GFA ENVEST

REDD+ Methodology Draft

„Estimation of carbon stock changes and greenhouse gas emissions from local people deforestation and forest degradation (REDD+)"

Version 1.0 – November 2009

I. SCOPE, APPLICABILITY AND DATA REQUIREMENT

Scope

This methodology allows the estimation of carbon stock changes and GHG emissions related to planned and unplanned deforestation and forest degradation by local people in the baseline case. It is conceived to be used as a methodology for the VCS (i.e. eligible categories "Avoided Unplanned Deforestation and Degradation (AUDD), Improved Forest Management (IFM)" and "Afforestation, Reforestation and Revegetation (ARR)"), and for other carbon crediting schemes.

In the methodology, deforestation and forest degradation are treated together using identical procedures (= anthropogenic forest disturbance AFD). This is considered necessary because in many cases it cannot be decided in the event of a forest clearing if this is a permanent land use change (i.e. deforestation), or only a temporal loss of forest cover (i.e. forest management or shifting cultivation).

The methodology does not distinguish between legal or illegal cutting because in practice the legal background of cuttings cannot be determined with reasonable efforts.

The project scope incorporates REDD+, i.e. REDD plus conservation, sustainable management of forests and enhancement of forest carbon stocks[1].

The methodology uses a dynamic baseline approach allowing for annual direct calculation of GHG emission reductions and thus avoids the use of complex hypothetical modelling.

Forest degradation is defined as any disturbance of forest lands, diminishing the aboveground living biomass. If a heavy forest degradation leads to a long-term or permanent land-use change, then it is classified as "deforestation". A long-term land use change means a conversion to a non-forest land use lasting for more than 5 years.

Applicability

The module is applicable for estimating the baseline emissions from deforestation or forest degradation in the baseline case, limited to the biomass (above ground and below ground) carbon pool. The limitation to the biomass carbon pool is for practicability reasons only and considered to be conservative. If other project proponents like to include the dead wood, litter soil carbon and wood product pools, they are invited to add these modules to the methodology.

The methodology applies to those areas, where the principal agents of forest deterioration are local people. This excludes areas where the principal agents are forest concession companies, so that the amount of carbon that ends up in long-lived wood products can then be safely ne-

[1] COP 13 Bali Action Plan (2007): A comprehensive approach to mitigate climate change should include „policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries".

glected representing decreases in carbon pools and increases in GHG emissions less than 5% of baseline emissions estimates[2].

Before being deforested or degraded in the project scenario, certain forest strata can be subject to carbon stock changes (degradation and carbon stock decrease, or growth and carbon stock enhancement).

The forest deforestation and/or forest degradation pattern can be mosaic and/or frontier[3]. Deforestation can be planned (designated and sanctioned) or unplanned (unsanctioned).

The project crediting period shall be between 20 and 100 years.

Data requirements

Data on annual deforestation and forest degradation areas, carbon stocks and carbon stock changes per stratum are required for this module.

II PROCEDURE

II.1. Carbon Pools

This methodology provides procedures to determine the following carbon pools:

Table 1. Considered carbon pools

Carbon pools	Selected (Yes or No)	Justification / Explanation of choice
Above-ground biomass	Yes	Major carbon pool. This methodology covers only tree biomass[4] over 5 cm DBH, which is conservative because small trees, shrubs and herbal biomass will decrease more or increase less under the baseline scenario.
Below-ground biomass	Yes	Important carbon pool related to the above-ground biomass pool, confined to tree biomass.
Dead wood	No	The dead wood carbon pool can be excluded because it can be conservatively assumed that the amount of dead wood in the baseline of anthropogenic forest disturbance (deforestation and forest degradation) will decrease more or increase less than the amount of dead wood in the project sce-

[2] The "Methodology for Estimating Reductions of GHG Emissions from *Frontier Deforestation*" (IDESAM / SAF 2008, p. 15) quotes an example by Figueroa et al. 2004 that even the logging in a concessions in Guatemala, removing 10 t C/ha which represents less than 10% of the standing stock finally yields only 1.4 t C/ha in wood products, the rest is short-lived waste. Figueroa, B., Kanninen, M., Louman, B., Pedroni, L., Gómez, M 2004: Contenido de corbono en los productos y residuos forestales generados por el aprovechamiento y el aserrío en la reserva de Biosfera Maya. Recoursos Naturales y Ambiente, 2004: 102-110.

[3] According to the VCS Guidance for AFOLU Projects (2008), the forest frontier configuration is defined where people and their infrastructure (roads, towns, etc.) are encroaching into areas with relatively little human activity. The forest mosaic configuration is defined where people and associated agricultural activities and infrastructure are spread out across the landscape and most forest areas within such a configured region are accessible.

[4] Tree biomass includes in this methodologies all woody perennials, e.g. trees, shrubs, palms, bamboos.

		nario of forest conservation or improved forest management.
Wood products	No	The amount of carbon in long-lived wood products can then be safely neglected representing decreases in carbon pools and increases in GHG emissions less than 5% of baseline emissions estimates.
Litter	No	The litter carbon pool can be excluded because it is conservative to assume that the amount of litter in the baseline of forest disturbance will decrease more or increase less than the amount of litter in the project scenario.
Soil organic carbon (SOC)	No	The SOC can be excluded because it is conservative to assume that the amount of SOC in the baseline of forest disturbance will decrease more or increase less than the amount of litter in the project scenario as biomass rich forests will have a higher SOC level than biomass poor forests.

It is expected that under the applicability conditions of the methodology the baseline dead wood and litter carbon pools will not show a permanent net increase and it can be conservatively assumed that their sum of changes and the changes in carbon stock in SOC is zero for all strata in the baseline scenario. In summary, only above ground and below ground biomass carbon pools are included.

