

Methodology for Estimating Reductions of Greenhouse Gases Emissions from *Frontier Deforestation*

This document was prepared when detailed political and regulatory guidance on accounting rules for RED project activities was not yet available. The document is thus a living proposal that will be further adapted and improved with evolving political decisions, scientific literature and field experience. Comments and feedbacks from the broader user community are warmly welcomed and can be addressed to the leading author of this methodology (lpedroni@carbondecisions.com).

Manaus, 28 November 2008

Proposed
Methodology for Estimating Reductions of GHG Emissions from *Frontier Deforestation*
RED-NM-002

Source

This methodology is based on the draft RED-PDD for the “Reserva do Juma Conservation Project” in Amazonas (Brazil), whose *baseline* study, monitoring and project design documents were prepared by IDESAM, the Amazonas Sustainable Foundation (FAS) and the Government of Amazonas (SDS/SEPLAN-AM), with inputs and review from a selected group of experts and scientists in Brazil. The methodology is an adaptation to “*Frontier Deforestation*” of the methodology for “*Mosaic Deforestation*” developed by the BioCarbon Fund.

Scope

The methodology is for estimating and monitoring greenhouse gas (GHG) emissions of *project activities* that reduce *frontier deforestation*. It includes methods to estimate *carbon stock* enhancement of *degraded* and *secondary forests* that would be deforested in the absence of the RED *project activity*. However, accounting for *carbon stock* enhancement is optional in this methodology.

Conceptual approach

The underlying conceptual approach of this methodology is based on drafts of the AFOLU Guidance Document of the Voluntary Carbon Standard¹ as available at the time of writing. According to these drafts, *deforestation* is either *planned* or *unplanned* and it occurs under different *forest* landscape configurations termed as *mosaic* or *frontier*.

Mosaic deforestation is where human population and associated agricultural activities and infrastructure (roads, towns, etc.) are spread out across the landscape and most areas of *forest* within such a configured region are practically accessible. *Mosaic deforestation* usually shows a patchy pattern of *forest* clearings and is associated to population pressure, shortened shifting cultivation cycles and other drivers.

Frontier deforestation is where humans and their infrastructure are encroaching into areas with relatively little preexisting human activity. It is often linked to infrastructure development and it happens where poor legislation enforcement, prices for agricultural commodities, speculation for land titling and other drivers provide incentives to farmers and ranchers to clear the *forest* as it becomes more accessible.

Planned deforestation can encompass a wide variety of activities such as: national resettlement programs from non-forested to forested regions; a component of a national land

¹ www.v-c-s.org

plan to reduce the *forest* estate and convert it to industrial-scale production of commodities or, plans to convert well-managed community-owned *forests* to other non-*forest* uses. Other forms of *planned deforestation* could include decisions by individual landowners or community groups whose land is legally zoned for agriculture, to convert their *forest* to crop production.

Different methodologies are needed for these distinct types of *deforestation*, and simplified methodologies could be considered for small-scale *deforestation*.

Where different types of *deforestation* exist within a *project area*, strata should be defined according to each type, and different methodologies applied to each stratum.

All terms in *italics* are defined in Appendix 1.

Acknowledgements

Idesam and FAS acknowledge the leading author of this methodology, Mr. Lucio Pedroni, and the BioCarbon Fund for publishing the methodology for “*mosaic deforestation*” which greatly facilitated the development of this methodology.

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SUMMARY

This methodology is for *project activities* that reduce emissions of greenhouse gases (GHG) from *frontier deforestation*². Where *carbon stock* enhancement in degraded and secondary *forests* that would be deforested in the absence of the RED *project activity* is important, methods are given to estimate them, but accounting for *carbon stock* enhancement is optional and can conservatively be omitted.

The methodology is applicable under the following conditions:

- a) *Deforestation* is linked to infrastructure development, which makes the *forest* accessible to *deforestation* agents.
- b) *Baseline* activities that may be displaced include fuel-wood collection, charcoal production, and agricultural and grazing activities.
- c) The *project area* can include different types of *forest*, such as old-growth *forest*, degraded *forest*, secondary *forests*, planted *forests* and agro-forestry systems meeting the definition of “*forest*”.
- d) The *project activity* does not change the groundwater table compared to the *baseline*.
- e) At project commencement, all lands within the *project area* meet the criteria for definition as *forest*.

The methodology defines two analytical domains from which information on historical *deforestation* is extracted and projected into the future: a broader *reference region* and the *project area*. Using a spatially explicit model, the methodology estimates how much *deforestation* is expected to occur under the *baseline scenario* and where it is most likely to happen.

The *baseline* projections of the *reference region* and *project area* are revisited after each *crediting period* and adjusted, as necessary, based on land-use and land-cover changes observed during the past period, updated information on agents, drivers and underlying causes of *deforestation* and new data on all variables included in the model.

Emissions of non-CO₂ gases in the *baseline* are conservatively omitted, except CH₄ and N₂O emissions from biomass burning, which can be counted when *fire* is the main technology used to deforest and when the project proponent considers that ignoring this source of emission would substantially underestimate *baseline* GHG emissions.

Two sources of potential *leakage* are considered in the methodology: displacement of *baseline deforestation* from inside the *project area* to outside, and increase of GHG emissions associated to *leakage* prevention measures.

² These activities are not eligible to the Clean Development Mechanism during the first commitment period (2008-2012). However, in December 2007, the thirteenth Conference of the Parties to the United Nations Framework Convention on Climate Change² encouraged the undertaking and reporting of such activities. Depending on the outcome of the ongoing political negotiations, RED project activities may, or may not, become eligible for carbon credits for the post-2012 period.

Leakage prevention measures such as tree planting, agricultural intensification, fertilization, fodder production and/or other measures to enhance cropland and grazing land areas can cause an increase in GHG emissions associated with these activities. If the estimated increase is significant, it is monitored and subtracted from the project's net emissions reductions.

If the RED *project activity* causes a displacement of *baseline* activities implemented by local communities and individuals to outside the *project area* and the displacement causes a significant decrease in *carbon stocks*, the decrease is measured and subtracted from the project's net emissions reductions. However, where the RED *project activity* causes a displacement of *baseline* activities implemented by immigrant *deforestation* agents, the displacement is considered as non-measurable in this methodology. Three options are given to address this type of activity displacement and associated increase in GHG emissions:

- (1) *Leakage* is assumed to be the difference between actual emission reductions and their net present value for climate change mitigation. The net present value is calculated based on the assumption that the *project activity* will not reduce the overall *deforestation* rate, but the total area of unprotected *forest*, which will anticipate the time point when *deforestation* will stop.
- (2) *Leakage* is accounted as an emission of a broader RED program that is monitoring *deforestation* outside the *project area*. *Leakage* must not be accounted under this option, but the project proponent must demonstrate that such a broader program actually exists and that any increase in GHG emission from *deforestation* associated to activity displacement from the *project area* will be detected by monitoring and included in GHG accounting of the broader RED program.
- (3) The risk of displacement of *baseline* activities is assessed and, based on the level of risk determined, a percentage of the credits issued for the net anthropogenic GHG emission reductions (calculated without *leakage* due to activity displacement) is earmarked and excluded from trade. Earmarked credits can be released for trade if option 2 is adopted in a future period.

METHODOLOGY DESCRIPTION

Part 1 - Applicability conditions and additionality

1 Applicability conditions

This methodology is applicable to *project activities* that reduce greenhouse gas (GHG) emission from *frontier deforestation*. Where *carbon stock* enhancement in degraded and secondary *forests* that would be deforested in the absence of the RED *project activity* is important, methods are given to estimate them, but accounting for *carbon stock* enhancement is optional and can conservatively be omitted.

The methodology is applicable under the following conditions:

- a) *Deforestation* is linked to infrastructure development, which makes the *forest* accessible to *deforestation* agents.
- b) *Baseline* activities that may be displaced include fuel-wood collection, charcoal production, and agricultural and grazing activities.
- c) The *project area* can include different types of *forest*, such as old-growth *forest*, degraded *forest*, secondary *forests*, planted *forests* and agro-forestry systems meeting the definition of “*forest*”.
- d) The *project activity* does not change the groundwater table compared to the *baseline*.
- e) At project commencement, all lands within the *project area* meet the criteria for definition as *forest*.

Demonstrate that the methodology is applicable to the proposed RED *project activity*.

2 Additionality

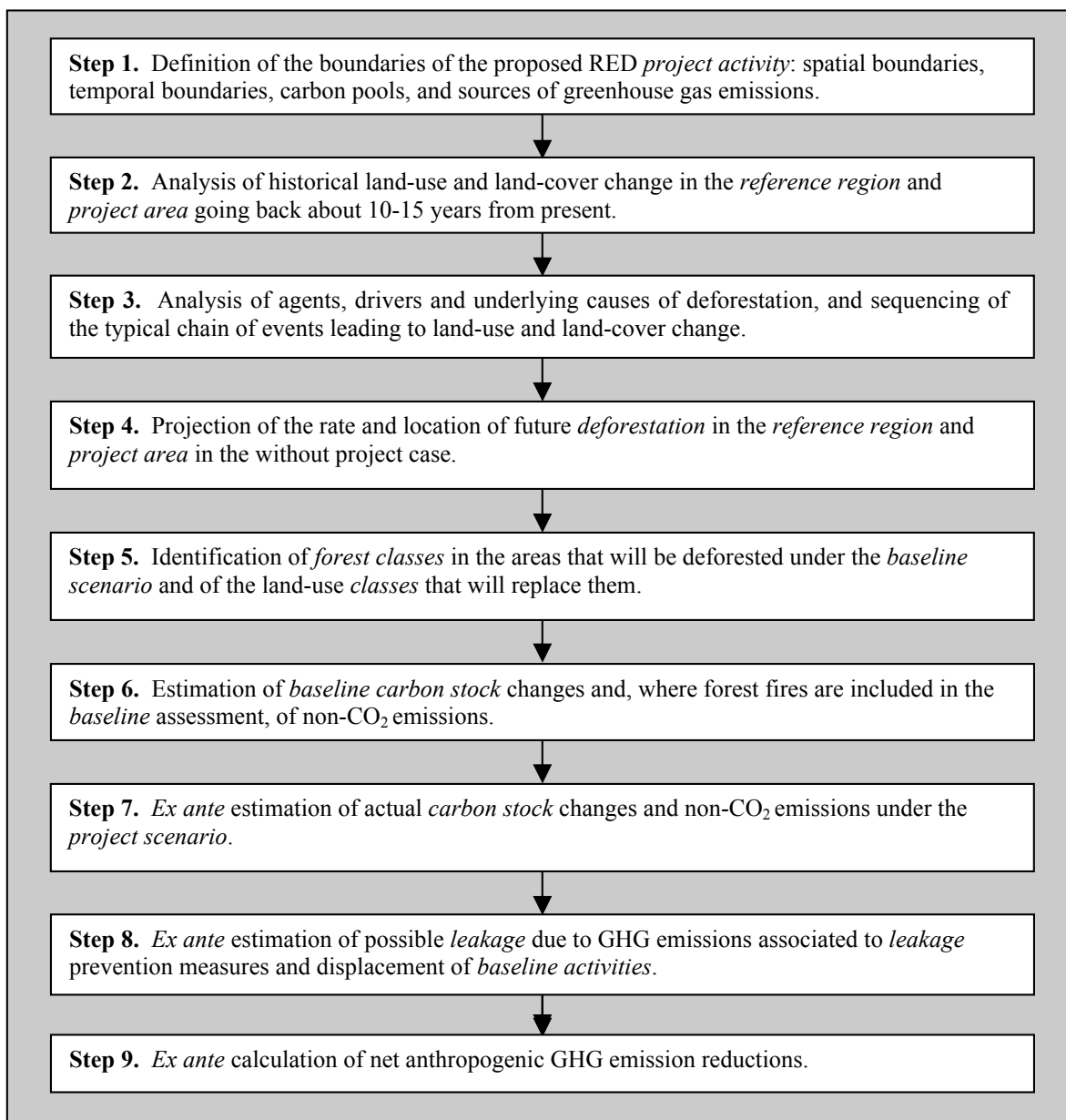
Demonstrate that the proposed RED *project activity* is additional using the latest version of the “*Tool for the demonstration and assessment of additionality for afforestation and reforestation CDM project activities*” approved by the CDM Executive Board³.

³ Demonstration of additionality is not necessary where the country has adopted an emission limitation or reduction target (a RED target).

Part 2 - Methodology steps for validation

The nine *ex ante* methodology steps that will lead the project to validation are summarized in Figure 1. In the Project Design Document (PDD) refer to each of these steps and sub-steps using the same titles and numbers so that the application of the methodology can transparently be validated.

Figure 1. *Ex ante* methodology steps



Step 1: Definition of boundaries

The purpose of this step is to define the following categories of project boundaries:

- 1.1 Spatial boundaries;
- 1.2 Temporal boundaries;
- 1.3 Carbon pools; and
- 1.4 Sources of emissions of greenhouse gases (other than *carbon stock* changes).

1.1 Spatial boundaries

Define the boundaries of the following three spatial features:

- 1.1.1 *Reference Region*;
- 1.1.2 *Project Area*; and
- 1.1.3 *Forest*.

For each spatial feature describe and justify the criteria used to define their spatial boundaries. Use appropriate sources of spatial data for each of these criteria, such as remotely sensed data, field information, and other verifiable sources of information.

Provide shape files, maps, GPS coordinates or any other location information allowing an unambiguous identification of the boundaries with a reasonable level of accuracy (< the minimum mapping unit of *forest land*).

1.1.1 *Reference region*

The boundary of the *reference region* is the spatial delimitation of the analytic domain from which information about *deforestation* rates, agents, drivers, and patterns of LU/LC-change will be obtained, projected into the future and monitored.

The *reference region* may include one or several discrete areas. It should be larger⁴ than the *project area* and include the *project area*. This will facilitate the demonstration, with the location-based analysis of step 4 that the *deforestation* frontier will reach the *project area* during the *project term*.

⁴ Brown *et al.* (2007b) suggest the following rule of thumb:

- For projects above 100,000 ha, the *reference region* should be about 5-7 times larger than the *project area*.
- For projects below 100,000 ha, the *reference region* should be 20-40 times the size of the *project area*.

The exact ratio between the two areas depends on the particular regional and project circumstances. The *reference region* may encompass from just the *project area* (e.g. in case of small isolated forests or islands) up to a broader sub-national category (e.g. a larger watershed, a province or a state) or even the entire country. Where a *project activity* deals with an entire island, the *reference region* may include other islands with similar conditions.

In a *frontier deforestation* situation, the current situation within the *project area* will most likely change during the *project term*. If no change similar to the one expected to occur has happened in the past 10 to 15 years in any surrounding area, the *reference region* may include a non-contiguous discrete area, placed in an even distant geographic area, where a change like the expected one has already occurred during the *historical reference period*⁵. The *reference region* can then be stratified in strata representing a chrono-sequence of current and future conditions within the *project area*.

