i);

$$EP_i = FC_i + FZ_i + ME_i - S_i$$

C sequestered by oil palm and understorey plants has been found to be 35 tC/ha over a 25 year life cycle; equating to 1.4 tC/ha/yr (Germer and Sauerborn 2008, Henson 2008, Henson 2009, Roundtable on Sustainable Palm Oil 2009). Therefore the CO_2 sequestered can be calculated from the area under oil palm plantation (AOP_i);

$$S_i = AOP_i \times 1.4 \times [44/12]$$

However, the productive life cycle of oil palm results in palms being killed at approximately 25 years of age, at which point the accumulate C stock in biomass (35 tC/ha) becomes decomposing residue ($DRLC_i$; decomposing residue associated with palm oil life cycle). Based on industry advice, we assume that cleared oil palms are not combusted, but are pushed into piles of decaying residue. Therefore, every year approximately one twenty fifth of the area under oil palm plantation (AOP_i) will be killed and cleared for replanting. This contribution to decomposing residue can be calculated;

$$DRLC_i = [1/25] \times 35 \times AOP_i$$

This contribution to decomposing residue assumes that there is a uniform age structure across oil palm areas, i.e., equal proportion in each age class (1 to 25 years old). This is a simplifying assumption. Data on the age structure of oil palm in PNG could be used to improve this estimate. It is also assumed that biomass material is not combusted, but left to decompose. The decomposition rate of non-living oil palm biomass will be similar to that of the fine debris pool (see section on decomposition above), and the CO_2 emissions associated with decomposition of $DRLC_i$ can be estimated using an exponential decay formula with an exponent of 0.2 (Keller *et al*. 2004).

CO_2 emissions due to fuel consumption (FC_i), fertilizer use (FZ_i), and from mill effluent (ME_i) have been estimated as 0.3, 1.75, and 3.25 tCO_2/ha/yr (Roundtable on Sustainable Palm Oil 2009). Therefore the CO_2 emissions can be calculated from the area under oil palm (AOP_i);