II.2. Greenhouse Gas Emissions

The project activity could potentially emit the following greenhouse gases from various pools:

Table 2. Emissions sources in the project boundary

GHG pools	Gas	Selected (Yes or No)	Justification / Explanation of choice
Combustion of fossil fuels	CO_2	Excluded	It can be conservatively assumed that in the project scenario of forest protection there are much less emissions from fossil fuels than in the baseline scenario, where forests are cut with chain saws, and wood and agricultural products are transported.
	CH_4	Excluded	Same justification as above.
	N_2O	Excluded	Same justification as above.
Burning of woody biomass (i.e., excluding her-	CO_2	Excluded	However, carbon stock decreases due to burning are accounted as a carbon stock change.
	CH_4	Excluded	This GHG emitted from woody biomass burning

GHG pools	Gas	Selected (Yes or No)	Justification / Explanation of choice
baceous biomass)			can be conservatively neglected. Burning of woody biomass will only occur in the slash-and-burn shifting agriculture and pasture management. This is more frequent in the baseline and it is therefore conservative to neglect this GHG, as long as the area of fields and pasture is relatively higher in the baseline than in the project case, which shall be monitored.
	N_2O	Excluded	Potential emissions are small and are conservatively neglected.
Emission from nitrogen fertilizers	N_2O	Excluded	Direct nitrous oxide emission can occur from nitrogen fertilization, which could occur in rare cases where forests are converted to (semi-) permanent crop fields. This is more frequent in the baseline and it is therefore conservative to neglect this GHG, as long as the area of fields is relatively higher in the baseline than in the project case, which shall be monitored.

II.3. Procedural steps

The methodology includes the following steps:

STEP 1	Identification of agents, drivers, underlying causes of anthropogenic forest disturbance (AFD) and forest participants
STEP 2	Definition of the temporal and spatial boundaries (project area, leakage area and reference area) of the REDD+ project activity
STEP 3	Stratification of project area, leakage area and reference area
STEP 4	Periodic estimation of biomass strata areas in project area, leakage area and reference area
STEP 5	Estimation of mean carbon dioxide stocks in aboveground biomass and belowground biomass of each stratum
STEP 6	Estimation of the sum of carbon dioxide stock changes in project area, leakage area and reference area
STEP 7	Estimation of the sum of project, leakage and baseline GHG emissions
STEP 8	Estimation of the net anthropogenic GHG emissions reductions

STEP 1: Identification of agents, drivers, underlying causes of anthropogenic forest disturbance (AFD) and forest participants

The first step includes an area survey to identify agents, drivers and underlying causes[5] of AFD, and eventually the local people who are going to participate in the REDD+ project activity. This survey will use existing knowledge of local organizations, local leaders, and eventually lead to a household survey of the potential target group.

The information derived should give a fairly clear picture of the estate of forest resources, historic disturbance patterns, agents, drivers und underlying causes of this disturbance, and finally lead to the definition of the spatial boundaries of the project area, leakage area and reference area as described in Step 2.

The survey should at the same time inform the potential target group about the planned REDD+ project and invite expressions of interest to participate in this project.

STEP 2: Definition of the temporal and spatial boundaries of the REDD+ project activity

Project Area

The temporal boundary of the project is 20-100 years.

The project area comprises all lands on which the proponents will undertake the project activities[6],. This may lead to a mosaic of non-forest and forest plots, each of which should have an extension equal or above the forest definition of the Designated National Authority (DNA) of the CDM (see Annex 1). The borders of all project plots shall be measured in the field and/or remote sensing by adapting a polygon with all corner points registered with GPS or geo-referencing techniques.

The following project activities may be considered with the aim to provide to the proponents incentives and / or alternative land-use options so that they will refrain from further forest disturbances:

- Improved sustainable cropping (irrigation, mulching, multicropping, improved varieties, crop protection, etc.)
- Increased income through alternative on-farm activities (reforestation, agroforestry, fish farming, apiculture, etc.)
- Alternative employment (off-farm, as forest guards, ecotourism, etc.)

Leakage Area

Although a part of the project activities should be directed to avoid or mitigate possible leakage effects, it cannot be excluded that some of the anthropogenic forest disturbance (AFD) may be shifted from project areas to neighbouring lands. In this methodology all leakage areas shall be located in a circle within a radius of 5 km around the centre of the project area plots of each proponent (see Annex 1). Although some leakage plots may be established in a distance larger than 5 km, the negative leakage effects on carbon stock per hectare decrease with larger dis-

[5] Agents, driver and underlying causes are defined like in the BioCarbonFund RED-NM-001, Version 01 methodology of 15 December 2008, e.g. agents may be a farmer or local timber concessionaire, drivers may be the price of timber, the rural wage level, or the proximity to settlements, and underlying causes may be land-use policies or population pressure.

[6] This corresponds to the project area definition of both IDESAM/SAF (2008) Frontier Deforestation Methodology and Biocarbon Fund (2008) Mosaic Deforestation Methodology.

tance. Therefore it is conservative to locate leakage sample plots nearer to the project area plots.

The agents, drivers, underlying causes, dynamics and amounts of GHG emissions in the leakage area should be similar to the reference area. This should be proven through remote sensing comparing the leakage area and the reference area for the last 10 years. The total amount of leakage area GHG emissions per hectare per year should not be more than 120%, or less than 80% of the GHG emissions of the reference area over the last 10 years, and the share of none of the 6 strata defined in the following Step 3 should differ by more than 20% between leakage and reference area. This should be checked every 10 years.

Reference Area

The reference area provides the baseline information on AFD related emissions in the without-project case. The following conditions must apply:

- The reference area should be spatially distinct from the project area and from the leakage area.
- The agents, drivers, underlying causes, dynamics and amounts of AFD in the reference area should be similar to the project area. This should be proven through remote sensing comparing the reference and project areas for the last 10 years. The total amount of reference area AFD emissions per hectare per year should not be more than 120%, or less than 80% of the AFD emissions of the project area, before the project start and the share of none of the 6 strata defined in the following Step 3 should differ by more than 20% between reference and project area. The reference area should be appropriately adjusted.
- The location of the reference area should be as close to the project area as possible to ensure that agents, drivers of AFD and natural conditions of both areas are as similar as possible.
- If during the project lifetime, the reference area should experience important new development events (e.g. construction of a main road opening lands that were inaccessible so far, arrival of a mayor agricultural company, etc.) that do not apply to the project area, lands effected by such events should be excludes from the reference area. The reference area should be bigger than the project area.