Criteria to demonstrate that the conditions determining the likelihood of *deforestation* within the *project area* are similar or expected to become similar to those found within the *reference region* include, among others that can be proposed by the project proponent, the following ones:

- **Access to forest** within the *project area* is or will become similar to that found in other strata of the *reference region*. For example, if there is a plan to construct a new road in or near the *project area* and no such road was built in the recent past (10-15 years) within or nearby the *project area*, it will not be possible to analyze the effect of road construction on *deforestation* by selecting the area near or surrounding the *project area* as the *reference region*. The *reference region* will have to include a geographic stratum where a road was constructed in the not too distant past. This will allow analyzing the spatial correlation between historical road construction and *deforestation* in the *reference region* and to project future *deforestation* in the *project area* based on the planned road construction.
- **LU/LC-change categories** represented within the *reference region* should include both all *LU/LC-change categories*, which are currently found within the *project area*, as well as all *categories*, which are projected to be found within the *project area* over the *project term*. For this reason, the *reference region* may include only one area, or several discrete areas of land, as required to achieve adequate representation of all *LU/LC-change categories*. Where a *LU/LC-change category* is unique to the *project area*, and other examples of this *category* for inclusion in the *reference region* cannot be found, proponents must explain in the PDD what the factors are which make this *category* unique, how they have projected a *baseline* for this *category*, and what steps they have taken to ensure that this baseline is conservative.
- **Agents and drivers of deforestation** within the *reference region* must be of the same type of those found or expected to encroach into the *project area*. For instance, if the expansion of the *deforestation* frontier into the *project area* is linked to population growth of small farmers practicing subsistence agriculture and fuel-wood collection on land that is considered marginal for commercial agriculture, it does not make sense to include in the *reference region* areas that are subject to *deforestation* by large cattle ranchers and cash-crop growers that are not interested in expanding their activities into the *project area*. However, if infrastructure development will make the *project area*

⁵ For instance, where the construction of a new road or paving of an existing road is expected to occur near or in the *project area*, but did not occur in any surrounding area in the recent past, a *reference region* could be placed on a location where the relationship between historical deforestation and road construction or paving can be analyzed to understand what is likely to happen to the forest within the *project area* in the future.

suitable to these large cattle and cash-crop growers, then the *reference region* should include areas where these groups are present.

- **Ecological conditions** within the *reference region* and *project area* must be of the same type. For instance, if the *project activity* is to protect a mountain *forest* on the top of a watershed, lowland humid *forests* or dry *forests* on the planes at the bottom of the valley should not be included in the *reference region*.
- **Enforced policies and regulations** applicable to the two areas should be of the same type taking into account the current or *baseline* level of enforcement. For instance, in a country where sub-national administrative units are governed by different *forest* institutions (including legislation) it would make sense to consider the boundary of the administrative unit as the region's boundary.

1.1.2 *Project area*

The *project area* is the area or areas of land on which the project proponent will undertake the *project activities* that reduce emissions from *deforestation*. No lands on which the *project activity* will not be undertaken can be included in the *project area*. Certain areas where the project participants implement activities may not lead to emission reductions and may therefore be excluded from the project boundary. Changes in carbon stocks and increases in emissions in such excluded areas must be accounted as *leakage*.

1.1.3 *Forest*

The boundary of the *forest* is dynamic and will change over time. It must be defined using an explicit and consistent *forest* definition over different time periods.

To define the boundary of the *forest*, specify:

- The definition of *forest* that will be used to monitor *deforestation* during the *project term* (see Appendix 1 for criteria to define "*forest*").
- The Minimum Mapping Unit (MMU).

An initial Forest Cover Benchmark Map is required to report only gross *deforestation* going forward. This map has to be updated for the starting date of each period analyzed and at the beginning of each new *crediting period*. It should depict the locations where *forest* land exists.

Areas covered by clouds or shadows and for which no spatially explicit and verifiable information on *forest* cover can be found or collected (using ground-based or other methods) shall be excluded (masked out). This exclusion would be:

- **Permanent** in the case that such an area exists in the data set corresponding to the *historical reference period*;
- **Temporal** in case information was available for the *historical reference period*, but not for a specific *monitoring period*. In this case, the area with no information must be excluded from the calculation of net anthropogenic GHG emission reductions of the current *monitoring period*, but not for subsequent periods, when information may

become available again. When information becomes available again, and the land appears with vegetation parameters below the thresholds for defining “*forest*”, the land should be considered as “deforested”, unless the period of time with no information was shorter than the period of time used to define “temporarily un-stocked”, which depends on the definition of “*forest*” adopted

1.2 Temporal boundaries

Define the following temporal boundaries:

1.2.1 Starting date and end date of the *historical reference period*

The starting date should not be more than 10-15 years in the past and the end date as close as possible to project start.

1.2.2 Starting date and end date of the RED *project activity*

The duration of the RED *project activity* must be at least 20 years.

1.2.3 Starting date and end date of the first *crediting period*

The *crediting period* can be up to, but no more than, 10 years.

1.2.4 Duration of the *monitoring periods*

The minimum duration of a *monitoring period* is one year and the maximum duration is one *crediting period*.

See Appendix 1 for the definition of these temporal concepts.

1.3 Carbon pools

The six carbon pools listed in Table 1 are potentially eligible in this methodology.

Table 1. Carbon pools included or excluded within the boundary of the proposed RED project activity

Carbon pools	Included / TBD/ Excluded	Justification / Explanation of choice
Above-ground	Included	Stock change in this pool is always significant
Below-ground	TBD - recommended	
Dead wood	TBD	
Harvested wood products	TBD	
Litter	TBD	
Soil organic carbon	TBD	

* TBD = To Be Decided by the project proponent.

- Above-ground biomass of trees must always be selected because it is in this pool that the greatest *carbon stock* change will occur.
- Below-ground biomass of trees is recommended, as it usually represents between 15% and 30% of the above-ground biomass.
- Harvested wood products are often not a significant pool⁶. Where the baseline includes logging activities, carbon stock changes in the long-term wood products carbon pool must be assessed using the latest version of the VCS approved module for this pool (Appendix 7). If the changes are significant, they must be accounted.
- The inclusion of other pools is to be decided (TBD) by the proponent taking into account the guidance provided below.

The decision on which carbon pool to select depends on available financial resources, ease and cost of measurement, the magnitude of potential change in the pool⁷ and the principle of conservativeness⁸. The following guidance is given:

⁶ Research carried out in the Mayan Biosphere Reserve (Guatemala) suggests that logging in the concessions removes about 10.2 tC/ha from the forest, which is less than 10% of the carbon stock in the above-ground biomass (104.7 tC/ha), but that only 1.4 tC/ha ends up in wood products, the rest is short-lived waste (Figuerola *et al.*, 2004). The quantity of carbon stored in wood products is therefore likely to be more than compensated in the first year of re-growth after logging which means that the wood product carbon pool can be neglected.

⁷ The *expected magnitude of change* in a carbon pool is an important criterion for its selection. The expected magnitude of change is correlated with the magnitude of the carbon pool. For instance, the above-ground biomass of trees should always be estimated as the trees are relatively easy to measure and they will always represent a significant proportion of the total carbon stock change. The remaining carbon pools represent varying proportions of total carbon, depending on local conditions, and may not be measured. For example, in a tropical forest landscape of the Porce region (Colombia) Sierra *et al.* (2007) estimated that in primary forests the mean total carbon stocks (TCS) was as 383.7 +/- 55.5 Mg C ha⁻¹ (+/-S.E.). Of this amount, soil organic carbon to 4 m depth represented 59%, total above-ground biomass 29%, total below-ground biomass

- In most cases the exclusion of a carbon pool will be conservative.
- The inclusion of a carbon pool is recommended (but not mandatory) where the pool is likely to represent an important proportion ($> 10\%$) of the total *carbon stock* change attributable to the *project activity*.
- For excluded pools, briefly explain why the exclusion is conservative.
- When the exclusion of a carbon pool is not conservative, demonstrate that the exclusion will not lead to a significant overestimation of the net anthropogenic GHG emission reduction. Significance in this methodology is tested using the most recent version of the “Tool for testing significance of GHG emissions in A/R CDM project activities”⁹ and the significance threshold is 5%. If the exclusion is significant, the pool must be included.
- Different carbon pools may be selected for different *categories of LU/LC-change*, depending on “conservativeness” and “expected magnitude of change”. The detailed selection of carbon pools per *category* is done in step 2.3. Within a *category of LU/LC-change*, the same carbon pools must be selected for the two *classes* involved. Table 1 in Appendix 2 provides an indication of the level of priority for including different carbon pools depending on the *category of LU/LC-change*.

Further guidance on the selection of carbon pools can be found in the GOFC-GOLD REDD Sourcebook (Brown *et al.*, 2007a) and further details are given in Appendix 3.

1.4 Sources of GHG emissions¹⁰

10%, and necromass 2%. In secondary forests, TCS was 228.2 \pm 13.1 Mg C ha⁻¹, and soil organic carbon to 4 m depth accounted for 84% of this amount. Total above-ground biomass represented only 9%, total below-ground biomass 5%, and total necromass 1% of TCS in secondary forests.

⁸ *Conservativeness* means that the exclusion of a carbon pool shall not lead to an overestimation of the carbon benefits (i.e. the carbon stock of the excluded carbon pool should be lower in the deforested land than in the forest).

⁹ Available at http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

¹⁰ Reducing deforestation and *forest degradation* has multiple impacts on sources of GHG emissions (other than carbon stock changes):

- *Baseline emissions are decreased.* Emissions of non-CO₂ gases from forest fires used to convert forests are avoided. Sources of GHG emissions that would be increased on deforested and degraded lands in the absence of the project activity are avoided (e.g. fossil fuel consumption due to transport of goods and the services and road construction; fertilization and periodical burning of crop land and grazing land; manure management and enteric fermentation of grazing animals introduced in the forest and deforested areas; drainage of deforested peat land forests; flooding of forest areas due to a reservoir construction; etc.).
- *Project emissions are generated* (e.g. CO₂ emissions due to fossil fuel consumption for project activities such as forest surveillance, improved forest management, carbon monitoring, educational activities, and fire prevention measures).
- *Leakage emissions are generated* (e.g. non-CO₂ emissions from biomass burning to clear new areas; N₂O emissions from fertilization for agricultural intensification as a *leakage* prevention measure; etc.).

The four sources of GHG emissions listed in Table 2 are potentially eligible. The inclusion of a source is to be decided (TBD) by the proponent taking into account the specific project circumstances and the guidance provided below.

Table 2. Sources and GHG included or excluded within the boundary of the proposed RED project activity

Sources	Gas	Included/ TBD/ excluded	Justification / Explanation of choice
Biomass burning	CO ₂	Excluded	Counted as <i>carbon stock</i> change
	CH ₄	TBD	
	N ₂ O	TBD	
Combustion of fossil fuels by vehicles	CO ₂	TBD	Almost never a significant source
	CH ₄	Excluded	Not a significant source
	N ₂ O	Excluded	Not a significant source
Use of fertilizers	CO ₂	Excluded	Not a significant source
	CH ₄	Excluded	Not a significant source
	N ₂ O	TBD	Most likely not a significant source
Livestock emissions	CO ₂	Excluded	Not a significant source
	CH ₄	TBD	
	N ₂ O	TND	

The decision on which source of GHG emission to select depends on available financial resources, ease and cost of measurement, the magnitude of potential change and the principle of conservativeness¹¹. The following guidance is given:

- In the *baseline scenario*: Non-CO₂ emissions from fires used to clear *forests* can be counted when sufficient data are available to estimate them and when they represent more than 10% of the *baseline* emissions. However, accounting for these emissions can conservatively be omitted. GHG emissions from land-uses implemented on deforested lands are conservatively ignored in this methodology¹².
- In the *project scenario*: It is reasonable to assume that the *project activity*, including when logging activities are planned, produces less emissions of GHG than the *baseline deforestation* and the land-use activities implemented on deforested lands. Therefore, the omission of GHG emissions generated by the RED *project activity* will not cause an overestimation of the net GHG emission reductions credited to the *project activity*. However, if non-CO₂ emissions from fires are counted in the *baseline*, they must also be counted in the *project scenario*.

¹¹ *Conservativeness* means that the exclusion of a source of GHG emission shall not lead to an overestimation of the net anthropogenic GHG emission reductions (i.e. the carbon stock of the excluded carbon pool should be lower in the deforested land than in the forest).

¹² Depending on future policy and regulatory guidance, this could be an area of potential future development of this methodology. As stated in the introduction, post-deforestation emissions could be significant.

- In the estimation of leakage: GHG emissions by sources that are *attributable*¹³ to *leakage* prevention measures¹⁴ and that are *increased* compared to preexisting GHG emissions count as *leakage* and should be estimated and counted if they are significant¹⁵. Non-CO₂ emissions from displaced *baseline* activities, which are conservatively omitted in the *baseline*, can be ignored, as in the worst-case scenario they would be similar to *baseline* emissions¹⁶. However, if non-CO₂ emissions from *forest fires* are counted in the *baseline*, they must also be counted in the estimation of *leakage* due to displacement of *baseline* activities.

Notes:

- Sources of GHG emissions that are not significant according to the validated *ex ante* assessment do not need not to be monitored *ex post*.
- Changes in emissions of GHG gases (other than *carbon stock* changes) are considered permanent, while *carbon stock* changes are considered non-permanent under certain standards (e.g. the Voluntary Carbon Standard¹⁷). For this reason, accounting of changes in *carbon stocks* and of GHG emissions must be kept separate at all times.

Step 2: Analysis of historical land-use and land-cover change

The goal of this step is to collect and analyze spatial data in order to identify current LU/LC conditions and to analyze land-use and land-cover change during the *historical reference period* within the *reference region* and the *project area*. The tasks to be accomplished in step 2 are the following:

- 2.1 Collection of appropriate data sources;
- 2.2 Definition of *classes* of land-use and land-cover;
- 2.3 Definition of *categories* of land-use and land-cover change;
- 2.4 Analysis of historical land-use and land-cover change;
- 2.5 Map accuracy assessment;
- 2.6 Preparation of a methodology annex to the PDD.

¹³ Only emissions from “activity displacement” and “*leakage* prevention measures” implemented in the *leakage belt* and *project area* are considered “attributable”. As explained earlier, market effects are not considered as attributable.

¹⁴ The methodology assumes that *leakage* prevention measures could be implemented within the *project area* as well as within the *leakage belt*. For simplicity, they are estimated under “*leakage*”.

¹⁵ In this methodology, “significance” is assessed using the latest version of the CDM-EB approved “Tool for testing significance of GHG emissions in A/R CDM project activities” available at http://cdm.unfccc.int/EB/031/eb31_repan16.pdf

¹⁶ However, changes in *carbon stocks* that are attributable to displaced *baseline activities* must be counted as *leakage*, because *carbon stocks* are included in the *baseline*.

¹⁷ www.v-c-s.org.

2.1 Collection of appropriate data sources

Collect the data that will be used to analyze land-use and land-cover change during the *historical reference period* within the *reference region* and the *project area*. It is good practice to do this for at least three time points, about 3-5 years apart. For still intact *forest* areas, it is sufficient to collect data for one single date, which must be as close as possible to present.