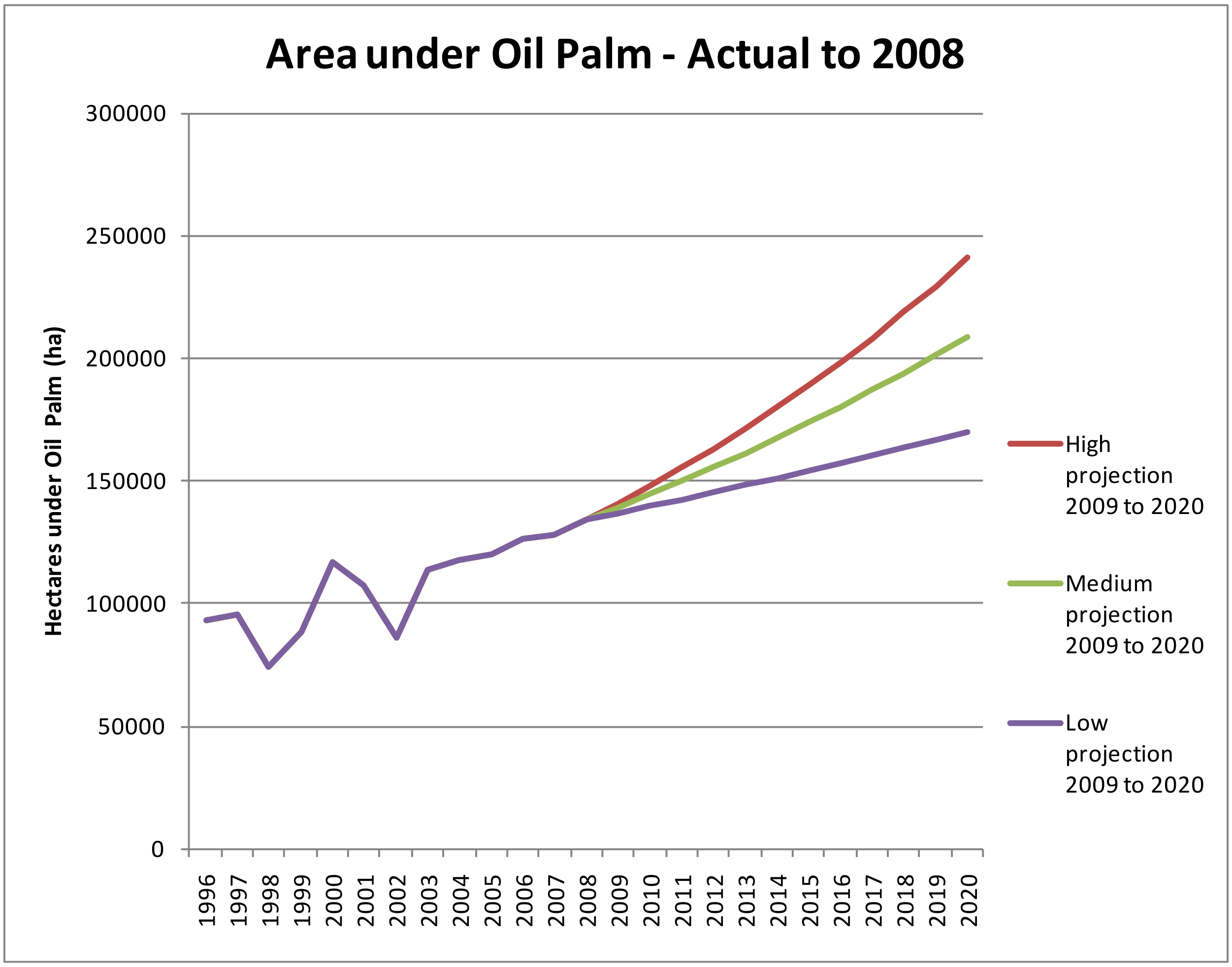
$$FC_i = AOP_i \times 0.3$$

$$FZ_i = AOP_i \times 1.75$$

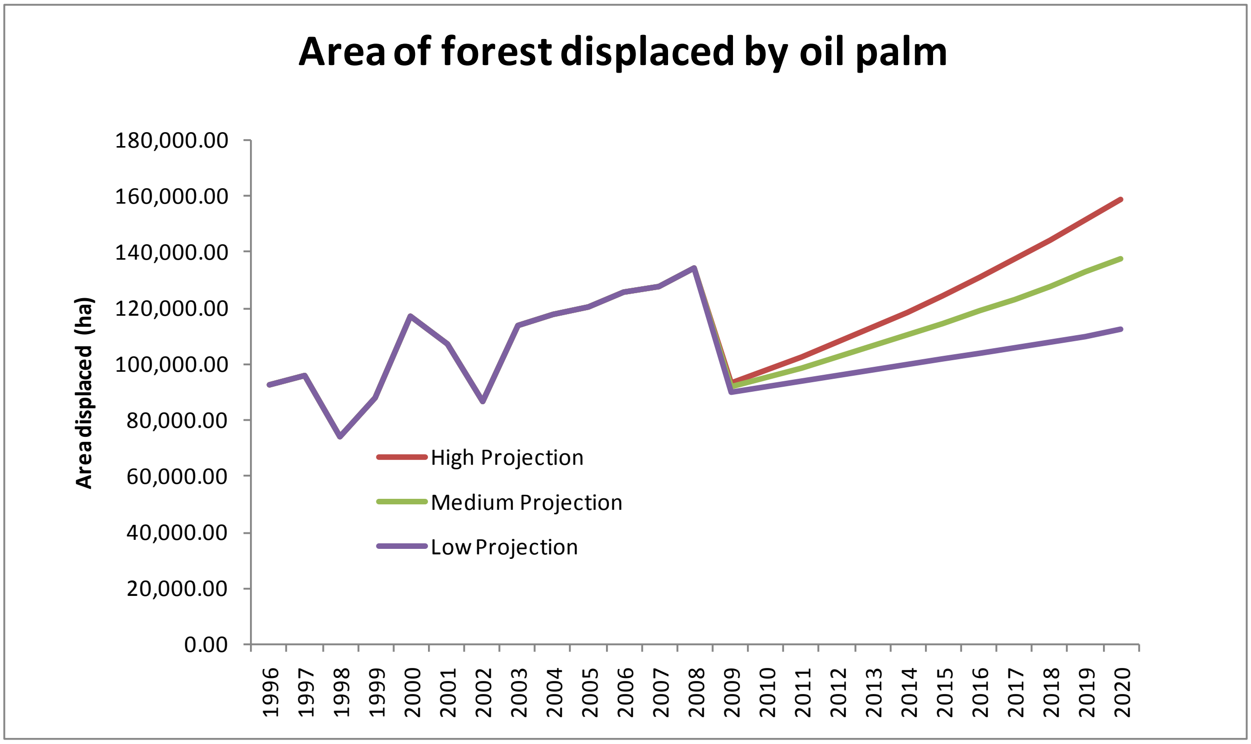
$$ME_i = AOP_i \times 3.25$$

Results

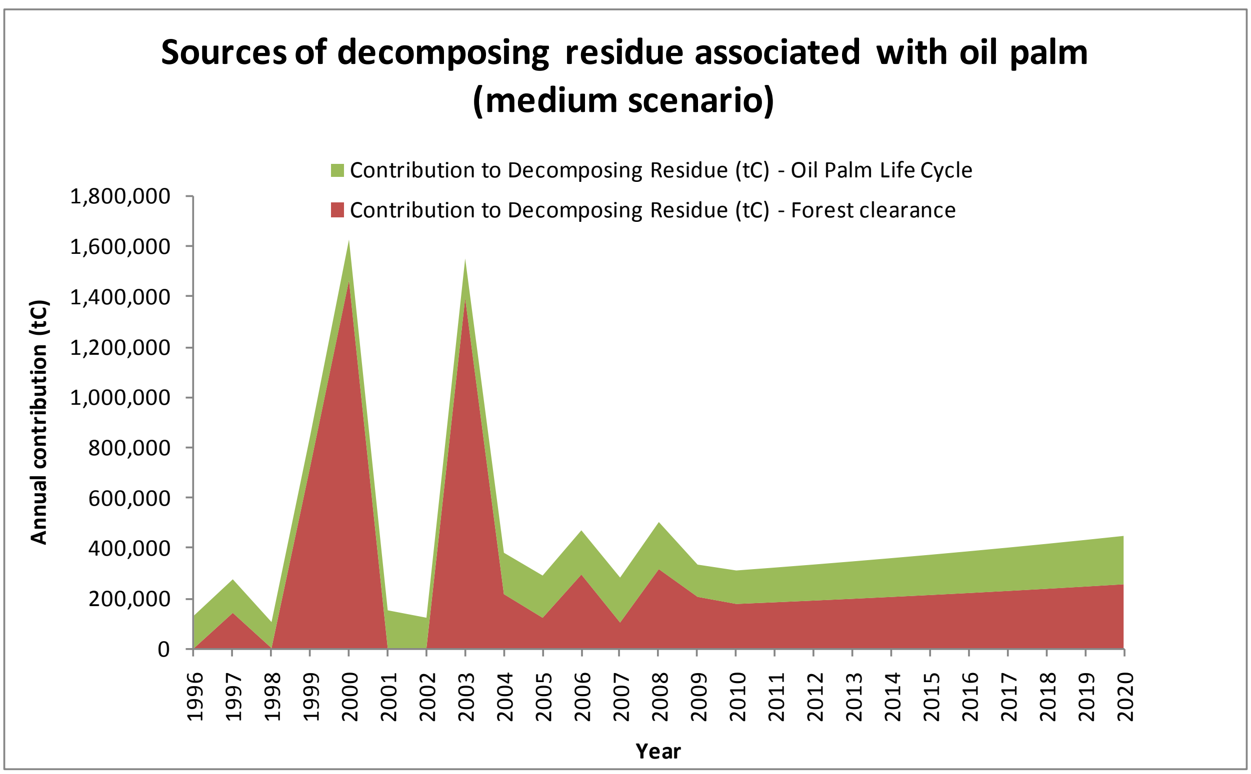
The national area of planted oil palm is available for Papua New Guinea from 1996 to 2008. This has been projected from 2009 to 2020 under three scenarios; Low projected area increase; Medium projected area increase; and High projected area increase (Hunt 2009b). The following graph depicts the total area planted to oil palm under the three scenarios;