STEP 3: Stratification of project area, leakage area and reference area

If not homogeneous, project, leakage and reference areas should be stratified. To allow for the inclusion of the stratified areas in the GHG emission equations, identical biomass strata should be defined for the three areas. The allocation to a stratum is considered necessary if the mean aboveground biomass stock of any spatially discrete sub-population represents ≥ 5% of the project area. Strata must be discernible by remote sensing including data processing and on the ground and allow a sufficiently precise calculation of GHG dynamic. Annual monitoring is required to identify the above-ground biomass stocks. A same plot may be classified as “strata A” in year *n* and as “strata B” in year *n+1*, due to either anthropogenic forest disturbance or forest regrowth.

Strata should regroup land-use with similar above-ground biomass stocks. The following strata should be distinguished, if present in the project, leakage or reference areas:

A) Least woody biomass areas (e.g. rivers, settlements, clearcut areas, annual crops, perennial non-woody crops, treeless pastures, young natural forest regeneration): $BS_{above\ ground}$ = 0-20% of maximum forest biomass

B) Low woody biomass areas (e.g. perennial woody crops, fruit tree plantations, agroforestry crops, palm plantations, young forest plantations, young secondary forests): $BS_{above\ ground}$ = >20-40% of maximum forest biomass

C) Medium biomass forest areas (e.g. medium aged forest plantations, medium age secondary forests, heavily exploited or disturbed primary forests, bamboo forests, palm forests): $BS_{above\ ground}$ = >40-60% of maximum forest biomass

D) High biomass forest areas (e.g. mature forest plantations, old secondary forests, primary forests on less suitable sites, medium exploited or disturbed primary forests): $BS_{above\ ground}$ = >60-80% of maximum forest biomass

E) Maximum biomass forest areas (e.g. primary forests, slightly): $BS_{above\ ground}$ = >80-100% of maximum forest biomass

In this way, each forest stratum contains only forest or landuse classes with very similar biomass stocks resulting in a single average carbon stock which keeps constant over time. Consequently, plots may belong in one year to one stratum (or several strata) and in other years to the same or another stratum, or the same or several other strata. If new significant land-use classes appear over the project time, they can be added to the strata in an equal procedure regarding project, reference and leakage areas. If new technologies should allow a higher degree of biomass distinction, more strata could be created after validation or each verification.

STEP 4: Periodic estimation of biomass strata areas in project area, leakage area and reference area

Due to the high growth dynamic in tropical lands it is mandatory to detect biomass changes annually for monitoring purpose. On the relatively large areas involved (i.e. several thousand hectares) to make REDD+ projects economically viable, only sophisticated automated analytical techniques on the basis of high spatial resolution satellite images are feasible.

Satellite data are first digitally processed, including radiometric and contrast corrections and geometric rectification. This includes, e.g. detection and removal of clouds, shadow and haze, and atmospheric correction.

An operational distinction of the electromagnetic spectra of vegetation and non-vegetation patterns reflected by the above defined 6 strata can be achieved by combing distinct bands from two satellites, e.g. the bands 4,3,2 of Landsat and CBERS satellites (i.e. infra-red in the red channel, red in the green channel. and green in the blue channel). After combining the image can be exported into TIF format and entered into a GIS software for further analysis. Here, the various land-use classes shall be assigned to the 5 biomass strata. A description of spectral mixture analysis is given in GOFC-GOLD (2008)[7].

The minimum size of all plots is defined by the national forest definition of the DNA. If such a definition has not been taken, the project proponents should chose a definition from the forest definition range cited under the CDM (0.05-1.0 ha) approved by the national ministry in charge of forests. This definition can be changed to a DNA forest definition after validation or each verification.

[7] GOFC-GOLD, 2008, Reducing greenhouse gas emissions from deforestation and degradation in developing countries: a sourcebook of methods and procedures for monitoring, measuring and reporting. GOFC-GOLD. GOFC-GOLD Project Office, Natural Resources Canada, Alberta, Canada. http://www.gofc-gold.uni-jena.de/redd/

The areas of all plots of a same stratum are measured and added separately for the project area, leakage area and reference area.

The total area of a given stratum *i* at time *t* in the project area is calculated as:

$$A_{PR,\ t,i} = \sum_{p=1}^{Pi} A_{PR,\ t,\ i,\ p} \qquad (1)$$

where:

$A_{PR,\ t,i}$	Total area of stratum *i* in year *t* in the project area; ha
$A_{PR,\ t,\ i,\ p}$	Area of plot *p* in stratum *i* and year *t* in the project area; ha
i	A, B, C, D, E, F strata, dimensionless
p	1, 2, 3, … P*i*, plots dimensionless
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

The total area of a given stratum *i* at time *t* in the leakage area is calculated as:

$$A_{LK,\ t,i} = \sum_{p=1}^{Pi} A_{BSL,\ t,\ i,\ p} \qquad (2)$$

where:

$A_{LK,\ t}$	Total area of stratum *i* in year *t* in the leakage area; ha
i	A, B, C, D, E, F strata, dimensionless
p	1, 2, 3, … P*i*, plots in stratum *i*, dimensionless
$A_{LK,\ t,\ i,\ p}$	Area of plot *p* in stratum *i* and year *t* in the leakage area; ha
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

The total area of a given stratum *i* at time *t* in the reference area is calculated as:

$$A_{BL,\ t,i} = \sum_{p=1}^{Pi} A_{BL,\ t,\ i,\ p} \qquad (3)$$

where:

$A_{BL,\ t,i}$	Total area of stratum *i* in year *t* in the reference area; ha
i	A, B, C, D, E, F strata, dimensionless
p	1, 2, 3, … P*i*, plots in stratum *i*, dimensionless
$A_{BL,\ t,\ i,\ p}$	Area of plot *p* in stratum *i* and year *t* in the reference area; ha

t	1, 2, 3,	t* years elapsed since the start of the project activity, dimensionless

STEP 5: Estimation of mean carbon dioxide stocks in aboveground biomass and belowground biomass of each stratum

Two methods to determine the aboveground carbon stock of living biomass ("trees" embracing trees, palms and eventually bamboo) are presented. If tree species specific volume tariffs are available or can be generated with sufficient precision, the first alternative should be preferred. Otherwise, the second method offers an easy applicable, robust method based on a generic IPCC allometric equation. Also, a combination of both alternative methods is possible.