As a minimum requirement:

- Collect medium resolution spatial data¹⁸ (30m x 30m resolution or less, such as Landsat or Spot sensor data) covering the past 10-15 years.
- Collect high-resolution data from remote sensors (< 5 x 5 m pixels) and/or from direct field observations for ground-truth validation of the posterior analysis. Describe the type of data, coordinates and the sampling design used to collect them.
- In tabular format (Table 3), provide the following information about the data collected:

Table 3. Data used for historical LU/LC change analysis

Vector (Satellite or airplane)	Sensor	Resolution		Coverage (km ²)	Acquisition date (DD/MM/YY)	Scene or point identifier	
		Spatial	Spectral			Path / Latitude	Row / Longitude

Where already interpreted data of adequate spatial and temporal resolution are available, with some caution¹⁹ these can also be considered for posterior analysis.

2.2 Definition of *classes* of land-use and land-cover

Define and describe the land-use and land-cover (*LU/LC*) *classes* present in the *reference region* and *project area* taking in to account the following guidance:

- At minimum, the six broad IPCC *LU/LC classes* used for national GHG inventories should be used (*Forest Land*, *Crop Land*, *Grassland*, *Wetlands*, *Settlements*, and *Other Land*). See IPCC 2006 GL AFOLU Chapter 3, Section 3.2, p. 3.5 for a description of these *classes*.

¹⁸ Guidance on the selection of data sources (such as remotely sensed data) can be found in Chapter 3A.2.4 of the IPCC 2006 GL AFOLU and in Brown *et al.* (2007b), Section 3.2.4. Appendix 2 gives an overview of present availability of optical mid-resolution (10-60m) sensors.

¹⁹ Existing maps should be used with caution because they often do not report documentation, error estimates, whether they were of the site or region in question or extracted from a national map, or whether they were obtained by change detection techniques rather than by static map comparison, etc. If data about historical LU/LC and/or LU/LC-change is already available, information about the minimum mapping unit, the methods used to produce these data, and descriptions of the LU/LC classes and/or LU/LC-change categories must be compiled, including on how these classes may match with IPCC classes and categories.

- Where non-forest *classes* are pooled together, the *carbon density* of the pooled *classes* must be estimated conservatively.
- The six broad IPCC *classes* listed above may include sub-*classes* with different *carbon densities* (t CO₂e ha⁻¹) and may therefore be further stratified in order to obtain *LU/LC-classes* having a homogeneous average *carbon density* within each *class*.
- Where the definition of IPCC *classes* used in national GHG inventory reports is applicable to the *project activity*, these should be used.
- List the resulting final *LU/LC-classes* in the following table:

Table 4. Land use and land cover *classes*

Class Identifier		Description	Average carbon density ± 95% CI					
ID	Name		CD_{AB}	CD_{BB}	CD_{DW}	CD_L	CD_{SOC}	CD_{HWP}
			t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹

CD_{AB} = Average *carbon density* in the above-ground biomass carbon pool; t CO₂e ha⁻¹
 CD_{BB} = Average *carbon density* in the below-ground biomass carbon pool; t CO₂e ha⁻¹
 CD_{DW} = Average *carbon density* in the dead wood biomass carbon pool; t CO₂e ha⁻¹
 CD_L = Average *carbon density* in the litter carbon pool; t CO₂e ha⁻¹
 CD_{SOC} = Average *carbon density* in the soil organic carbon pool; t CO₂e ha⁻¹
 CD_{HWP} = Average *carbon density* in the harvested wood products pool; t CO₂e ha⁻¹

Notes:

- The average *carbon density* of a *LU/LC class* and its 95% confidence interval (95% CI) must be reported only for the selected carbon pools and only for the *LU/LC classes* involved in the *deforestation* process (see step 6.1.1). For this reason, it is recommended to collect *carbon density* data after completing step 6.
- The description of a *LU/LC class* must include criteria and thresholds that are relevant for the discrimination of that *class* from all other *classes* using the data sets collected in step 2.1. Select criteria and thresholds allowing a transparent definition of the boundaries of the *LU/LC polygons* of *each class*. Such criteria may include spectral definitions as well as other criteria used in post-processing of image data, such as elevation above sea level, aspect, soil type, distance to roads²⁰, etc. Where needed, in

²⁰ Some *classes* may be defined using indirect criteria (e.g. “Intact old-growth forest” = Forest at more than 500 m from the nearest road; “Degraded forest” = Forest within 500 m from the nearest road). Using a definition of “degraded forest” as in this example, the boundary of the polygon class “degraded forest” would be a function of how the road network develops over time, which implies that such development will have to be monitored.

the column “description” of table 4 refer to more detailed descriptions in the Methodological Annex to be prepared in step 2.6.

- The *carbon stock* of a discrete area of land changes over time. However, per definition a *LU/LC class* must always have the same average *carbon density*. For this reason, the same discrete area of land may have to be allocated to different *LU/LC classes* over time. Under some circumstances, a *LU/LC class* can be defined as an “age class” within a typical “regeneration” or “management” time sequence (e.g. in case of *forest plantations*, *secondary forests* or managed old-growth *forests*). In such cases the definition of *stand models* may be necessary (see step 7.1).
- Land converted from *forest* land to non-*forest* land often does not have a stable *carbon density* because different land uses may be implemented on it over time or because the *carbon density* of the same land use changes over time (e.g. in case of tree plantations). The question thus arises of what *LU/LC class* and *carbon density class* to allocate to a discrete area once deforested²¹. In this methodology the most likely land-use activity that would be implemented immediately after the *deforestation* event in the absence of the RED *project activity* is considered to be representative of the final land use or final mosaic of land uses after *deforestation* (this is analyzed in step 5.2). The *carbon density* of this land-use activity must be estimated as the average *carbon density* over one production cycle and can be determined from measurements in chrono-sequences, long-term studies and other verifiable sources. Where the most likely land-use activity that would be implemented immediately after the *deforestation* event is short lived, use the average *carbon density* of a typical land-use sequence, or the *carbon density* of the land-use with the highest *carbon density*.

2.3 Definition of *categories* of land-use and land-cover change

Prepare a list of the *LU/LC-change categories* that have occurred within the *project area* during the *historical reference period* and that are likely to occur during the *project term*. This can be done by analyzing a land-use change matrix that combines all *LU/LC-classes* previously defined. See Table 3 in Appendix 2 for an example of a potential land-use change matrix.

List the resulting final *LU/LC-change categories* in Table 5.

²¹ The IPCC methods for estimating the annual carbon stock change on forest land converted to non-forest land includes two components: (i) the initial change in carbon stocks due to the land conversion; and (ii) the gradual carbon loss (or gain) during a transition to a new steady-state system. Ignoring the second component can lead to an overestimation or to an underestimation of the *baseline* emissions, depending on land use and management after deforestation (which could range from forest plantations to progressive revegetation and soil degradation). Considering the second component would imply tracking annual carbon stock changes on deforested lands, which is unpractical and costly. To avoid these problems, the methodology estimates the average *carbon density* of each LU/LC-class established on deforested land within a pre-defined period of time. In this way, the first and second components are incorporated in the carbon stock change estimates without increasing complexity and monitoring costs.

Table 5. Land use and land cover change *categories*

Category Identifier		From Class	To Class	Average carbon density - 95% CI of the "from" Class					Average carbon density + 95% CI of the "to" Class					Emission Factor "from" - "to"					
ID	Name	ID	ID	CD_{AB}	CD_{BB}	CD_{DW}	CD_L	CD_{SOC}	CD_{AB}	CD_{BB}	CD_{DW}	CD_L	CD_{SOC}	EF_{AB}	EF_{BB}	EF_{DW}	EF_L	EF_{SOC}	EF_{CP}
				t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹	t CO ₂ e ha ⁻¹

CD_{AB} = Average carbon density in the above-ground biomass carbon pool; t CO₂e ha⁻¹

CD_{BB} = Average carbon density in the below-ground biomass carbon pool; t CO₂e ha⁻¹

CD_{DW} = Average carbon density in the dead wood biomass carbon pool; t CO₂e ha⁻¹

CD_L = Average carbon density in the litter carbon pool; t CO₂e ha⁻¹

CD_{SOC} = Average carbon density in the soil organic carbon pool; t CO₂e ha⁻¹

EF_{AB} = Emission factor in the above-ground biomass carbon pool ; t CO₂e ha⁻¹

EF_{BB} = Emission factor in the below-ground biomass carbon pool; t CO₂e ha⁻¹

EF_{DW} = Emission factor in the wood biomass carbon pool; t CO₂e ha⁻¹

EF_L = Emission factor in the carbon pool; t CO₂e ha⁻¹

EF_{SOC} = Emission factor in the soil organic carbon pool; t CO₂e ha⁻¹

EF_{CP} = Emission factor in the all selected carbon pools; t CO₂e ha⁻¹

Notes:

- Add CD_{HWP} and EF_{HWP} if harvested wood products are accounted.
- A category of LU/LC-change is represented by its initial "from" class and its final "to" class. To be conservative, emission factors (EF) are calculated as the difference between the average carbon density of the "from" LU/LC class minus its 90% confidence interval, minus the average carbon density of the "to" LU/LC class plus its 90% confidence interval.
- Emission factors must be calculated taking into account the selected carbon pools of each category. Where the selected carbon pools are different between categories, briefly explain these different choices and demonstrate that the selection of carbon pools is conservative.
- Emission factors must be calculated in conjunction with method 2 of step 5. They are not required for method 1. For this reason, it is recommended to finalize table 5 only after completing step 5.

2.4 Analysis of historical land-use and land-cover change

Using the data collected in step 2.1, divide the *reference region* and the *project area* in polygons²² representing the *LU/LC-classes* and *LU/LC-change categories* defined in steps 2.2 and 2.3.

Use existing LU/LC or LU/LC-change maps if the *classes* and *categories* are well described in these maps, so that they can be matched to the *classes* and *categories* defined in step 2.2 and 2.3. Check with the competent national or regional authority if a regional or national *baseline* study is already available or has been approved. Give priority to already approved and validated studies.

Where already processed data of good quality are unavailable, unprocessed remotely sensed data must be analyzed to produce LU/LC maps and LU/LC-change maps. Given the heterogeneity of methods, data sources and software, LU/LC-change detection should be undertaken by trained interpreters.

Typically, the analysis of LU/LC-change is undertaken by performing the following three tasks:

- 2.4.1 Pre-processing
- 2.4.2 Interpretation and classification
- 2.4.3 Post-processing

2.4.1 Pre-processing

Pre-processing typically includes:

- a) Geometric corrections to ensure that images in a time series overlay properly to each other and to other GIS maps used in the analysis (i.e. for post-classification stratification). The average location error between two images should be < 1 pixel.
- b) Cloud and shadow removal using additional sources of data (e.g. Radar, aerial photographs, field-surveys).
- c) Radiometric corrections may be necessary (depending on the change-detection technique used) to ensure that similar objects have the same spectral response in multi-temporal datasets
- d) Reduction of haze, as needed.

See Chapter 3 of the GOFC-GOLD sourcebook on REDD (Brown *et al.*, 2007a) or consult experts and literature for further guidance on pre-processing techniques.

Duly record all pre-processing steps for later reporting.

²² Raster or grid data formats are allowed.

2.4.2 Interpretation and classification

Two main categories of change detection exist and can be used (see IPCC 2006 GL AFOLU, Chapter 3A.2.4):

- (1) Post-classification change detection: Two LU/LC maps are generated for two different time points and then compared to detect LU/LC changes. The techniques are straightforward but are also sensitive to inconsistencies in interpretation and classification of the *LU/LC classes*.
- (2) Pre-classification change detection: These are more sophisticated approaches to LU/LC-change detection. They also require more pre-processing of the data (i.e. radiometric corrections). The basic approach is to compare by statistical methods the spectral response of the ground using two data sets acquired at different dates to detect the locations where a change has occurred and then to allocate different patterns of spectral change to specific *LU/LC-change categories*. This approach is less sensitive to interpretation inconsistencies but the methods involved are less straightforward and require access to the original unclassified remotely sensed data.

As several methods are available to derive LU/LC and LU/LC-change maps from multi-temporal data sets, no specific method is recommended here. As a general guidance:

- Automated classification methods should be preferred because the interpretation is more efficient and repeatable than a visual interpretation.
- Independent interpretation of multi-temporal images should be avoided (but is not forbidden).
- Interpretation is usually more accurate when it focuses on change detection with interdependent assessment of two multi-temporal images together. A technique that may be effective is image segmentation followed by supervised object classification.
- Minimum mapping unit should be equal or above the minimum area threshold used for defining “*forest*”, but not above 5 times this value. Where mapping at this spatial resolution is not possible in the *ex ante* assessment of historical LU/LC change, at least monitoring must satisfy the MMU requirement.
- See Chapter 3 of the GOFC-GOLD sourcebook on REDD (Brown *et al.*, 2007a) or consult experts and literature for further guidance on methods to analyze LU/LC-change using remotely sensed data.

Duly record all interpretation and classification steps for later reporting.

2.4.3 Post-processing

Post-processing includes the use of non-spectral data to further stratify *LU/LC-classes* with heterogeneous *carbon density* in *LU/LC classes* with homogenous *carbon density*. Post-classification stratification can be performed efficiently using a Geographical Information System (GIS).

Current remote sensing technology is unable to discriminate *carbon density* classes. However, some *forest* types (e.g. broadleaved *forest*, coniferous *forests*, mangroves) can be discriminated with high accuracy using remotely sensed data only.

LU/LC-classes that can not be stratified further using remote sensing techniques but that are likely to contain a broad range of *carbon density* classes should be stratified using:

- Biophysical criteria (e.g. climate or ecological zone, soil and vegetation type, elevation, rainfall, aspect, etc.)²³;
- Disturbance indicators (e.g. vicinity to roads; concession areas; etc.); age (in case of plantations and secondary *forests*);
- Land management categories (e.g. protected *forest*, logging concession, indigenous reserve, etc.); and/or
- Other criteria relevant to distinguish *carbon density* classes.

See Section 4.3 of the GOFC-GOLD sourcebook on REDD (Brown *et al.*, 2007a) and IPCC 2006 GL AFOLU for further guidance on stratification. The criteria finally used should be reported transparently in the PDD and referenced to in Table 6. Some iteration between steps 2.2, 2.3, and 2.4.3 may be necessary.

Duly record all post-processing steps for later reporting.

At the end of step 2, the following products should be prepared for the *reference region* and the *project area*:

- a) A Forest Cover Benchmark Map for each date analyzed (showing only “*forest*” and “*non-forest*”).
- b) A Land-Use and Land-Cover Map for each time point in the past depicting the *LU/LC-classes* defined in step 2.2.
- c) A Land-Use and Land-Cover Change Map for each sub-period analyzed, depicting the *LU/LC-change categories* defined in step 2.3.
- d) A Land-Use and Land-Cover Change Matrix for each sub-period analyzed, derived from the *LU/LC-change* maps mentioned above, showing *activity data* for each *LU/LC-change category*. These data will be used to project historical *LU/LC-change* into the future. See Appendix 2, Table 4 for an example of a *LU/LC change matrix*.

2.5 Map accuracy assessment

A verifiable accuracy assessment of the maps produced in the previous step is necessary to produce a credible *baseline*²⁴.

²³ IPCC 2006 Guidelines for National GHG Inventories provide default climate and soil classification schemes in Annex 3A.5 and guidance on stratifying *LU/LC* areas in Section 3.3.2.

²⁴ See Chapter 5 of IPCC 2003 GPG, Chapter 3A.2.4 of IPCC 2006 Guidelines for AFOLU, and Section 3.2.4 of Sourcebook on REDD (Brown *et al.*, 2007b) for guidance on map accuracy assessment.