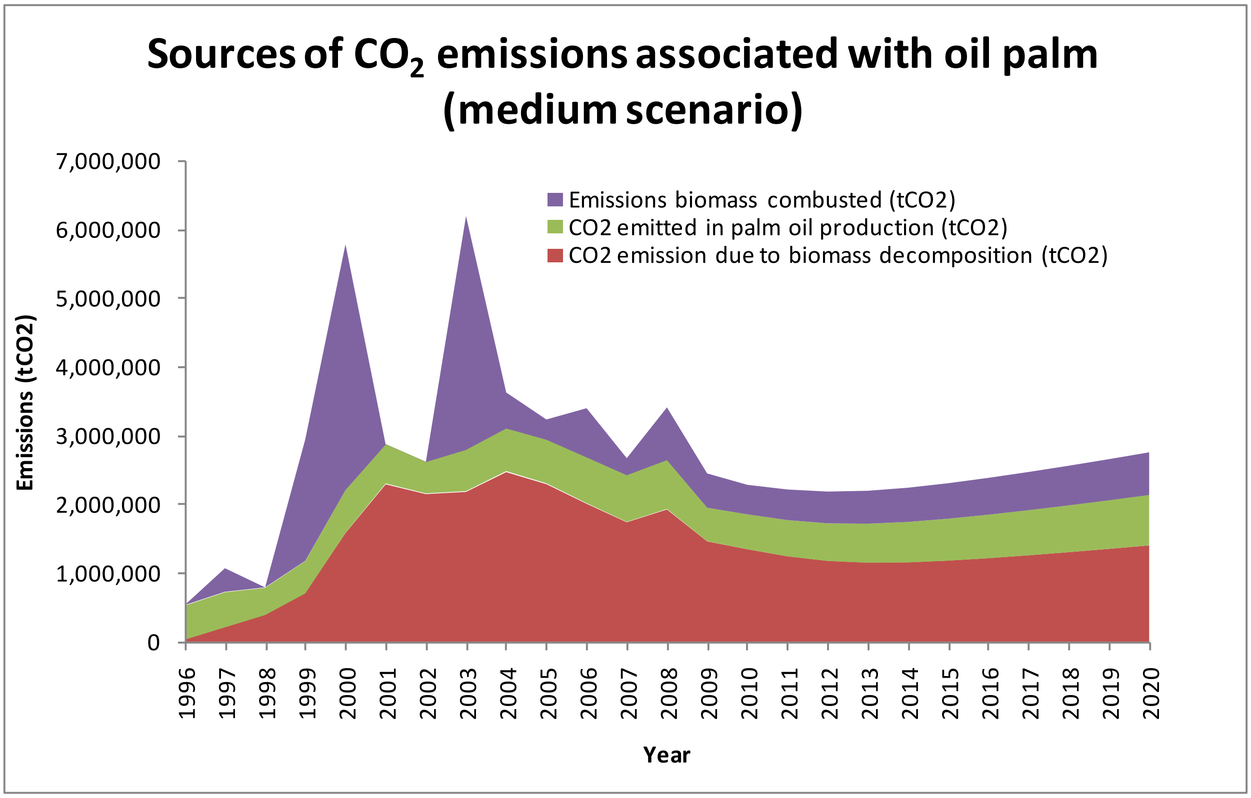
The PNG oil palm industry advises that one third of future plantings will be on grassland. Therefore the area of forest that is displaced can be estimated as;



Using the methodology described above, the C and CO_2 emission contributions from various sources can be estimated.