As an orientation regarding sample size and allocation among strata, the tool "Calculation of the number of sample plots for measurements within A/R CDM project activities" in its latest version approved by the CDM Executive Board shall be consulted.

ALTERNATIVE 1: BCEF Method (equations 4 – 5)

In the first alternative, mean carbon stock in aboveground biomass per hectare is estimated with BCEF method (biomass conversion and expansion factor for conversion of merchantable volume to total aboveground tree biomass) based on field measurements in sample plots before the project start. This measurement may be later repeated, if the biomass stocks of any plots are in doubt. A combination with Light Detection and Ranging (LiDAR) airborne or spaceborne mapping of carbon stocks is possible.

All trees above 5 cm diameter at breast height of 1.3 m above ground level are included are measured, taking tree diameter (DBH) and tree species or tree species group in sample plots of 0.5 hectares (e.g. taxation lines of 250 m long and 20 m broad).

Then the following equations are applied:

$$V_{l,j,sp,i} = fV_j\ (DBH) \qquad (4)$$

where:

$V_{l,j,sp,i}$	Merchantable volume of tree *l* of species *j* in sample plot *sp* in stratum *i*; m³
l	1, 2, 3, … $N_{j,sp}$ sequence number of individual trees of species *j* in sample plot *sp*, dimensionless
j	1, 2, 3, …S tree species
sp	1, 2, 3, … P*i*, sample plots in *stratum i*, dimensionless
i	A, B, C, D, E, F *strata*, dimensionless
$fV_j\ (DBH)$	Allometric equation (tariffs) for species *j* linking stem diameter at breast height (*DBH*) to merchantable timber volume, m³. Tariffs should be obtained from national forestry literature, e.g. management plans of concessionaires, research papers, reports, or publications. If for certain species or species groups no tariffs are available, they should be developed by the project.

Tariffs can be developed by applying the following procedure:

Selecting randomly 20 trees distributed over the chosen diameter range of the species, or 40 trees in case of a species group. Measure stem diameter DBH (cm) and commercial height (m).

Measure mid diameter (the stem diameter at 50% of the commercial height). This can be done directly with special instruments (e.g. Vertex, Tele-Relaskop, telescopic caliper), by climbing or felling the tree.

Calculate the merchantable volume with the following equation (Huber's formula):

$$V_{l,i} = 4*10^{-4} * \pi * D_m^2 H_{com}$$

where:

$V_{l,i}$	Merchantable volume of tree *l* of species *j*, m³
π	3.1415927
D_m	Stem diameter at 0.5 * H_{com}; cm
H_{com}	Commercial tree height (= height of merchantable stem usually up to the beginning of crown branches)

Derive a tariff using the following or another general equations: $V_{l,i} = a - b * DBH_{l,i} + c * DBH_{l,i}^2$

Apply regression analysis to calculate the parameters *a*, *b*, and *c* until the best fit is reached.

For the selection of a BCEF factor in equation 5 the aboveground commercial stem volume per hectare has to be determined with the following equation:

$$V_{AB} = \sum_{j=1}^{S} \sum_{l=1}^{Nj,sp} V_{l,j,sp,} * SP_i^{-1}$$

where:

V_{ABi}	Merchantable stem volume in sample plot *sp*, m³ ha^{-1}

The mean carbon stock in aboveground biomass per hectare is estimated with the following equation:

$$C_{AB\_tree,sp,i} = \sum_{j=1}^{S} (BCEF_j * CF_j \sum_{l=1}^{Nj,sp} V_{l,j,sp,i}) * SP_i^{-1} \quad (5)$$

where:

$C_{AB\_tree,sp,i}$	Aboveground biomass carbon stock of trees in sample plot *sp*, in stratum *i*; t C ha^{-1}
$BCEF_j$	Biomass conversion and expansion factor for conversion of merchantable volume to total aboveground tree biomass for tree species *j*; dimensionless. Default values from IPCC (2006) AFOLU Guidelines for National GHG Inventories Table 4.5, specified for climatic zones, forest types and growing stock levels, or locally derived values.
CF_j	Carbon fraction of biomass for tree species *j*; dimensionless. IPCC default value = 0.5
$V_{l,j,sp,i,}$	Merchantable volume of tree *l* of species *j* in sample plot *sp* in stratum *i*; m^3
$SP_{,i}$	Sample plot area in stratum *i*; ha
l	1, 2, 3, … $N_{j,sp}$ sequence number of individual trees of species *j* in sample plot *sp*, dimensionless
j	1, 2, 3, …S tree species
sp	1, 2, 3, … P*i*, sample plots in *stratum i*, dimensionless
i	A, B, C, D, E, F *strata*, dimensionless

ALTERNATIVE 2: Allometric AGB estimations (equations 6 – 7)

For tropical lowland wet broadleaf forests (annual rainfall above 4,000 mm), the following allometric equation shall be used (IPCC GPG 2003, Table 4.A.1):

$$Y_{l,j,sp,i,} = 21.297 - 6.953 * (DBH) + 0.74 * (DBH)^2 \qquad (6a)$$

For tropical lowland moist broadleaf forests (annual rainfall 2,000 – 4,000 mm), the following allometric equation shall be used (IPCC GPG 2003, Table 4.A.1):

$$Y_{l,j,sp,i,} = exp[-2.289 + 2.649 * ln (DBH) - 0.021 * (ln (DBH))^2] \qquad (6b)$$

where:

$Y_{l,j,sp,i,}$	Aboveground biomass of tree *l* of species *j* in sample plot *sp* in stratum *i*; kg dry matter (DM) $tree^{-1}$
exp	Euler's number "e" (2,7182…) to the power of [ ]
ln	Natural logarithm (logarithm with basis "e")
DBH	Stem diameter at breast height of 1.3 m above ground, cm

In case where the rainfall pattern is in between wet and moist and where the second equation seems to over estimate the biomass, the more conservative equation 6a should be preferred.