The accuracy must be estimated on a *class-by-class* (LU/LC map) and *category-by-category* (LU/LC-change map) basis, respectively. A number of sample points on the map and their corresponding correct classification (as determined by ground-surveys or interpretation of higher resolution data as collected in step 2.1) can be used to create an error matrix with the diagonal showing the proportion of correct classification and the off-diagonal cells showing the relative proportion of misclassification of each *class* or *category* into the other *class* or, respectively, *categories*. Based on the error matrix (also called confusion matrix), a number of accuracy indices can be derived (see e.g. Congalton, 1991 and Pontius, 2000).

The minimum overall accuracy of the *Forest Cover Benchmark Map* should be 90%.

The minimum classification accuracy of each *class* or *category* in the *Land-Use and Land-Cover Map* and *Land-Use and Land-Cover Change Map*, respectively, should be 80%. If the classification of a *class* or *category* is lower than 80%:

- Consider merging the *class/category* with other *classes/categories*²⁵; or
- Exclude from the *Forest Cover Benchmark Map* the *forest-classes* that are causing the greatest confusion with non-*forest* classes according to the error matrix (e.g. initial secondary succession and heavily degraded *forest* may be difficult to distinguish from certain types of grassland or cropland, such as agro-forestry and silvo-pastoral systems not meeting the definition of “*forest*”). This implies conservatively reducing the area of the *Forest Cover Benchmark Map*.
- Both commission errors (false detection of a *class/category*, such as “*deforestation*”) and omission errors (non-detection of actual *class/category*, such as “*deforestation*”) should be estimated and reported.
- If ground-truthing data are not available for time periods in the past, the accuracy can be assessed only at the most recent date, for which ground-truthing data can be collected.
- The “goodness of fit” measure should include an assessment of the correct estimation of the quantity of change and an assessment of the correct location of change. To measure the degree to which a simulated map agrees with a reality map with respect to both location and quantity of pixels, Kappa-for-location and Kappa-for-quantity can be used, respectively (Pontius, 2000).

Where the assessment of map accuracy requires merging or eliminating *classes* or *categories* to achieve the required map accuracy, the definitions in the previous sub-steps must be adjusted accordingly. The final maps and the class/category definitions must be consistent.

2.6 Preparation of a methodology annex to the PDD

LU/LC-change analysis is an evolving field and will be performed several times during the *project term*. A consistent time-series of LU/LC-change data must emerge from this process.

²⁵ The tradeoff of merging classes or categories is that carbon estimates will be subject to a higher degree of variability.

To achieve a consistent time-series, the risk of introducing artifacts from method change must be minimized. For this reason, the detailed methodological procedures used in pre-processing, classification, post classification processing, and accuracy assessment of the remotely sensed data, must be carefully documented in an Annex to the PDD. In particular, the following information must be documented:

- a) Data sources and pre-processing: Type, resolution, source and acquisition date of the remotely sensed data (and other data) used; geometric, radiometric and other corrections performed, if any; spectral bands and indexes used (such as NDVI); projection and parameters used to geo-reference the images; error estimate of the geometric correction; software and software version used to perform pre-processing tasks; etc.
- b) Data classification: Definition of the *LU/LC classes* and *LU/LC-change categories*; classification approach and classification algorithms; coordinates and description of the ground-truthing data collected for training purposes; ancillary data used in the classification, if any; software and software version used to perform the classification; additional spatial data and analysis used for post-classification analysis, including class subdivisions using non-spectral criteria, if any; etc.
- c) Classification accuracy assessment: Accuracy assessment technique used; coordinates and description of the ground-truth data collected for classification accuracy assessment; post-processing decisions made based on the preliminary classification accuracy assessment, if any; and final classification accuracy assessment.
- d) Methodological changes: If in subsequent periods changes will be made to the original methodology:
 - Each change and its justification should be explained and recorded; and
 - When methods change, at the moment of change, the entire time-series of past estimates that is needed to update the *baseline* must be recalculated using the new method.

Step 3: Analysis of agents, drivers and underlying causes of deforestation

Understanding “who” is deforesting the *forest* (the “agent”) and what drives land-use decisions (drivers and underlying causes) is necessary for two main reasons: (i) Estimating the quantity and location of future *deforestation*; and (ii) Designing effective measures to address *deforestation*, including *leakage* prevention measures.

This analysis is performed through the following four sub-steps²⁶:

- 3.1 Identification of agents of *deforestation*;
- 3.2 Identification of *deforestation* drivers;
- 3.3 Identification of underlying causes;

²⁶ See Angelsen and Kaimowitz (1999) and Chomitz *et al.* (2006) for comprehensive analysis of deforestation agents and drivers.

- 3.4 Analysis of chain of events and relations between agents, drivers and underlying causes.
- 3.5 Conclusion of the analysis of agents and drivers

3.1 Identification of *deforestation* agents

Identify the main agent groups of *deforestation* (farmers, ranchers, loggers, etc.) and their relative importance (i.e. the amount of historical LU/LC-change that can be attributed to each of them). To do this identification, use existing studies, the maps prepared in step 2, expert-consultations, field-surveys and other verifiable sources of information, as needed.

Sometimes, the relative importance of each agent can be determined from the LU/LC-change matrix developed in step 2.4, since each agent usually converts *forests* for a specific purpose (cattle ranching, cash-crop production, subsistence farming, etc.).

If the relative importance of different agents is spatially correlated (e.g. small farmers are concentrated in the hills, while ranchers on the plains) it may be useful to stratify the *reference region* and the *project area* accordingly, and to continue the *baseline* assessment for each stratum separately in order to increase the accuracy of the projections.

For each identified agent group, provide the following information:

- a) Name of the main agent group or agent;
- b) Brief description of the social, economic, cultural and other attributes of the agent group that are relevant to understand the agent's motivations to deforest;
- c) Current and likely future development of the population size of the agent group in the *reference region* and *project area*.

3.2 Identification of *deforestation* drivers

For each identified agent group, analyze factors that drive their land-use decisions. The goal is to identify the immediate causes of *deforestation*.

Two sets of driver variables have to be distinguished:

- a) Non-spatial driver variables(to be used in step 4.1), such as:
 - Prices of agricultural products;
 - Costs of agricultural inputs;
 - Population density;
 - Rural wages;
 - *Etc.*
- b) Spatial variables explaining the location of land-use and land-cover change, also called "predisposing factors" (De Jong *et al.*, 2007) (to be used in step 4.2), such as:

- Access to *forests* (such as vicinity to existing or planned roads, railroads, navigable rivers and coastal lines);
- Slope;
- Proximity to markets;
- Proximity to existing or planned industrial facilities (e.g. sawmills, pulp and paper mills, agricultural products processing facilities, etc.);
- Proximity to *forest* edges;
- Proximity to existing or planned settlements;
- Spatial variables indicating availability within the *forest* of land with good ecological conditions to expand agriculture and cattle ranching, such as soil fertility and rainfall;
- Management *category* of the land (e.g. national park, indigenous, indigenous reserve, etc.)
- *Etc.*

In case of spatial variables representing planned infrastructure (e.g. roads, industrial facilities, settlements), include them in the location analysis of step 4.2 taking into account the different time points in which new segments will be developed. Provide strong evidence that the planned infrastructure will actually be constructed and the time table of the construction of different segments (e.g. how much kilometers of road will be constructed, where and when). Strong evidence includes: approved plans and budgets for the construction, signed construction contracts, public announcements from the government, or open bidding process with approved budgets and finance. If such evidence is not available use one of the two following options:

- Exclude the planned infrastructure from the driver variables considered in the analysis; or
- Adjust the *baseline post facto* (Task 2 of the *post* validation methodology), based on monitoring of actual infrastructure development during each *monitoring period*.

Some variables can be used to explain both, the quantity and the location of *deforestation* (i.e. road construction or paving, see for instance Soares-Filho *et al.*, 2006).

For each of these two sets of variables:

- 1) List the 1-5 key driver variables and provide any relevant source of information that provides evidence that the identified variables are a driver for *deforestation*.
- 2) Briefly describe for each main agent group identified in step 3.1 how the key driver variables have and will most likely impact on each agent group's decision to deforest.
- 3) For each identified key driver variable provide information about its likely future development, by providing any relevant source of information.

- 4) For each identified driver variable briefly describe the project measures that will be implemented to address them, if applicable.

3.3 Identification of underlying causes of *deforestation*

The agents' characteristics and decisions are themselves determined by broader forces, the *underlying causes* of *deforestation* and *forest degradation*, such as:

- Land-use policies and their enforcement;
 - Population pressure;
 - Poverty and wealth;
 - War and other types of conflicts;
 - Property regime;
 - *Etc.*
- 1) List the 1-5 key underlying causes and cite any relevant source of information that provides evidence that the identified variables are an underlying cause for *deforestation*.
 - 2) Briefly describe how each key underlying cause determines the key drivers identified in step 3.2 and the decisions of the main agent groups identified in step 3.1.
 - 3) For each identified key underlying cause provide information about its likely future development, by citing any relevant source of information.
 - 4) For each identified underlying cause describe the project measures that will be implemented to address them, if applicable.

3.4 Analysis of chain of events leading to *deforestation*

Analyze the relations between main agent groups, key drivers and underlying causes and explain the sequence of events that typically leads to *deforestation*. Consult local experts, literature and other sources of information as necessary. Briefly summarize the results of this analysis in the PDD. At the end, provide a concluding statement from the above analysis (steps 3.1-3.4) about the most likely evolution of *deforestation* in the *reference region* and *project area*.

3.5 Conclusion of the analysis of agents and drivers

The analysis of agents, drivers, underlying causes and chain of events must conclude with a statement about whether the available evidence about the most likely future *deforestation* trend within the *reference region* and *project area* is:

- Inconclusive; or
- Conclusive

In case the evidence is conclusive state whether the weight of the available evidence suggests that the future baseline *deforestation* rates will be:

- decreasing;
- about constant;
- increasing.

Step 4: Projection of future *deforestation*

This step is the core of the *baseline* methodology. Its objective is to locate in space and time the *baseline deforestation* expected to occur within the *reference region* and the *project area* during the first *crediting period* and the *project term*.

Several approaches to estimate the *quantity* (ha) and *location* of future *deforestation* exist and will become available in the future. Where future *deforestation* has already been projected in previous studies, the results of these studies can be used provided they fulfill all of the following requirements:

1. The projection must cover the entire *reference region* and *project area*.
2. The projection must cover at least the duration of the first *crediting period*.
3. The projection must show the location of *deforestation* at different time points.
4. Time points for which there is a projection must coincide with the proposed *monitoring periods* and verification events.
5. The spatial resolution of the projection should be equal or finer than the minimum mapping unit of “forest land” that will be used for monitoring LU/LC-change during the *crediting period*.
6. Methods used to do the projections must be transparently documented.
7. It can be shown that all assumptions and data used to do the projections yield a conservative *deforestation* projection.
8. The projection must have been carried out by a team independent from the project proponent and must have been peer-reviewed; if these two requirements are not satisfied, an independent validation of the projection is required.

Where projections are not available or they do not fulfill all the above requirements, continue with step 4.1; otherwise continue with step 5.

4.1 Projection of the quantity of future *deforestation*

This sub-step is to determine the quantity of *baseline deforestation* (in hectares) for each future year (or *monitoring period*).

Where a country or a sub-national administrative entity (e.g. a state or province) has adopted a RED target and a monitoring system has been established by the competent national or sub-national authority, the *baseline deforestation* rate can be allocated to the *project area* by the

competent authority²⁷, in which case no further analysis is required²⁸ under this sub-step (continue with step 4.2).

Where the above conditions do not exist, future *deforestation* must be determined by the project proponent taking into account the expected changes at the level of agents, drivers and underlying causes of *deforestation* and the remaining *forest* area that is suitable for the further expansion of the *deforestation* frontier according to the perceptions of the main groups of *deforestation* agents. This task is performed through the following two sub-steps:

- 4.1.1 Analysis of constraints to the further expansion of the *deforestation* frontier;
- 4.1.2 Quantitative projection of future *deforestation*.

4.1.1 Analysis of constraints to the further expansion of the *deforestation* frontier

A continuation or increase of *deforestation* compared to past trends can only be justified if there are no biophysical constraints to the further expansion of the *deforestation* frontier. To assess whether there are constraints or scarcity of *forest* land that is suitable for conversion to non-*forest* uses do the following:

- 1) Identify land-use constraints: Identify the biophysical and infrastructure constraints (soil, climate, elevation, slope, distance to roads, etc.) that limit the geographical area where *deforestation* agents could expand their land-use activities in currently forested areas. Consider the constraints as they are expected to exist at the end of the *project term* (e.g. taking into account future road construction) and as they are perceived by the main groups of *deforestation* agents.
- 2) Estimate the remaining *forest* area that is suitable for conversion to non-*forest* use: Using the constraints identified above, map the area currently covered by *forests* that is potentially suitable for the further expansion of non-*forest* uses in the *reference region*²⁹ (Maximum Potential Deforestation Map). Where the area that is suitable for conversion to non-*forest* uses is more than 100 times the average area annually deforested within the *reference region* during the *historical reference period*, conclude that there is no constraint to the further expansion of the *deforestation* frontier and continue with step 4.1.3; otherwise continue with (3) below.
- 3) Stratify the “Maximum Potential Deforestation Map” in broad suitability classes: Considering the constraints identified above, define criteria and thresholds that delineate “optimal”, “sub-optimal” and “marginal”³⁰ conditions for each of the main

²⁷ This option is consistent with the “Nested Approach”, a proposal submitted to the UNFCCC by a number of Latin American countries (Pedroni and Streck, 2007).

²⁸ Evidence must be provided that a quantitative *deforestation baseline* has been allocated to the *project area* by the competent authority. Where such a *baseline* has been allocated to the *project area* but not to the *reference region*, continue with 4.1.1. for the *reference region* only.

²⁹ Including the *project area*.

³⁰ More or different “suitability classes can be used, depending on the information that is available and the specific project circumstances.

land uses implemented by the main *deforestation* agent groups (e.g. by defining ranges of distance to road, slope, rainfall, etc). Select thresholds that are relevant from the point of view of the *deforestation* agents. Using the selected criteria and thresholds stratify the “Maximum Potential *Deforestation* Map” in three broad suitability classes representing “optimal”, “sub-optimal” and “marginal” areas for non-forest uses. When available from other sources, use existing maps.