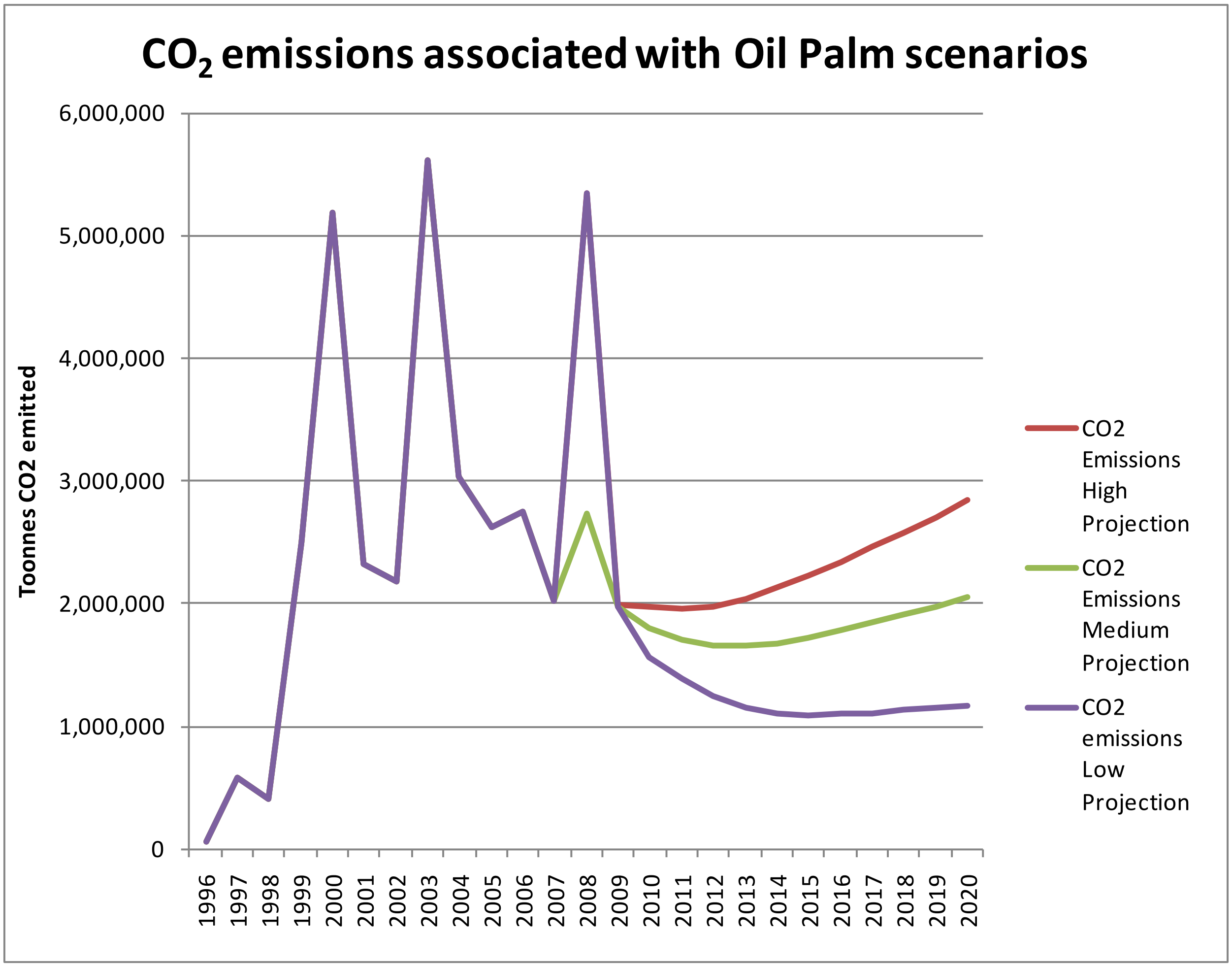


The figure above depicts the annual contribution to the pool of decomposing residue from forest clearance and from oil palm life cycle (residue resulting from oil palm clearance at 25 years of age). Clearly, forest clearance is the most important source of C emission, with emissions peaking in years of high conversion of secondary native forests.



This figure depicts contributions to emissions from biomass combustion, palm oil production, and biomass decomposition. Biomass combustion associated with forest clearance peaks in years when conversion from secondary forest to oil palm is high.

Finally, we can estimate the total CO2 emission associated with oil palm as depicted in the graph below;



The emissions drop beyond 2010 due to one third of future oil palm plantings being established on grassland.

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