Using tree aboveground biomass, the carbon stock per hectare is calculated as:

$$C_{AB\_tree,sp,i} = \sum_{j=1}^{S} (CF_j \sum_{l=1}^{Nj,p,i,t} Y_{l,j,sp,i} * 10^{-3}) * SP_i^{-1} \qquad (7)$$

where:

$C_{AB\_tree,sp,i}$	Aboveground biomass carbon stock of trees in sample plot *sp*, in stratum *i*; t C ha^{-1}
CF_j	Carbon fraction of biomass for tree species *j*; dimensionless. IPCC default value = 0.5
$Y_{l,j,sp,i,}$	Aboveground biomass of tree *l* of species *j* in sample plot *sp* in stratum *i*; kg DM $tree^{-1}$
$SP_{,i}$	Sample plot area in stratum *i*; ha
l	1, 2, 3, … $N_{j,sp}$ sequence number of individual trees of species *j* in sample plot *sp*, dimensionless
j	1, 2, 3, …S tree species
sp	1, 2, 3, … P*i*, sample plots in *stratum i*, dimensionless
i	A, B, C, D, E, F *strata*, dimensionless

The mean carbon stock in belowground biomass per hectare is estimated by using a generic allometric equation for all forest types (IPCC GPG 2003, Table 4.A.4):

$$C_{BB\_tree,sp,i} = exp\,[-1.085 + 0.9256 * ln\,(C_{AB\_tree,sp,i})] \qquad (8)$$

where:

$C_{BB\_tree,sp,i}$	Belowground biomass carbon stock of trees in sample plot *sp*, in stratum *i*; t C ha^{-1}
$C_{AB\_tree,sp,i}$	Aboveground biomass carbon stock of trees in sample plot *sp*, in stratum *i*; t C ha^{-1}
exp	Euler's number "e" (2,7182…) to the power of [ ]
ln	Natural logarithm (logarithm with basis "e")
sp	1, 2, 3, … P*i*, sample plots in *stratum i*, dimensionless
i	A, B, C, D, E, F *strata*, dimensionless

The mean aboveground carbon dioxide stock per area unit for each stratum is calculated:

$$CO_{2,AB\_tree,i} = \sum_{sp=1}^{Pi} C_{AB\_tree,sp,i} * Pi^{-1} * 44/12 \qquad (9)$$

and the mean belowground carbon dioxide stock per area unit for each stratum is calculated:

$$CO_{2,BB\_tree,i} = \sum_{sp=1}^{Pi} C_{BB\_tree,sp,i} * Pi^{-1} * 44/12 \qquad (10)$$

where:

$CO_{2,AB\_tree,i}$	Mean aboveground biomass carbon dioxide stock of trees in stratum *i*; t CO_2 ha^{-1}
$CO_{2,BB\_tree,i}$	Mean belowground biomass carbon dioxide stock of trees in stratum *i*; t CO_2 ha^{-1}
$C_{AB\_tree,sp,i}$	Aboveground biomass carbon stock of trees in sample plot *sp*, in stratum *i*; t C ha^{-1}
$C_{BB\_tree,sp,i}$	Belowground biomass carbon stock of trees in sample plot *sp*, in stratum *i*; t C ha^{-1}
Pi	Total number of sample plots in stratum *i*; dimensionless
i	A, B, C, D, E, F *strata*, dimensionless
sp	1, 2, 3, … P*i*, sample plots in *stratum i*, dimensionless
44/12	Ratio of molecular weight of CO_2 to carbon, tCO_2 t C^{-1}

STEP 6: Estimation of the sum of carbon dioxide stock changes in project area, leakage area and reference area

As each forest stratum contains only forest or landuse classes with very similar biomass stocks resulting in a single average carbon stock which keeps constant over time, the carbon dioxide stock in all carbon pools in stratum *i* is calculated:

$$CO_{2\ TOT\text{-}FOR,i} = CO_{2,AB\_tree,i} + CO_{2,BB\_tree,i} \qquad (11)$$

where:

$CO_{2\ TOT\text{-}FOR,i}$	Carbon dioxide stock in all carbon pools in stratum *i*; t CO_2 ha^{-1}
$CO_{2,AB\_tree,i}$	Mean aboveground biomass carbon dioxide stock of trees in stratum *i*; t CO_2 ha^{-1}
$CO_{2,BB\_tree,i}$	Mean belowground biomass carbon dioxide stock of trees in stratum *i*; t CO_2 ha^{-1}
i	A, B, C, D, E, F strata, dimensionless

The total carbon dioxide stock of all carbon pools and all forest strata in the **project area** is:

$$CO_{2\ TOT\text{-}FOR,\ PR,t} = \sum_{i=A}^{i=F} CO_{2\ TOT\text{-}FOR,i} * A_{PR,\ t,i} \qquad (12)$$

where:

$CO_{2\ TOT\text{-}FOR,PR,t}$	Carbon dioxide stock in the project area in year *t*; t CO_2
$CO_{2\ TOT\text{-}FOR,i}$	Carbon dioxide stock in all carbon pools in the forest stratum i; t CO_2 ha^{-1}
$A_{PR,\ t,i}$	Total area of stratum *i* in year *t* in the project area; ha
i	A, B, C, D, E, F strata, dimensionless
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

The total carbon dioxide stock of all carbon pools and all forest strata in the **leakage area** is:

$$CO_{2\ TOT\text{-}FOR,\ LK,t} = \sum_{i=A}^{i=F} CO_{2\ TOT\text{-}FOR,i} * A_{LK,\ t,i} \qquad (13)$$

where:

$CO_{2\ TOT\text{-}FOR,LK,t}$	Carbon dioxide stock in the leakage area in year *t*; t CO_2
$CO_{2\ TOT\text{-}FOR,i}$	Carbon dioxide stock in all carbon pools in the forest stratum i; t CO_2 ha^{-1}
$A_{LK,\ t,i}$	Total area of stratum *i* in year *t* in the leakage area; ha
i	A, B, C, D, E, F strata, dimensionless
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

The total carbon dioxide stock of all carbon pools and all forest strata in the **reference area** is:

$$CO_{2\ TOT\text{-}FOR,\ BL,t} = \sum_{i=A}^{i=F} CO_{2\ TOT\text{-}FOR,i} * A_{BL,\ t,i} \qquad (14)$$

where:

$CO_{2\ TOT\text{-}FOR,BL,t}$	Carbon dioxide stock in the reference area in year *t*; t CO_2
$CO_{2\ TOT\text{-}FOR,i}$	Carbon dioxide stock in all carbon pools in the forest stratum i; t CO_2 ha^{-1}
$A_{BL,\ t,i}$	Total area of stratum *i* in year *t* in the reference area; ha
i	A, B, C, D, E, F strata, dimensionless
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

STEP 7: Estimation of the sum of project, leakage and baseline GHG emissions

Carbon dioxide losses by deforestation and degradation and gains by revegetation or reforestation shall be monitored on an annual basis, due to the high dynamic of these processes. The annual carbon dioxide dynamic in the project, leakage and reference area at year *t* is calculated on a per hectare basis in order to allow the comparison between these areas of usually different sizes:

$$\Delta CO_{2PR,t} = (CO_{2\ TOT\text{-}FOR,\ PR,t=t} - CO_{2\ TOT\text{-}FOR,\ PR,t=t-1}) * A_{PR,t}^{-1} \quad (15)$$

where:

$\Delta CO_{2PR,t}$	Annual carbon dioxide stock exchanges and GHG emissions under the project scenario at year *t*; t CO_2 ha^{-1} $year^{-1}$
$CO_{2\ TOT\text{-}FOR,PR,t}$	Carbon dioxide stock in the project area in year *t*; t CO_2
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless
$A_{PR,\ t}$	Total project area in year *t* ; ha

$$\Delta CO_{2LK,t} = (CO_{2\ TOT\text{-}FOR,\ LK,t=t+1} - CO_{2\ TOT\text{-}FOR,\ LK,t=1}) * A_{LK,t}^{-1} \quad (16)$$

where:

$\Delta CO_{2LK,t}$	Annual carbon dioxide stock exchanges and GHG emissions due to leakage at year *t*; t CO_2 ha^{-1} $year^{-1}$
$CO_{2\ TOT\text{-}FOR,LK,t}$	Carbon dioxide stock in the leakage area in year *t*; t CO_2
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless
$A_{LK,\ t}$	Total leakage area in year *t* ; ha

$$\Delta CO_{2BL,t} = (CO_{2\ TOT\text{-}FOR,\ BL,t=t+1} - CO_{2\ TOT\text{-}FOR,\ BL,t=1}) * A_{BL,t}^{-1} \quad (17)$$

where:

$\Delta CO_{2BL,t}$	Annual carbon dioxide stock exchanges and GHG emissions under the baseline scenario at year *t*; t CO_2 ha^{-1} $year^{-1}$
$CO_{2TOT\text{-}FOR,BL,t}$	Carbon dioxide stock in the reference area in year *t*; t CO_2
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

$A_{BL,t}$ Total reference area in year t ; ha

STEP 8: Estimation of the net anthropogenic GHG emission reductions

The annual net anthropogenic GHG emissions reductions are calculated as follows:

$$\Delta CO_{2REDD+,t} = [\Delta CO_{2BL,t} - \Delta CO_{2PR,t} - (\Delta CO_{2LK,t} - \Delta CO_{2BL,t})] * A_{PR,t} \quad (18)$$

and the net anthropogenic GHG emissions reductions over the project period are given by:

$$CO_{2REDD+} = \sum_{t=1}^{t*} \Delta CO_{2REDD+,t} \quad (19)$$

where:

$\Delta CO_{2REDD+,t}$	Annual net anthropogenic greenhouse gas emissions reductions of the REDD+ project activity at t year t; t CO_2 $year^{-1}$
CO_{2REDD+}	Net anthropogenic greenhouse gas emissions reductions of the REDD+ project activity over the project period of t* years; t CO_2 $year^{-1}$
$\Delta CO_{2BL,t}$	Sum of the carbon dioxide stock exchanges and GHG emissions under the baseline scenario at year t; t CO_2 ha^{-1} $year^{-1}$
$\Delta CO_{2PR,t}$	Sum of the carbon dioxide stock exchanges and GHG emissions under the project scenario at year t; t CO_2 ha^{-1} $year^{-1}$
$\Delta CO_{2LK,t}$	Sum of the carbon dioxide stock exchanges and GHG emissions due to leakage at year t; t CO_2 ha^{-1} $year^{-1}$
$A_{PR,t}$	Total project area in year t; ha
t	1, 2, 3, t* years elapsed since the start of the project activity, dimensionless

II.4. Data and Parameters not monitored (default or measured one time)

Data / Parameter:	$fV_j\ (DBH)$
Data unit:	m^3
Used in equation:	4
Description:	Allometric equation (tariffs) for species *j* linking stem diameter at breast height (*DBH*) to merchantable timber volume
Source of data used:	National forestry literature, e.g. management plans of concessionaires, research papers, reports, or publications. If for certain species or species groups no tariffs are available, they should be developed by the project.
Value applied:	Various
Justification of the choice of	If necessary, measurement of mid diameter of randomly se-

data or description of measurement methods and procedures actually applied :	lected trees of species or species groups and linking volumes with DBH via regression analysis.
Any comment:	none

Data / Parameter:	$BCEF_j$
Data unit:	dimensionless
Used in equation:	5
Description:	Biomass conversion and expansion factor for conversion of merchantable volume to total aboveground tree biomass for tree species *j*
Source of data used:	Default values from IPCC (2006) AFOLU Guidelines for National GHG Inventories Table 4.5, specified for climatic zones, forest types and growing stock levels, or locally derived values.
Value applied:	various
Justification of the choice of data or description of measurement methods and procedures actually applied :	Values have to be selected from the above mentioned Table according to the forest type and growing stock volume (range <10->200 m^3/ha).
Any comment:	none

Data / Parameter:	CF_j
Data unit:	dimensionless
Used in equation:	5
Description:	Carbon fraction of biomass for tree species *j*;
Source of data used:	IPCC default value
Value applied:	0.5
Justification of the choice of data or description of measurement methods and procedures actually applied :	Standard
Any comment:	none

Data / Parameter:	SP_i
Data unit:	ha
Used in equation:	5
Description:	Sample plot area in stratum *i*
Source of data used:	Area defined for sampling
Value applied:	0.5
Justification of the choice of data or description of measurement methods and procedures actually applied :	Standard size for sampling plots in natural forests
Any comment:	none

III MONITORING METHODOLOGY

III.1. Monitoring of project implementation

Project implementation involves many activities which should be planned and monitored with provisions for quality assurance (QA) and quality control (QC) via a QA/QC plan. A part from administrative activities, there are project activities supporting the participants in their effort to reduce forest deterioration. Such project activities could include the intensification of agricultural crops, pastures or animal keeping, lengthen of fallow periods, agroforestry practices, establishment of fast-growing trees, improved forest management, sustainable production of non-wood forest products, ecotourism or alternative jobs in town.