Calculate the following parameters:

- $A_{optimal}$ Area of “optimal” forest land suitable for conversion to non-forest land within the *reference region*; ha
- $A_{average}$ Area of “average” forest land suitable for conversion to non-forest land within the *reference region*; ha
- $A_{sub-optimal}$ Area of “sub-optimal” forest land suitable for conversion to non-forest land within the *reference region*; ha

- 4) Assume that *deforestation* will happen first in “optimal” areas and that in these areas it can continue at the historical or even higher rate. Once “optimal” areas are exhausted, *deforestation* continues in “sub-optimal” areas but at a lower speed. Finally, *deforestation* must slow down drastically and at the end stop when all “marginal” areas have been cleared.
- 5) Define future periods that will have different *deforestation* rates:
- Divide the area of the “optimal” class by the average area (ha) deforested in the *reference region* during the *historical reference period* to obtain the number of years where the further expansion of the *deforestation* frontier will not be constrained by insufficient availability of suitable land. During this first period of time the average annual *deforestation* rate can be set as high (or higher) as the average of the *historical reference period*. Where, a higher future *deforestation* rate can be justified (as per step 4.1.2), recalculate the number of years of this first period accordingly.
 - Once “optimal” areas become exhausted, *deforestation* is likely to decline because only “sub-optimal” and “marginal” areas would remain available. Economic returns from activities implemented in “sub-optimal” areas may not be sufficient for all *deforestation* agents to continue with their traditional activities. For this second period, the *deforestation* rate should be set lower than the average of the *historical reference period*. Where the first period is shorter than the *project term* calculate the duration of the second period by dividing the area of the “sub-optimal” class by an estimated and reduced average annual *deforestation* area of the second period.
 - Once “sub-optimal” areas are exhausted, *deforestation* should decline drastically. Where the duration of the first and second period is shorter than the *project term*, assume a drastically reduced *deforestation* rate and calculate the number of years

needed to exhaust all “marginal” areas. After this third period, no more *deforestation* can happen.

4.1.2 Quantitative projection of future *deforestation*

The goal of this sub-step is to determine the average annual *deforestation* area (ha yr^{-1}) or rate (% of remaining *forest* land) for different strata and future periods within the *reference region* and *project area*.

Three approaches are available:

- a) Historical average approach: Under this approach, the regional rate of unplanned *baseline deforestation* is assumed to be a continuation of the average annual rate measured during the *historical reference period*. In case of inconclusive evidence in step 3, a discount factor will be used to allow conservative estimates..
- b) Linear extrapolation approach: With this approach, the regional rate of unplanned *baseline deforestation* will be estimated by extrapolating the historical trend using linear regression.
- c) Modeling approach: With this approach, the rate of unplanned *baseline deforestation* will be estimated using a model that expresses *deforestation* as a function of driver variables selected by the project proponents.

Select and justify the most appropriate *baseline* approach following the decision criteria described below:

1. The regional *deforestation* rates measured in different historical sub-periods do not reveal any trend (decreasing, constant or increasing *deforestation*) and:
 - 1.1. No conclusive evidence emerges from the analysis of agents and drivers explaining the different historical *deforestation* rates: use approach “a” and the lower boundary of the 90% confidence interval of the mean.
 - 1.2. Conclusive evidence emerges from the analysis of agents and drivers explaining the different historical *deforestation* rates: use approach “c”.
2. The regional *deforestation* rates measured in different historical sub-periods reveal a clear trend and this trend is:
 - 2.1. A decrease of the regional *deforestation* rate and:
 - Conclusive evidence emerges from the analysis of agents and drivers explaining the decreasing trend and making it plausible that this trend will continue in the future: use approach “b”.
 - Conclusive evidence emerges from the analysis of agents and drivers explaining the decreasing trend but this evidence also suggest that the decreasing trend will change in the future due to predictable changes at the level of agents and drivers: use approach “c”.

- No conclusive evidence emerges from the analysis of agents and drivers explaining the decreasing trend: use approach “a” and the lower boundary of the 90% confidence interval of the mean.

2.2. A constant regional *deforestation* rate and:

- Conclusive evidence emerges from the analysis of agents and drivers explaining the historical trend and making it plausible that this trend will continue in the future: use approach “a”.
- Conclusive evidence emerges from the analysis of agents and drivers explaining the historical trend and this evidence also suggest that the historical trend will change in the future due to predictable changes at the level of agents and drivers: use approach “c”.
- No conclusive evidence emerges from the analysis of agents and drivers explaining the historical trend: use approach “a” and the lower boundary of the 90% confidence interval of the mean

2.3. An increase of the regional *deforestation* rate and:

- Conclusive evidence emerges from the analysis of agents and drivers explaining the increased trend and making it plausible that this trend will continue in the future: use approach “b”. If the future deforestation trend is likely to be higher than predicted with approach “b”, use approach “c”.
- Conclusive evidence emerges from the analysis of agents and drivers explaining the increased trend but this evidence also suggests that the future trend will change: use approach “a” or develop a model (approach “c”).
- No conclusive evidence emerges from the analysis of agents and drivers explaining the increasing trend: use approach “a”.

The methodology procedure is to first calculate the regional *deforestation* rate, then to locate the expected *deforestation* using the estimated regional rate (Step 4.2.4), and finally to determine the *deforestation* rate in the *project area* and *leakage belt*.

4.1.2.1 Projection of the regional *baseline deforestation* rate

The method to be used depends on the baseline approach selected.

Approach “a”: Historical deforestation

- 1) Estimation of the average regional rate of baseline *deforestation* that applies to the *reference region* during the first $T_{optimal}$ years:

$$A_{RR,t} = A_{RR,hrp} / T_{hrp} * DF \quad (1)$$

Where:

$A_{RR,t}$	Regional rate of <i>baseline deforestation</i> in the <i>Reference Region</i> at year t ; ha yr ⁻¹
$A_{RR,hrp}$	Total area deforested during the <i>historical reference period</i> in the <i>reference region</i> ; ha
T_{hrp}	Duration of the <i>historical reference period</i> in years; yr
DF	Discount factor (0,5 of the 90% confidence interval of the mean (CI _{90%}) in case of inconclusive evidence about future <i>deforestation</i> trends and 1,0 in case of conclusive evidence).
t	a year of the proposed <i>project term</i> .

2) Determination of the number of years during which the calculated regional rate of *baseline deforestation* is applicable ($T_{optimal}$):

$$T_{optimal} = A_{optimal} / A_{RR,unplanned,t} \quad (2)$$

Where:

$T_{optimal}$	Number of years since the start of the REDD <i>project activity</i> during which the regional rate of <i>baseline deforestation</i> calculated with equation 1 is applicable; yr
$A_{optimal}$	Area of “optimal” <i>forest</i> land suitable for conversion to non-forest land within the <i>reference region</i> ; ha
$A_{RR,unplanned,t}$	Regional rate of <i>baseline deforestation</i> in the <i>Reference Region</i> at year t ; ha yr ⁻¹

If: $T_{optimal} \geq \text{Project term}$: The regional rate calculated with equation 1 is applicable during the entire *project term*.

If: $T_{optimal} < \text{Project term}$: The regional rate calculated with equation 1 is applicable only to the first $T_{optimal}$ years. For the following $T_{average}$ years use $A_{RR,t} * 0,5$

3) Determination of $T_{average}$:

$$T_{average} = A_{average} / (A_{RR,t} * 0,5) \quad (3)$$

Where:

$T_{average}$	Number of years during which the regional rate of <i>baseline deforestation</i> is half the value calculated with equation 1; yr
---------------	--

- $A_{average}$ Area of “average” forest land suitable for conversion to non-forest land within the *reference region*; ha
- $A_{RR,t}$ Regional rate of *baseline deforestation* at year t ; ha yr⁻¹
- If: $T_{optimal} + T_{average} \geq \text{Project term}$: After $T_{optimal}$ years since the start of the REDD *project activity* and until the end of the *project term* the regional rate of *baseline deforestation* will be $A_{RR,t} * 0,5$.
- If: $T_{optimal} + T_{average} < \text{Project term}$: For $T_{sub-optimal}$ years after $T_{optimal} + T_{average}$ years since the start of the REDD *project activity* use $A_{RR,t} * 0,25$. After $T_{optimal} + T_{average} + T_{sub-optimal}$ years the regional rate of *baseline deforestation* will be zero.

4) Determination of $T_{sub-optimal}$:

$$T_{sub-optimal} = A_{sub-optimal} / (A_{RR,t} * 0,25) \quad (4)$$

Where:

- $T_{suboptimal}$ Number of years during which the regional rate of *baseline deforestation* is 25% of the value calculated with equation 1; yr
- $A_{sub-optimal}$ Area of “sub-optimal” forest land suitable for conversion to non-forest land within the *reference region*; ha
- $A_{RR,t}$ Regional rate of *baseline deforestation* in the *Reference Region* at year t ; ha yr⁻¹

Approach “b”: Linear extrapolation

- 1) Estimation of the regional rate of *baseline deforestation* in the *reference region* at year t during the first $T_{optimal}$ years:

$$A_{RR,t} = a + b * t \quad (5)$$

Where:

- $A_{RR,t}$ Regional rate of *baseline deforestation* in the *Reference Region* at year t ; ha yr⁻¹
- a Estimated intercept of the regression line; ha
- b Estimated coefficient of the time variable; ha yr⁻¹
- t a year of the proposed *project term*.

- 2) Determination of the number of years during which the calculated regional rate of *baseline deforestation* is applicable ($T_{optimal}$):

- If: $b < 0 \rightarrow T_{optimal}$ is the period of time during which equation 5 yields a positive value. After that period of time, $A_{RR,t} = 0$.

If: $b > 0 \rightarrow T_{optimal}$ is the period of time between $t=1$ and $t=t_{optimal}$, the latter being the year at which the following condition is satisfied:

$$A_{optimal} - A_{RR,t} = 1 \quad (6)$$

Where:

$A_{optimal}$	Area of “optimal” forest land suitable for conversion to non-forest land within the <i>reference region</i> ; ha
$A_{RR,t}$	Regional rate of <i>baseline deforestation</i> in the <i>Reference Region</i> at year t ; ha yr ⁻¹
$t_{optimal}$	Year at which $T_{optimal}$ ends; yr

If: $T_{optimal} \geq Project\ term$: The regional rate calculated with equation 5 is applicable during the entire *project term*.

If: $T_{optimal} < Project\ term$: The regional rate calculated with equation 5 is applicable only to the first $T_{optimal}$ years. For the following $T_{average}$ years use the following equation:

$$A_{RR,t} = a + b * t_{optimal} \quad (7)$$

Where:

$A_{RR,unplanned,t}$	Regional rate of <i>baseline deforestation</i> in the <i>Reference Region</i> at year t ; ha yr ⁻¹
a	Estimated intercept of the regression line; ha
b	Estimated coefficient of the time variable; ha yr ⁻¹
$t_{optimal}$	Year at which $T_{optimal}$ ends; yr

3) Determination of $T_{average}$:

$T_{average}$ is the period of time between $t = t_{optimal}$ and $t = t_{average}$, the latter being the year at which the following condition is satisfied:

$$A_{average} = \sum_{t=t_{optimal}}^{t_{average}} A_{RR,t} \quad (8)$$

Where:

$A_{average}$	Area of “average” forest land suitable suitable for conversion to non-forest land within the <i>reference region</i> ; ha
$A_{RR,t}$	Regional rate of <i>baseline deforestation</i> in the <i>Reference Region</i> at year t ; ha yr ⁻¹

$t_{optimal}$	Year at which $T_{optimal}$ ends and $T_{average}$ starts; yr
$t_{average}$	Year at which $T_{average}$ ends, yr

If: $T_{optimal} + T_{average} \geq Project\ term$: The regional rate calculated with equation 8 is applicable during the entire *project term*.

If: $T_{optimal} + T_{average} < Project\ term$: The regional rate calculated with equation 5 is applicable only to the first $T_{average}$ years following $T_{optimal}$. For the following years use the following equation:

$$A_{RR,t} = a - b * t \quad (9)$$

Where:

$A_{RR,t}$ Regional rate of *baseline deforestation* in the *Reference Region* at year t ; ha yr⁻¹

a Estimated intercept of the regression line; ha

b Estimated coefficient of the time variable; ha yr⁻¹

Note: If $A_{RR,t}$ calculated with equation 9 is < 0 , use $A_{RR,t} = 0$.

Approach “c”: Modeling

This approach is applicable only where there are sufficient observations in the *historical reference period* for a robust statistical analysis. Where data from only two historical time periods are available, it is possible to generate additional data points by stratifying the *reference region* and considering the different strata as representative of a possible chronosequence of what will happen in the *project area*. For instance, the historical *deforestation* rate measured in strata with high population density may be considered as representative of the future *deforestation* rate in strata that currently have a lower population density but whose population density is expected to grow. Using the data of population density and historical *deforestation* obtained from each stratum, a statistical model would be developed and used to project the *baseline deforestation* rate of the *RED project activity* according to the population density and its expected growth in the strata in which the *project area* is located.

Deforestation will usually be modeled as a function of several independent variables (e.g. population density, gross regional product, exports, agricultural product prices, etc. consistently with step 3) for which there are good historical data and future projections (Brown and Dushku, 2003). The result is a multivariate statistical model, such as a multiple regression:

$$A_{RR,t} = a + b_1 * V_1 + b_2 * V_2 + + b_{n_i} * V_n \quad (10)$$

Where:

$A_{RR,t}$	Regional rate of <i>baseline deforestation</i> in the <i>Reference Region</i> at year t ; ha yr ⁻¹
$a; b_1; b_2; \dots; b_n$	Estimated coefficients of the model
$V1; V2; \dots; Vn$	Variables included in the model
t	a year of the proposed <i>project term</i> .

The model and its rationale must be explained by the project participants using logical arguments and verifiable sources of information.

Typically, the regional rate of *baseline deforestation* will be modeled as a function of several independent variables (e.g. population density, gross regional product, exports, agricultural product prices, etc. consistently with step 3). Good historical data and credible future projections are required for each of these variables³¹.

To avoid an overestimation of the deforestation rate, variables that constrain deforestation (such as limited availability of forest land that is suitable for conversion to non-forest land – as per step 5) should be included in the model.

Several models based on different combinations of independent variables should be tested. The model with the best fit with historical deforestation data should be used.

No specific procedures are prescribed here to validate a model or test its goodness of fit with historical data³². However, project proponents must demonstrate that such tests have been realized and that a credible and conservative model has been chosen to project the baseline rate of unplanned *deforestation*.

Seek assistance from an expert statistician as necessary.

Statistical considerations:

One of the aims of multiple regression analysis is to identify what are the independent driver variables that should be included in the model. To select the driver variables do the following:

- a) Perform an analysis of correlation to find correlated variables. To do this correlation analysis, estimate the multiple correlation matrix and if two variables are correlated

³¹ To determine the future values of the variables included in the model use official projections, expert opinion, other models, and any other relevant and verifiable source of information. Justify with logical and credible explanations any assumption about future trends of the driver variables and use values that yield conservative estimates of the deforestation rate.

³² If sufficient historical data are available, divide them in two sub-periods: an earlier “calibration” period and a following “validation” period. Use the data of the “calibration period” to estimate the coefficients of the model and then evaluate how well each model predicts the *deforestation* observed for the validation period. Select the model that yields the best fit. If two models yield about the same accuracy, the most conservative one should be chosen (the one that predicts less *deforestation*). In selecting the final model, also consider the conceptual logic underlying the choice of the independent variables. Once the best model has been chosen, recalculate its coefficients using data from the entire *historical reference period* (calibration + validation period).

then, select one of them for the model (the one for which there are better historical data and future projections).

- b) Run a multi-regression analysis with the un-correlated driver variables and obtain:
- The Mallows criteria prediction (CP) of each variable. Those variables with $CP > k$ should be included in the model ($k = \text{the number of variables} + 1$); and/or
 - Use an appropriate statistical software to select the model by means of backward selection, forward selection, or stepwise selection; and/or
 - Use fit statistics like adjusted R^2 or mean square error.

With the selected driver variables run the multiple regressions and calculate the expected *deforestation* for each future *monitoring period*.

4.1.2.2 Projection of the *baseline deforestation* rate in the *project area*

To project the *baseline deforestation* rate in the *project area* (and *leakage belt* – where considered) it is necessary to first determine the location of the expected *baseline deforestation* within the *reference region*. To do this projection, apply step 4.2. to the *reference region*, then estimate the *baseline deforestation* rate of the *project area* (and *leakage belt*) as follow:

$$A_{PA,t} = A_{RR,t} * P_{PA,t} \quad (11)$$

$$A_{LB,t} = A_{RR,t} * P_{LB,t} \quad (12)$$

Where:

$A_{PA,t}$	Rate of <i>baseline deforestation</i> in the <i>project area</i> at year t ; ha yr ⁻¹
$A_{LB,t}$	Rate of <i>baseline deforestation</i> in the <i>leakage belt</i> at year t ; ha yr ⁻¹
$A_{RR,t}$	Rate of <i>baseline deforestation</i> in the <i>reference region</i> at year t ; ha yr ⁻¹
$P_{PA,t}$	Proportion of the area of the <i>reference region</i> deforested in year t that is within the boundary of the <i>project area</i> at year t ; %
$P_{LB,t}$	Proportion of the area of the <i>reference region</i> deforested in year t that is within the boundary of the <i>leakage belt</i> at year t ; %
t	a year of the proposed <i>project term</i> .

4.1.2.3 Summary of step 4.1.2

Present the result of the previous assessments in Table 6 as shown below.

Table 6. *Baseline deforestation* during the *project term*

Project year yr	Reference Region		Project Area	
	annual ha	cumulative ha	annual ha	cumulative ha
1				
2				
3				
...				
n				
Total	Sum		Sum	

4.2 Projection of the location of future *deforestation*

Step 4.1 was to estimate the *quantity* of future *deforestation*. Step 4.2 is to analyze *where* future *deforestation* is most likely to happen in order to match location with *carbon stocks*.

Several models and software have been proposed to analyze where *deforestation* is most likely to happen in a future period. This methodology is inspired by the “Geomod” model (see Box 1 in Appendix 2), however, since LU/LC-change modeling is an active field, all models that implement at least the tasks described in step 4.2 can be used³³. Some models, such as “Dinamica”³⁴, estimate *quantity* and *location* iteratively and can also be used, provided they produce projections that satisfy the eight conditions specified at the beginning of step 4. Where no pre-existing model or software is available, the methodology can be implemented by following step by step the tasks described below.

Step 4.2 is based on the assumption that *deforestation* is not a random event but a phenomenon that occurs in a clustered fashion, at locations that attract *deforestation* agents due to their favorable biogeophysical attributes. For instance, a *forest* located on fertile soil, flat land, and near to roads and markets for agricultural commodities is at greater risk of *deforestation* than a *forest* located on poor soil, steep slope, and far from roads and markets. Locations at higher risk are assumed to be deforested first. This hypothesis can be tested empirically by analyzing the spatial correlation between historical *deforestation* and geo-referenced biogeophysical variables. In the previous example, soil fertility, slope, distance to roads and distance to markets are the hypothesized spatial driver variables (SDV_i), or “predisposing factors” (De Jong *et al.*, 2007). These variables can be represented in a map (or “driver image”) and overlaid to a map showing historical *deforestation* using a Geographical Information System (GIS). From the combined spatial dataset information is extracted and analyzed statistically in order to produce a map that shows the level of *deforestation* risk at each spatial location (= “pixel” or “grid cell”). The risk at a given spatial location will change each time there is a change of a driver variables. For example, when a new road is

³³ There are already a few good models and software packages that can be considered to perform the tasks described in this step.

³⁴ “Dinamica” is the *deforestation* model used by Soares-Filho *et al.* (2006) to develop *deforestation* scenarios for the Amazon Forest. The model is publicly available and can be downloaded from the internet (<http://www.csr.ufmg.br/dinamica/>).

constructed, the variable “distance to road” will have smaller values and the risk of *deforestation* will increase.

The basic tasks to perform the analysis described above are:

- 4.2.1 Preparation of driver maps;
- 4.2.2 Preparation of *deforestation* risk maps;
- 4.2.3 Selection of the most accurate *deforestation* risk map;
- 4.2.4 Mapping of the locations of future *deforestation*.

4.2.1 Preparation of driver maps

Based on the analysis of step 3 and step 4.1, identify the spatial variables that most likely are correlated with *deforestation*. Obtain spatial data for each variable identified and create digital maps representing the Spatial Features. Then, for each of the digital maps, create Distance Maps from the mapped features or maps representing continuous variables (e.g. slope) and categorical variables (e.g. soil quality classes). For simplicity, let's call these maps “Distance Maps”.

To create the Driver Maps use one of the following two approaches:

- **Heuristic approach:** Define “value functions” representing the likelihood of *deforestation* as a function of distance from point features (e.g. saw mills) or linear features (e.g. roads), or as a function of polygon features representing classes (e.g. of soil type, population density) based on expert opinion or other sources of information. Specify and briefly explain each value function in the PDD.

A useful approach to estimate value functions is to sample spatially uncorrelated points in the Distance Maps and their corresponding location in the Land-Use and Land-Cover Change Maps produced with step 2 and to use regression techniques³⁵ to define the probability of *deforestation* as a function of “distance”.

- **Empirical approach:** Categorize each Distance Map in a number of predefined distance classes (e.g. class 1 = distance between 0 and 50 m; class 2 = distance between 50 and 100 m, etc.). In a table describe the rule used to build the classes and the *deforestation* likelihood assigned to each distance class³⁶. The *deforestation* likelihood is estimated as the percentage of pixels that were deforested during the period of analysis (i.e. the *historical reference period*).

³⁵ e.g. logistic regression

³⁶ When building classes of continuous variables it is important to build classes that are meaningful in terms of *deforestation* risk. This implies the parameterization of a “value function” (Malczewski, 1999) based on specific measurements. For instance, the criterion “distance to roads” might not have a linear response to assess the *deforestation* risk: a forest located at 50 km from the nearest road may be subject to the same *deforestation* risk of a forest located at 100 km, while at 0.5 km the risk may be twice as much as at 1.0 km. Data to model the value function and build meaningful classes can be obtained by analyzing the distribution of sample points taken from historically deforested areas.

The empirical approach should be preferred over the heuristic approach. Use the heuristic approach only where there is insufficient information about the spatial location of historical *deforestation* or where the empirical approach does not produce accurate results.

In the finalized Driver Maps the value of a pixel must represent the *deforestation* risk or, as an approximation, the percentage of area that was deforested during the period of analysis in the distance class to which the pixel belongs.

4.2.2 Preparation of *deforestation* risk maps

A Risk Map shows at each pixel location l the risk (or “suitability”) of *deforestation* in a numerical scale (e.g. 0 = minimum risk; 255 = maximum risk).

To produce Risk Maps calculate different weighted average combinations of the Driver Maps prepared with the previous task (4.2.1). Choose different combinations of Driver Maps and weights, taking into account expert opinion and the analysis performed in the previous steps.

$$R(l) = \left(\sum_{SDV=1}^N W_{SDV} * P_{SDV}(l) \right) \div \left(\sum_{SDV=1}^N W_{SDV} \right) \quad (13)$$

Where:

$R(l)$ = Risk of *deforestation* at the location l (pixel or grid cell); dimensionless

SDV = A particular driver image; dimensionless

N = Total number of driver images; dimensionless

W_{SDV} = Weight of the driver image SDV ; %

$P_{SDV}(l)$ = Value of the grid cell of driver image SDV at location l ; dimensionless

The weights (W_{SDV}) of each Driver Map can be determined heuristically through expert consultations or empirically using statistical analysis. For instance, Geomod 2 uses non-linear multiple-regression to weight each Driver Map.

4.2.3 Selection of the most accurate *deforestation* risk map

A model validation is needed to determine which of the *deforestation* risk maps is the most accurate. A good practice to validate a model (such as a risk map) is “calibration and validation”.

Model calibration and validation:

Two options are available to perform this task: (a) calibration and validation using two historical sub-periods; and (b) calibration and validation using tiles. Option (b) should be preferred where recent *deforestation* trends have been different from those in the more distant past.

- a) Where two or more historical sub-periods have shown a similar *deforestation* trend, data from the most recent period can be used as the “validation” data set, and those from the previous period as the “calibration” data set.

Prepare Risk Maps using only the data from the calibration period, and then evaluate their accuracy with the locations that were actually deforested during the validation period. Select the combination of Driver Maps that produced the best fit in the validation period to prepare a final Risk Map using the data from the calibration and the validation period.

- b) Where only one historical sub-period is representative of what is likely to happen in the future, divide the *reference region* in tiles and randomly select half of the tiles for the calibration data set and the other half for the validation set. Do the analysis explained above (see Castillo-Santiago *et al.*, 2007).

To evaluate which of the Risk Maps prepared with the calibration data set has the best fit with the validation data set do the following:

- For the validation period and for each Risk Map, map the spatial distribution of the *deforestation* predicted within the *reference region* using the known total area deforested in the *reference region* during the validation period.
- Combine the polygon representing the boundary of the *project area* with the results of the previous step.
- Calculate the area of predicted *deforestation* within the project boundary for the validation period and each Risk Map.
- Compare the area of *deforestation* predicted by each Risk Map with the area actually deforested within the project boundary during the validation period.
- The Risk Map that produces the best fit between the area of actual *deforestation* and the area of predicted *deforestation* within the *project area* should be used.

Another indicator of goodness-of-fit that is often used is “Kappa-for-location” statistic. If the previous analysis does not produce a clear result, use the Kappa-for-location statistic. To do this, combine each of the Risk Maps with a map representing *deforestation* in the validation data set. For each Risk Map, calculate the “Kappa-for-location” statistic, which is a measure of the goodness-of-fit between actual and simulated *deforestation*³⁷. Select the map that produces a simulation with the highest Kappa statistic.

Briefly report the results of the validation test in the PDD.

4.2.4 Mapping of the locations of future *deforestation*

Future *deforestation* is assumed to happen first at the pixel locations with the highest *deforestation* risk value.

³⁷ The Kappa statistic has a value between 0.0 and 1.0. A value of 0.0 indicates no fit, i.e. the allocation of suitability values in the map is equivalent to a random allocation. A value of 1.0 means perfect fit and a negative value that the classification is worse than random. For details on the use a derivation of this statistic consult a statistician or see Pontius (2000) and Pontius (2002).

To determine the locations of future *deforestation* do the following:

- Mask out all current “non-forest land” from the selected *Deforestation Risk Map*³⁸.
- In the so transformed *Deforestation Risk Map* select the pixels with the highest value whose total area is equal to the area expected to be deforested in project year one (or first *monitoring period*) according to table 8. The result is the *Map of Baseline Deforestation for Year 1* (or first *monitoring period* as defined in step 1.2.4).
- Repeat the above pixel selection procedure for each successive project year (or *monitoring period*) to produce a *Map of Baseline Deforestation* for each future project year (or *monitoring period*). Do this at least for the upcoming *crediting period* and, optionally, for the entire *project term*.
- Add all yearly (or periodical) *baseline deforestation* maps in one single map showing the expected *Baseline Deforestation for the Crediting Period* and, optionally, *Project Term*.

Step 5: Definition of the land-use and land-cover change component of the *baseline*

The goal of this step is to complete the LU/LC-change component of the *baseline* by determining the *forest classes* that would be deforested and the *LU/LC classes* that would replace them in the without project case³⁹.

Two methods can be used to achieve this objective:

- Method 1:** For each future year (or *monitoring period*) the area and location (polygons) that would be deforested in the absence of the RED *project activity* is determined for each *forest class*. In case of the non-forest classes that replace the *forest* after a *deforestation* event only the area, but not the location, is identified. Use this method when the same carbon pools are estimated in all *LU/LC classes*.
- Method 2:** The area and location is determined for each future year (or *monitoring period*) for both, the *forest classes* and the non-forest classes that replace them. Use this method when different carbon pools are estimated depending on the *LU/LC class* considered.

When using method 1, complete step 5.1 and 5.2. When using method 2, also complete step 5.3.

- 5.1 Identification of *forest classes* that would be deforested;
- 5.2 Identification of non-forest classes on deforested land; and
- 5.3 Identification of land-use and land-cover change *categories*.

³⁸ The Geomod model refers to these maps as “Potential for Land Use Change” (PLUC).

³⁹ This is necessary because the various *LU/LC-change categories* have different emission factors. For instance, the *broad category* “deforestation” may include “conversion of old-growth forests to grassland” (high emission factor) and “conversion of degraded forest to agro-forestry” (low emission factor).

5.1 Identification of forest classes that would be deforested under the baseline scenario

Combine the Maps of Baseline Deforestation of each future year (or *monitoring period*) produced in the previous step with the Land-Use and Land-Cover Map produced for the current situation in step 2 to produce a set of maps showing for each *forest class* the polygons that that would be deforested each year (or *monitoring period*) in the absence of the RED *project activity*. Extract from these maps the number of hectares of each *forest class* that would be deforested and show the results in the following table.

Table 7. Baseline deforestation activity data per forest class

Project year yr	Forest Class A (ID and Name)		Forest Class B (ID and Name)		Forest Class ... (ID and Name)		Forest Class N (ID and Name)		Total	
	annual ha	cumulative ha	annual ha	cumulative ha	annual ha	cumulative ha	annual ha	cumulative ha	annual ha	cumulative ha
1										
2										
3										
...										
n										
Total	Sum		Sum		Sum		Sum		Sum	

Note: Do this table for the *project area* (Table 7_{PA}) and for the *leakage belt* (Table 7_{LB}) – where considered - and, optionally, for the *reference region* (Table 7_{RR}).

5.2 Identification of non-forest classes on deforested land

Predicting the land-use and land-cover *classes* that will replace *forests* in the *baseline* case is less straightforward than the previous task because it implies guessing what *deforestation* agents would do in the lands they will deforest in the future.

Three options are available to perform this task (1) “Simple conservative approach”; (2) “Historical LU/LC-change” and (3) “Suitability modeling”. All three options can be used in conjunction with method 1, but option 3 should be the preferred one under method 2.

Option 1: Simple conservative approach

A conservative average *carbon density* is estimated for all post-*deforestation* land uses. Do the following:

- List the non-*forest classes* of Table 4 in descending order of *carbon density*.
- Select from the top of the list the *classes* that represent 30% of all non-*forest classes* (at least one *class*).
- Calculate the average *carbon density* of the selected *classes*.
- Assume that the calculated average *carbon density* is representative of the post-*deforestation carbon density* on all lands that will be deforested during the project term.