The following information will be retrieved and kept in electronic and printed documents:

1) List of project participants with exact location of plots, type of initial forest, land-use strata in each year of project activity.
2) List of contracts with each participant regulating the carbon rights, mutual obligations and benefits received from the project.
3) List of project activities with description of measures, quantities, times and project participants profiting from such activities. These measures should have a clear link to diminishing or avoiding biomass reductions from deforestation or degradation of forests.
4) Annual satellite image analysis of all plots composing the project area, the leakage area and the reference area.
5) Cost-benefit analysis of supported project activities.
6) Calculation of carbon credits generated by the project activity.

III.2. Stratification and sampling design

Stratification

Before starting the project, the project area, reference area and project area will be defined, by areas with a land-use pattern and land-use dynamic not significantly different from each other. In these areas land-use classes will be grouped into 6 strata according to their aboveground biomass (in terms of dry matter) per hectare equivalent to their aboveground carbon stocks. Each stratum extends over 20% of a maximum biomass per hectare, except the first which groups all land-use classes with no or insignificant biomass. Details on the strata and landuse classes are given in Step 3 of chapter II.3.

Sampling design

With satellite images analysis the forest carbon changes caused by deforestation, degradation or revegetation can be monitored, if aboveground carbon stocks (ACS) have been previously assessed (see chapter II.3 Step 5).

For monitoring of REDD+ projects with areas of several thousand hectares, airborne Light Detection and Ranging (LiDAR) should be used for ACS estimation, i.g. the biomass strata detection. LiDAR allows a stratified sampling of the three dimensional structure of the forest canopy and data conversion to ACS. Then only a limited number of field plots is needed to calibrate and validate the LiDAR, i.e. relate the airborne tree height and canopy profile information to field-based estimates of aboveground biomass and ACS. The number of sample plots per land-use class is defined by the heterogeneity of ACS inside the land-use class and the targeted precision level. The targeted precision level for biomass estimation within each stratum is ± 10% of the mean at a 90% confidence level.

The project area shall be monitored entirely (100%) with remote sensing (see Annex 1).

The leakage area is much bigger than the project area, defined by a circle of 5 km around each project proponent area. Remote sensing monitoring of the leakage area can be confined to leakage area sample plots (see Annex 1). Four sample square plots of 1 km² each shall be located systematically in different distances from the centre of the each leakage circle area along a north-south line and an east-west line. E.g. the centres of the square plots could be located at 4.5 km (north), 3.5 km (east), 2.5 km (south), and 1.5 km (west) from the square plots. The centre of the leakage circles is defined by drawing a north-south and east west oriented rectangle around each project proponent area.

Remote sensing monitoring of the reference area can be confined to reference area sample plots (see Annex 1). To avoid a subjective choice of sample plot locations, the sample square plots of 1 km² each shall be located systematically in a grid with equal distance between the plots with a random start in the north-east corner of the leakage area. The number of sample plots – the sample size – is determined by the homogeneity of the area regarding biomass strata distribution (10% sampling error at 90% confidence level).

III.3. Data and parameters monitored

The following parameters should be monitored during the project activity. When relevant equations are applied for *ex ante* calculation of net anthropogenic GHG reductions, project proponents shall provide transparent estimations for the parameters that are later on monitored during the project crediting period.

Data / Parameter:	$A_{PR,\,t,\,i,\,p}$
Data unit:	ha
Used in equation:	1
Description:	Area of plot *p* in stratum *i* and year *t* in the project area
Source of data used:	Satellite images combination, e.g. bands 4,3,2 of Landsat and CBERS
Justification of the choice of data or description of measurement methods and procedures actually applied :	Analysis of satellite images with specific software, allowing to distinguish the 6 carbon strata
Any comment:	This distinction of carbon strata will improve with further development of technique and software

Data / Parameter:	$A_{LK,\,t,\,i,\,p}$
Data unit:	ha
Used in equation:	2
Description:	Area of plot *p* in stratum *i* and year *t* in the leakage area; ha
Source of data used:	Satellite images combination, e.g. bands 4,3,2 of Landsat and CBERS
Justification of the choice of data or description of measurement methods and procedures actually applied :	Analysis of satellite images with specific software, allowing to distinguish the 6 carbon strata
Any comment:	This distinction of carbon strata will improve with further development of technique and software

Data / Parameter:	$A_{BL, t, i, p}$
Data unit:	ha
Used in equation:	3
Description:	Area of plot *p* in stratum *i* and year *t* in the reference area
Source of data used:	Satellite images combination, e.g. bands 4,3,2 of Landsat and CBERS
Justification of the choice of data or description of measurement methods and procedures actually applied :	Analysis of satellite images with specific software, allowing to distinguish the 6 carbon strata
Any comment:	This distinction of carbon strata will improve with further development of technique and software

Data / Parameter:	*DBH*
Data unit:	cm
Used in equation:	4, 6
Description:	Stem diameter at breast height of 1.3 m above ground level
Source of data used:	Measurement in sample plots
Justification of the choice of data or description of measurement methods and procedures actually applied :	All trees above 5 cm diameter at breast height are measured, taking tree diameter (DBH) and tree species or tree species group in sample plots of 0.5 hectares (e.g. taxation lines of 250 m long and 20 m broad)
Any comment:	Increase number of sample plots until the biomass of each pixel class can be determined with an acceptable error margin