Option 2: Historical LU/LC-change

Historical LU/LC-changes are assumed to be representative for future trends. Hence, the combination of *non-forest classes* in future periods is assumed to remain similar to the one observed during the *historical reference period*. Do the following calculations:

- Using the maps produced in step 2, calculate the area of each *non-forest class* on lands deforested during the *historical reference period*.
- Calculate the percentage of area of each *non-forest class* relative to the total area deforested during the *historical reference period*.
- Multiply the annual (or periodical) *deforestation* area calculated in table 8 by the percentage calculated for each *LU/LC-class* and report the result in the following table:

Table 8. Baseline activity data on deforested land

Project year	Non-Forest Class A (ID and Name)		Non-Forest Class B (ID and Name)		Non-Forest Class ... (ID and Name)		Non-Forest Class N (ID and Name)		Total	
	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative
yr	ha	Ha	ha	ha	ha	ha	ha	ha	ha	ha
1										
2										
3										
...										
n										
Total	Sum		Sum		Sum		Sum		Sum	

Note: Do this table for the *project area* (Table 8_{PA}) and for the *leakage belt* (Table 8_{LB}) – where considered - and, optionally, for the *reference region* (Table 8_{RR}).

Option 3: Suitability modeling

The future spatial distribution of *LU/LC classes* on *non-forest* converted from *forest* land is determined using suitability modeling. Do the following:

- Model the spatial suitability of each *LU/LC-class* using a technique similar to the one that was used to model the spatial suitability for “*deforestation*”.
- Assume that at each spatial location the *LU/LC-class* with the highest suitability value will be the one that would be implemented in the absence of the RED *project activity*.
- Show the results obtained in maps and summarize the results in Table 8 above.

Selection of the most appropriate option:

Option 1 is the most simple and conservative approach and can always be used. However, the use of this option can lead to an overly conservative underestimation of the *baseline*, in which case option two or three should be considered.

Option 2 is simple where good information on historical land-use and land-cover exists, but it may not be applicable where scarcity of “optimal” and “sub-optimal” land for some of the main land-uses has been detected in step 4.1.2. In this case option three should be used.

Option 3 is more laborious and costly to implement, but it may represent future changes in a more accurate manner than option one or two. It should be used where the different land-uses are already competing for suitable land or where such competition is likely to become a critical factor during the *crediting period* according to the analysis performed in step 4.1.2.

5.3 Identification of land-use and land-cover change *categories*

Do this sub-step only if the method selected for step 5 is method 2.

The goal of this sub-step is to identify the *categories* of LU/LC-change and the level of *activity data* of each of these *categories*. This is performed as follows:

- Combine the maps showing the polygons of *forest classes* that would be deforested during each future year (or *monitoring period*) produced in step 4.2.4 with the map showing the most suitable non-forest LU/LC class prepared in step 5.2.
- From the combined datasets produce a new set of maps showing the polygons of the *categories* of LU/LC change for each future year (or *monitoring period*).
- Extract from the maps produced above the number of hectares (= *activity data*) corresponding to each future year (or *monitoring period*).
- Summarize the results in the following table:

Table 9. Baseline activity data

Project year	Category 1 (ID and Name)		Category 2 (ID and Name)		Category ... (ID and Name)		Category N (ID and Name)		Total	
	annual ha	cumulative Ha	annual ha	cumulative ha	annual ha	cumulative ha	annual ha	cumulative ha	annual ha	cumulative ha
1										
2										
3										
...										
n										
Total	Sum		Sum		Sum		Sum		Sum	

Note: Do this table for the *project area* (Table 9_{PA}) and for the *leakage belt* (Table 9_{LB}) – where considered - and, optionally, for the *reference region* (Table 9_{RR}).

Step 6: Estimation of *baseline carbon stock* changes and non-CO₂ emissions

The goal of this step is to finalize the *baseline* assessment by calculating:

- 6.1 *Baseline carbon stock* changes; and (optionally)
- 6.2 *Baseline* changes in non-CO₂ emissions

6.1 Estimation of *baseline carbon stock* changes

Before calculating the *baseline carbon stock* changes it is necessary to estimate the average *carbon density* of each *LU/LC class*.

6.1.1 Estimation of average *carbon densities*

The average *carbon density* must be estimated only for the *LU/LC classes* listed in the Tables 7 and 8 and the results of the estimations must be reported in Table 4. Analyze existing data and collect new data for the *LU/LC-classes* for which there is insufficient information taking into account the following guidance:

- a) Assess existing data. It is likely that some existing data could be used to quantify the *carbon stocks* of one or more *classes*. These data could be derived from a *forest* inventory or perhaps from scientific studies. Analyze these data if the following criteria are fulfilled (Brown *et al.*, 2007b):
 - The data are less than 10 years old;
 - The data are derived from multiple measurement plots;
 - All species must be included in the inventories;
 - The minimum diameter for trees included is 30 cm or less at breast height (DBH);
 - Data are sampled from good coverage of the *classes* over which they will be extrapolated.

Existing data that meet the above criteria should be applied across the *classes* from which they were representatively sampled and not beyond that. See the GOFC-GOLD sourcebook on REDD (Brown *et al.*, 2007a) and Gillespie, *et al.* (1992) for methods to analyze these data.

- b) Collect missing data. For the *LU/LC-classes* for which no existing data are available it will be necessary to either obtain the data from field measurement or to use conservative estimates from the literature.

Field measurements:

Locate the samples sites. To increase the accuracy of the *carbon density* estimates select the sample sites at the locations expected to be deforested.

Design the sampling framework and conduct the field measurements following the guidance of appendix 3 (see also Chapter 4.3 of GPG LULUCF and in the Sourcebook for LULUCF by Pearson *et al.*, 2006). Summarize the sampling design in the PDD and provide a map and the coordinates of all sampled locations.

Literature estimates:

The use of carbon stock estimates in similar ecosystems derived from local studies, literature and IPCC defaults is permitted, provided the accuracy and conservativeness of the estimates are demonstrated. For instance, when defaults are used, the lowest value of the range given in the literature source (or the value reduced by 30%) should be used for the *forest* classes, and the highest value (or the value augmented by 30%) for non-*forest* classes.

The same conservative principle applies to factors used to convert volume data to above-ground biomass data (biomass expansion factor) or to estimate below-ground biomass (root to shoot ratio) and other non-measured carbon pools.

6.1.2 Calculation of carbon stock changes

Carbon stock changes are calculated differently, depending on the method chosen in step 5.

- When using Method 1, *activity data* are given a negative sign in case of *forest classes* and a positive sign in case of the non-*forest classes* that replace them after *deforestation*. The numbers are taken from Table 7 and 8, respectively, and are multiplied by their corresponding average *carbon density* (from Table 4). The sum of products is calculated for each future year (or *monitoring period*). These calculations are transparently reported in Table 12.

Table 10. Baseline carbon stock changes calculated using Method 1

Project year	LU/LC Class A (ID and Name)		LU/LC Class B (ID and Name)		LU/LC Class ... (ID and Name)		LU/LC Class N (ID and Name)		Total	
	Activity data	Activity data x Carbon density	Activity data	Activity data x Carbon density	Activity data	Activity data x Carbon density	Activity data	Activity data x Carbon density	Activity data x Carbon density	
yr	ha	tCO ₂ e	ha	tCO ₂ e	ha	tCO ₂ e	ha	tCO ₂ e	annual tCO ₂ e	cumulative tCO ₂ e
1										
2										
3										
...										
n										
Total		Sum		Sum		Sum		Sum	Sum	

Note: Do this table for the *project area* (Table 10_{PA}) and for the *leakage belt* (Table 10_{LB}) – where considered - and, optionally, for the *reference region* (Table 10_{RR}).

- When using Method 2, *activity data* of each *category* of LU/LC-change have always a positive sign. They are taken from Table 9 and multiplied by their corresponding *emission factor* (taken from Table 5) and the sum products is calculated for each future year (or *monitoring period*). Transparently report these calculations using Table 11.

Table 11. Baseline carbon stock changes calculated using Method 2

Project year	Category 1 (ID and Name)		Category 2 (ID and Name)		Category ... (ID and Name)		Category N (ID and Name)		Total	
	Activity data	Activity data x Emission factor	Activity data	Activity data x Emission factor	Activity data	Activity data x Emission factor	Activity data	Activity data x Emission factor	Activity data x Emission factor	
yr	ha	tCO ₂ e	ha	tCO ₂ e	ha	tCO ₂ e	ha	tCO ₂ e	annual tCO ₂ e	cumulative tCO ₂ e
1										
2										
3										
...										
n										
Total		Sum		Sum		Sum		Sum	Sum	

Note: Do this table for the *project area* (Table 11_{PA}) for the *leakage belt* (Table 11_{LB}) – where considered - and, optionally, for the *reference region* (Table 11_{RR}).

6.2 Estimation of non-CO₂ emissions from *forest fires*

Conversion of *forest* to non-*forest* involving fires is a source of emissions of non-CO₂ gases (CH₄ and N₂O). When sufficient data on such *forest* fires are available from the *historical reference period* and the project proponent considers that these emissions are an important component of the *baseline*, emissions of non-CO₂ gases from biomass burning can be estimated. Where such data are unavailable, or of insufficient accuracy, emissions from biomass burning should not be considered (which is conservative). Where applicable to the local conditions, emission data from peer reviewed studies or other credible and verifiable sources can also be used.

The effect of fire on carbon emissions is counted in the estimation of *carbon stock* changes; therefore CO₂ emissions from *forest* fires should be ignored to avoid double counting.

To estimate non-CO₂ emissions from *forest* fires, it is necessary to estimate the average percentage of the deforested area in which fire was used, the average proportion of mass burnt in each carbon pool ($P_{burned,p}$), and the average combustion efficiency of each pool (CE_p). These average percentage values are estimated for each *forest class* and are assumed to remain the same in the future.

Based on revised IPCC 1996 GL LULUCF, GHG emissions from biomass burning can be estimated as follows.

$$GHG_{BiomassBurn} = E_{BiomassBurn,N_2O} + E_{BiomassBurn,CH_4} \quad (14)$$

Where:

$GHG_{BiomassBurn}$ = total GHG emission from biomass burning; tonnes CO₂e

$E_{BiomassBurn,N_2O}$ = N₂O emission from biomass burning; tonnes CO₂e

$E_{BiomassBurn,CH_4}$ = CH₄ emission from biomass burning; tonnes CO₂e

$$E_{BiomassBurn,N_2O} = E_{BiomassBurn,CO_2} \cdot 12/44 \cdot (N/C_{ratio}) \cdot ER_{N_2O} \cdot 44/28 \cdot GWP_{N_2O} \quad (15)$$

$$E_{BiomassBurn,CH_4} = E_{BiomassBurn,CO_2} \cdot 12/44 \cdot ER_{CH_4} \cdot 16/12 \cdot GWP_{CH_4} \quad (16)$$

Where:⁴⁰

$E_{BiomassBurn,CO_2}$ = Per hectare CO₂ emission from biomass burning in slash and burn; tonnes CO₂e ha⁻¹

$E_{BiomassBurn,N_2O}$ = Per hectare N₂O emission from biomass burning in slash and burn; tonnes CO₂e ha⁻¹

$E_{BiomassBurn,CH_4}$ = Per hectare CH₄ emission from biomass burning in slash and burn; tonnes CO₂e ha⁻¹

N/C_{ratio} = Nitrogen/Carbon ratio; dimensionless

ER_{N_2O} = Emission ratio for N₂O (IPCC default value = 0.007)

ER_{CH_4} = Emission ratio for CH₄ (IPCC default value = 0.012)

GWP_{N_2O} = Global Warming Potential for N₂O (IPCC default value = 310 for the first commitment period)

GWP_{CH_4} = Global Warming Potential for CH₄ (IPCC default value = 21 for the first commitment period)

$$E_{BiomassBurn,CO_2} = F_{l,burnt} * (C_{l,p}) * P_{burned,l,p} * CEI_{l,p} \quad (17)$$

Where:

$E_{BiomassBurn,CO_2}$ = Per hectare CO₂ emission from biomass burning; tonnes CO₂e ha⁻¹

$F_{l,burnt}$ = Proportion of *forest* area burned during the *historical reference period* in the *forest class l*; %

⁴⁰ Refers to Table 5.7 in 1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 in IPCC GPG-LULUCF

- $C_{l,p}$ = Average *carbon stock* per hectare in the carbon pool p burnt in the *forest class* l ; tonnes CO₂e ha⁻¹
- $P_{burned,l,p}$ = Average proportion of mass burnt in the carbon pool p in the *forest class* l ; %
- $CE_{l,p}$ = Average combustion efficiency of the carbon pool p in the *forest class* l ; dimensionless
- p = Carbon pool (above-ground biomass, dead wood, litter)
- l = *Forest class*

The combustion efficiencies may be chosen from Table 3.A.14 of IPCC GPG LULUCF. If no appropriate combustion efficiency can be used, the IPCC default of 0.5 should be used. The Nitrogen/Carbon ratio (N/C ratio) is approximated to be about 0.01. This is a general default value that applies to leaf litter, but lower values would be appropriate for fuels with greater woody content, if data are available. Emission factors for use with above equations are provided in Tables 3.A.15 and 3.A.16 of IPCC GPG LULUCF.

Report the values of all estimated parameters in the following table.

Table 12. Parameters used to calculate non-CO₂ emissions from *forest fires*

Forest Class		Parameters									N ₂ O emissions			CH ₄ emissions			Total	
		F_{burnt}	C_{AB}	C_{DW}	C_L	$P_{burned,AB}$	$P_{burned,DW}$	$P_{burned,L}$	CE_{AB}	CE_{DW}	CE_L	GHG_{AB}	GHG_{DW}	GHG_L	GHG_{AB}	GHG_{DW}	GHG_L	GHG
ID	Name	%	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	%	%	%	%	%	%	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹	tCO ₂ e ha ⁻¹

Finally, using the parameters specified in Table 12 and the projected *activity data* from Table 9 calculate the projected total non-CO₂ emissions from *forest fires* and report the results in Table 13.

Table 13. Baseline non-CO₂ emissions from forest fires

Project year	Forest Class 1 (ID and Name)		Forest Class 2 (ID and Name)		Forest Class ... (ID and Name)		Forest Class N (ID and Name)		Total	
	Activity data	Activity data x Total non-CO ₂ GHG	Activity data	Activity data x Total non-CO ₂ GHG	Activity data	Activity data x Total non-CO ₂ GHG	Activity data	Activity data x Total non-CO ₂ GHG	Activity data x Total non-CO ₂ GHG	
yr	Ha	tCO ₂ e	ha	tCO ₂ e	ha	tCO ₂ e	ha	tCO ₂ e	annual tCO ₂ e	cumulative tCO ₂ e
1										
2										
3										
...										
n										
Total		Sum		Sum		Sum		Sum	Sum	

Note: Do this table for the *project area* (Table 13_{PA}) and for the *leakage belt* (Table 13_{LB}) – where considered - and, optionally, for the *reference region* (Table 13_{RR}).

Step 7: Estimation of actual carbon stock changes and non-CO₂ emissions

The goal of this step is to provide an *ex ante* estimate of *carbon stock* change under the *project scenario* and, where included in the *baseline*, non-CO₂ emissions from *forest fires*. Since actual changes will be subject to monitoring and verification, the rationale of estimating them at the beginning of a *crediting period* is to assist in guiding optimal implementation of emission reduction measures, and to allow reasonable projections of revenue to be made.

7.1 Estimation of actual carbon stock changes

This estimation involves the following two tasks:

- 7.1.1 Estimation of the quantity and location of actual *deforestation*
- 7.1.2 Adjustment of the mosaic of *forest polygons* and *classes*
- 7.1.3 Calculation of actual *carbon stock* changes

7.1.1. Estimation of the quantity and location of actual deforestation

At the beginning of a *crediting period*, the quantity and location of actual *deforestation* must be estimated for the *project area* and for each project year (or *monitoring period*). The projected *deforestation* must represent the expected results of the management regime proposed by the project proponent. In most cases modeling of quantity and location of

deforestation will not be necessary and a land-use planning exercise consistent with any existing management plan will be sufficient.