Data / Parameter:	D_m
Data unit:	cm
Used in equation:	Tariff calculation after equation 4
Description:	Stem diameter at 0.5 * H_{com}
Source of data used:	Measurement in sub-sample plots
Justification of the choice of data or description of measurement methods and procedures actually applied :	Selecting randomly 10 trees distributed over the diameter range of the species, or 20 trees in case of a species group
Any comment:	Only necessary if no tariff is available for a given species or species group

Data / Parameter:	H_{com}
Data unit:	m
Used in equation:	Tariff calculation after equation 4
Description:	Merchantable volume of tree *l* of species *j*
Source of data used:	Measurement in sub-sample plots
Justification of the choice of data or description of measurement methods and procedures actually applied :	Selecting randomly 10 trees distributed over the diameter range of the species, or 20 trees in case of a species group
Any comment:	Only necessary if no tariff is available for a given species or

	species group

Data / Parameter:	$V_{l,j,sp,i}$
Data unit:	m³
Used in equation:	4
Description:	Merchantable volume of tree *l* of species *j* in sample plot *sp* in stratum *i*
Source of data used:	Stem diameters at breast height (DBH) and specific tariffs from reliable sources or own elaborations
Justification of the choice of data or description of measurement methods and procedures actually applied :	DBH of species or species group *j* measured in sample plot *sp* of stratum *i* and linked with species or species group / stratum specific allometric equations (tariffs)
Any comment:	none

Data / Parameter:	$Y_{l,j,sp,i,}$
Data unit:	kg dry matter $tree^{-1}$
Used in equation:	6, 7
Description:	Aboveground biomass of tree *l* of species *j* in sample plot *sp* in stratum *i*; kg DM $tree^{-1}$
Source of data used:	Calculated
Justification of the choice of data or description of measurement methods and procedures actually applied :	This equation is based on a sample of 226 trees of a DBH range of 5-148 cm, giving a very high correlation coefficient of R^2 = 0.98
Any comment:	none

Data / Parameter:	*Pi*
Data unit:	dimensionless
Used in equation:	9, 10
Description:	Total number of sample plots in stratum *i*
Source of data used:	Taken from measurement protocol
Justification of the choice of data or description of measurement methods and procedures actually applied :	Number of sample plots depending on acceptable error margin of biomass of each pixel class
Any comment:	none

III.4. Uncertainties and conservative project approach

a) Conceptual approach to reduce uncertainties

This methodology combines several conservative approaches in order to reduce uncertainty:

1. For emission reductions, only the biomass carbon pool is included. Dead wood, litter and soil carbon pools are conservatively disregarded, although it is evident that these carbon

pools are decreased in the medium and long term by forest disturbance compared to protected forest of the project case.

2. Apart from CO_2 emissions resulting from forest stock decreases, no other GHG emissions are included. This is conservative because emissions from fertilization and combustion of fossil fuels are clearly much higher in the baseline case, where shifting agriculture or logging operations with connected forest road construction will emit more carbon dioxide and other GHG than any low-level conservation management of the forest combined with improvement of existing agricultural systems (project case).

Depending on the quality of satellite images changes in forest biomass can be estimated with more or less precision. Therefore, low resolution satellite images could cause uncertainties in the actual forest biomass which should be avoided.

b) Conservative approach on data collection

From various experiences the uncertainty in stand-level biomass assessments derived from stem volumes is estimated to range from 12% up to 50% and the uncertainty of conversion of airborne LiDAR canopy structure data to aboveground biomass stocks ranges between 8-25% in tropical and 10-15% in temperate and boreal forests[8]. Standard Operating Procedures (SOP) should be developed for each step of the field measurements, data elaboration and verification as outlined in IPCC 2003 GPG (chapter 4.3.4).

To reduce uncertainties in accounting of emissions and removals, this methodology uses whenever possible the proven methods from the GPG-LULUCF, GPG-2000, and the IPCC's Revised 2006 Guidelines. Tools and guidance from the CDM Executive Board on conservative estimation of emissions and removals are also used as well. Despite this, potential uncertainties still arise from the choice of parameters. For example, the use of biomass conversion and expansion factors (*BCEFs*) or wood densities could result in uncertainties in the estimation of both baseline net GHG removals by sinks and the actual net GHG removals by sinks as global default values are used.

It is recommended that project participants identify key parameters that would significantly influence the accuracy of estimates. Local values that are specific to the project circumstances should then be obtained for these key parameters, whenever possible. These values should be based on:

- Data from well-referenced peer-reviewed literature or other well-established published sources[9] or
- National inventory data or default data from IPCC literature that has, whenever possible and necessary, been checked for consistency against available local data specific to the project circumstances; or
- In the absence of the above sources of information, expert opinion may be used to assist with data selection. Experts will often provide a range of data, as well as a most probable value for the data. The rationale for selecting a particular data value should be briefly noted in the project document. For any data provided by experts, the project document shall also record the experts name, affiliation, and principal qualification as an expert (e.g., that they are a member of a country's national forest inventory technical ad-

[8] Asner, G.P. 2009: Tropical forest carbon assessment: integrating satellite and airborne mapping approaches. Environ. Res. Lett. 4 (2009) 034009, 11 pp.

[9] Typically, citations for sources of data used should include: the report or paper title, publisher, page numbers, publication date etc (or a detailed web address). If web-based reports are cited, hardcopies should be included as Annexes in the JI-FM-PDD if there is any likelihood such reports may not be permanently available.

visory group)—plus inclusion of a 1-page summary CV for each expert consulted, included in an annex.

In choosing key parameters or making important assumptions based on information that is not specific to the project circumstances, e.g. in case of default data, project participants should select values that will lead to a conservative estimation of net GHG removals by sinks, i.e. data that tends to under-estimate, rather than over-estimate, net GHG removals by sinks. E.g. regarding the estimation of preservation factors the technical staff should in case of doubts always select the lower of two values.

The conservative application of all parameters and methods and due provisions to deal with uncertainties shall be documented in the quality assurance (QA) and quality control (QC) plan (ref. IPCC 2003 GPG, chapter 4.3.4).

Annex 1: Definition and measuring of Project Area, Reference Area and Leakage Area