Define the projected quantity and location of actual *deforestation* and justify it by briefly describing the planned management. Refer to any verifiable management plan and prepare Maps of Actual Deforestation for each future year (or *monitoring period*) showing the expected locations of actual *deforestation* and the timing where different *forest* polygons are expected to be deforested under the *project scenario*⁴¹. In most cases, a proxy estimate expressed as a percentage of the *baseline deforestation* will be sufficient to do this *ex-ante* assessment. Where actual *deforestation* is assumed to be a percent number of the *baseline deforestation*, apply the estimated % thorough all *categories*.

7.1.2 Adjustment of the mosaic of forest polygons and classes

Under the project conditions it is possible that different discrete areas of *forest* will change their *carbon density* over time in a rather different way than under the *baseline scenario*.

Where changes in *carbon stock* are due to management, these must be accounted when they are negative and significant (*carbon stock* decrease) and can be accounted when they are positive (*carbon stock* enhancement)⁴².

Changes in *carbon stocks* that are not attributable to management can not be accounted.

Carbon stock decrease:

Where the RED *project activity* includes harvesting of timber⁴³, *carbon stocks* may decrease compared to the *baseline*. If this is the case do the following:

- a) Identify the *forest polygons* within the *project area* that will be subject to logging activities during the *project term*.
- b) Overlay the polygons subject to logging activities to the Land-Use and Land-Cover Map produced in step 2 for the start date of the *crediting period* and identify the *forest classes* that will be subject to logging.
- c) Estimate the impact of timber harvesting on *carbon stocks* of the accounted pools and assess whether such impact implies that certain *polygons* will change to a *forest class* with a lower *carbon density*. It could happen that some *classes* not present under the *baseline* case will exist under the project case. In this case the *carbon densities* of these new *classes* should be estimated following the methodological principles explained under step 6.

⁴¹ Where no deforestation is expected under the *project scenario* briefly explain why this is likely to happen.

⁴² This is to be conservative.

⁴³ *Carbon stocks* in the long-lived wood products carbon pool are conservatively ignored in this version of the methodology.

- d) Present the result of the above assessment in a table (Table 14⁴⁴). Make conservative assumptions regarding the average values of wood density, biomass expansion factor, root-to-shoot ratio and carbon fraction of the harvested trees.
- e) Adjust the mosaic of *forest polygon classes* in the areas subject to logging, taking into account the time points where harvesting is scheduled.
- f) Prepare an adjusted sequence of maps showing the LU/LC situation under the project case for each future project year (or *monitoring period*).

Table 14. List of changes in *forest class* due to logging

Pre-harvest class									Post-harvest class		
Identification		Carbon density	Harvest volume	Average wood density	Average Biomass Expansion Factor	Average root-to-shoot ratio	Average Carbon Fraction	Change in carbon density	Identification		Carbon density
ID	Name	tCO ₂ e ha ⁻¹	m ³ ha ⁻¹ yr ⁻¹	t dm m ⁻³	dimensionless			tCO ₂ e ha ⁻¹	ID	Name	tCO ₂ e ha ⁻¹

Notes:

- Changes in above-ground biomass of trees must be accounted.
- Changes in below-ground biomass of trees are to be accounted, where included.
- Changes in the dead wood biomass, which will be positive in most cases, are conservatively omitted, but should be included if management reduces the *carbon stock* in this pool⁴⁵.
- Do this table for the *project area* (Table 14_{PA}) and for the *leakage belt* (Table 14_{LB}) – where considered -and, optionally, for the *reference region* (Table 14_{RR}).

Carbon stock enhancement:

Consideration of *carbon stock* enhancement is optional in this methodology and can conservatively be ignored.

Carbon stock enhancement is attributable to the RED *project activity* when it happens in the following two types of polygons:

⁴⁴ Use Table 15 instead of Table 14 if *carbon stock* enhancement is included.

⁴⁵ This could be the case, for instance, where local communities will exploit deadwood as a fuel-wood resource of for charcoal production.

- Polygons subject to re-growth after logging activities in the *project scenario*.
- Polygons encompassing areas of degraded or secondary *forests* that would be deforested in the *baseline* case.

Only under the above two circumstances *carbon stock* enhancement is attributable to the RED *project activity*.

Where *carbon stock* enhancement is included in the RED *project activity*, do the following:

- Identify the *forest polygons* that are within the boundaries of the areas that would be deforested under the *baseline scenario* or/and logged under the *project scenario*.
- Select the polygons representing *degraded*⁴⁶ and secondary *forest classes*.
- Develop conservative *stand models* for the *polygons* identified above and briefly describe each of them. Use field data, literature, existing databases and other credible and verifiable sources of information to develop these *stand models*.
- Identify the *forest classes* that will be allocated over time to a *stand model* due to changes in *carbon density* and the time points when *forest class* transitions will occur. It could happen that some *classes* not present under the *baseline* case will exist under the *project* case. In this case the *carbon densities* of these new *classes* should be estimated following the methodological principles explained under step 6. Present the results in tables (Table 15).
- Carbon stock* changes in the selected polygons can only be counted from the date of harvesting or from the date of *baseline deforestation* onward, whichever comes first. This is because before that date *carbon stock* changes in the *baseline* and *project scenario* would be similar.
- Adjust the mosaic of *forest polygon classes* in the areas subject to logging, taking into account the time points where harvesting is scheduled and/or *baseline deforestation* would happen.
- Prepare an adjusted sequence of maps showing the LU/LC situation under the *project* case for each future project year (or *monitoring period*).

Table 15. Stand model X

Age or years since first harvesting	Initial stand volume	Annual growth	Harvest volume	Total change in volume	Averag e wood density	Average Biomass Expansion Factor	Averag e root- to-shoot ratio	Change in living wood biomass	Change in dead wood biomass	Averag e Carbon Fraction	Total change in <i>carbon density</i>	<i>Forest class</i>			
												Identification		<i>Carbon density</i>	
												ID	Name		
yr	m ³ ha ⁻¹	m ³ ha ⁻¹ yr ⁻¹	m ³ ha ⁻¹ yr ⁻¹	m ³ ha ⁻¹ yr ⁻¹	t dm m ⁻³	dimensionless		t dm m ⁻³ yr ⁻¹	t dm m ⁻³ yr ⁻¹	%	tCO ₂ e ha ⁻¹	ID	Name	tCO ₂ e ha ⁻¹	
0															
1															
2															
...															

⁴⁶ “Degraded” polygons include areas subject to logging activities under the *project scenario*.

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7.1.3 Calculation of actual *carbon stock* changes

Use tables 7 to 13 to transparently present the results of the estimated *carbon stock* changes under the *project scenario*.

7.2 Estimation of actual non-CO₂ emissions from *forest fires*

Where *forest* fires have been included in the *baseline*, non-CO₂ emissions from biomass burning must be included in the *project scenario*. Use the methods explained under step 6.2 to estimate these emissions, and table 12 and 13 to transparently report how estimates are calculated. Briefly justify all parameter assumptions.

Assess whether these emissions are significant, in which case they must be accounted and monitored.

Step 8: Estimation of potential decrease in *carbon stock* and increase in GHG emissions due to *leakage*

The goal of this step is to provide an *ex ante* estimate of the potential decrease in *carbon stock* and increase in GHG emissions (other than *carbon stock* changes) outside the *project area* as a consequence of the implementation of the RED *project activity*. As in the case of the *project scenario*, the rationale of estimating *leakage ex ante* is to assist in guiding the design of optimal *leakage* prevention measures, identify sources of *leakage* that are potentially significant, and therefore subject to monitoring, and to make reasonable projections of revenue to be made.

Two sources of *leakage* are considered in this methodology and must be addressed:

- 8.1 Increase in GHG emissions associated with *leakage* prevention measures;
- 8.2 Decrease in *carbon stocks* outside the project boundary due to displacement of *baseline* activities from inside the *project area* to outside.

8.1 Increase in GHG emissions associated with *leakage* prevention measures

If *leakage* prevention measures include tree planting, agricultural intensification, fertilization, fodder production and/or other measures to enhance cropland and grazing land areas, then the increase in GHG emissions associated with these activities must be estimated *ex ante* and, when significant, monitored *ex post*.

In this version of the methodology there are three sources of GHG emissions that could increase due to *leakage* prevention measures:

- 8.1.1 Nitrous oxide (N₂O) emissions from nitrogen fertilization;

8.1.2 Methane (CH₄) and nitrous oxide (N₂O) emissions from livestock intensification (involving a change in the animal diet and/or animal numbers); and

8.1.3 Consumption of fossil fuels.

Where such sources of GHG emissions are not included in the project design, they must not be estimated.

8.1.1 Estimation of N₂O emissions from nitrogen fertilization

To estimate emissions of nitrous oxide (N₂O) from nitrogen fertilization it is necessary to have data on the amount of fertilizer that will be applied in the areas where fertilization will increase compared to the *baseline* situation.

The amount of fertilizer applied can vary depending on soil fertility, economic capacity of the land-user and stage of the production cycle. These factors must be analyzed and duly accounted for in the estimation of the amount of fertilizer applied.

N₂O emissions from fertilization are accounted during the *project term* but not beyond. The most recent version of the CDM-EB approved tool for “Estimation of direct nitrous oxide emissions from nitrogen fertilization” for A/R CDM project activities⁴⁷ must be used.

8.1.2 Estimation of CH₄ and N₂O emissions from grazing animals

To estimate emissions of methane (CH₄) and nitrous oxide (N₂O) from grazing animals it is necessary to collect data on grazing activities that will be implemented in the areas where grazing activities will be increased compared to the *baseline* situation.

The GHG emissions are estimated as follows:

The most common manure management system in the *project area* shall be selected for the estimations of GHG emissions. If different livestock groups or management systems are present, it is possible to calculate the emissions as an area-weighted average of each livestock group and management system. In any case, survey data on livestock type, population, area and management system shall be collected and presented in the PDD. See Appendix 5 for methods to estimate emissions from enteric fermentation and manure management.

8.1.3 Estimation of CO₂ emissions from fossil fuels

Leakage prevention measures may involve increased consumption of fossil fuels. Estimate these emissions using the latest CDM-EB approved tool for “Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities”⁴⁸.

⁴⁷ Available at: http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

⁴⁸ Available at: http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

8.1.4 Total increase in GHG emissions due to *leakage* prevention measures

Summarize the results of the previous estimations in Table 16, where only significant sources must be reported.

Table 16. *Leakage* due to *leakage* prevention measures

Project year	Fertilization		Grazing Animals						Fossil Fuels		Total	
	N ₂ O emissions		CH ₄ emissions from enteric fermentation		CH ₄ emissions from manure management		N ₂ O emissions from manure management		CO ₂ emissions			
	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative
Year	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e
1												
2												
...												
N												
Total	Sum		Sum		Sum		Sum		Sum		Sum	

8.2 Estimation of decreases in *carbon stocks* due to displacement of *baseline* activities

Baseline activities that would be implemented inside the *project area* in the absence of the RED *project activity* could be displaced outside the project boundary due to the implementation of the RED *project activity*.

Two different groups of *deforestation* agents could displace their *baseline activities* in case of *frontier deforestation*:

- Deforestation agents living inside or near the project area.*** In most cases these local groups will be local and indigenous communities or individuals producing small impacts on *forest cover* and whose *baseline activities* are not the main cause of *frontier deforestation*. GHG emissions from *baseline activities* displaced by these groups will not be significant in most cases and should be addressed in the design of the *project activity* by excluding from the *project area* the *forest* locations that are likely to be deforested by these groups and by providing sustainable livelihood alternatives to them. However, where local groups are likely to displace their *baseline activities* due to the *project activity* and significantly impact on *carbon stocks* outside the *project area*, the methods described in Appendix 6, which are similar to those proposed in the methodology for “*mosaic deforestation*” (RED-NM-001), must be used to estimate these impacts.
- Deforestation agents expected to encroach into the project area as infrastructure develops.*** In most cases, immigrant groups will be expected to cause most of the *frontier deforestation*. Influencing the land-use decisions of these groups may be difficult, particularly if they are coming from distant locations and are driven by powerful economic reasons. *Leakage* prevention measures may not be sufficient to avoid some level of activity displacement by these immigrant groups. To address potential *leakage* in this case use one of the following options.

- Option 1: Time discount approach
- Option 2: *Leakage* measured and accounted in a broader program
- Option 3: Buffer of credits

Select the approach deemed most applicable to the RED *project activity* and briefly justify the choice.

Option 1: Time discount approach

Under the time discount approach, *leakage* is assumed to be the difference between actual emission reductions and their net present value for climate change mitigation. The net present value is calculated based on the assumption that the *project activity* will cause a 100% displacement of the *baseline deforestation*. As a consequence, the overall *deforestation* rate will not change compared to the *baseline* situation. However, the total area of unprotected *forest* will be reduced due to the implementation of the RED *project activity*, which will anticipate the time point when *deforestation* will end and reduce the total area deforested in the long-term.

Using a 100-year time horizon, a discount rate of 1%, and the atmospheric carbon decay curve from the version of the Bern model used in the IPCC's Third Assessment Report, Fearnside (2007) calculate the net present value of avoiding the emission of one ton of CO₂ as being 0.6 tCO₂e. Thus, under option 1, *leakage* due to displacement of *baseline* activities is assumed to be 40% of the project's net anthropogenic GHG emission reductions calculated without leakage discount.

Option 2: *Leakage* measured and accounted in a broader

Under this approach, *leakage* from the project activity is measured and accounted in a broader RED program (e.g. a state- or nation- wide RED program) instead of being measured and deducted from the project's net emission reductions. To demonstrate that *leakage* is being measured and accounted in a broader RED program, provide evidence about the following:

- a) A broader RED program covering the region encompassing the *project area* exists and it has adopted a RED target or established a regional *deforestation baseline*.
- b) A plan to reduce and monitor *deforestation* in the region surrounding the *project area* has been established and will monitor *deforestation* during the *crediting period* of the RED *project activity*. Any increase in *deforestation* outside the boundary of the *project activity* will be detected by the monitoring plan of the broader RED program and included in its GHG accounting.
- c) The broader RED program is implemented by or on behalf of a national or sub-national public entity and is consistent with existing policies and regulations.

Where the above conditions are not yet in place, but a regional or national RED program is being designed, the proponent of the RED *project activity* may enter into an agreement with the entity managing the broader RED program to prove that any *leakage* due to activity

displacement from the *project area* to the surrounding region will be counted as a GHG emission of the region's broader program. Such agreement may include additional clauses, such as transfer of a share of the stream of emission reductions (or revenues from sales of emission reductions) issued from the *project activity* to the broader program. Emission reductions transferred to the program entity may be used as a credit buffer to compensate possible future excess emission above the region's *deforestation baseline* while transferred revenues from sales of emission reductions may be invested in *RED activities* of the broader program.

Option 3: Buffer of credits

With this option, the net anthropogenic GHG emissions reductions are calculated without taking into account displacement of *baseline activities* of immigrant groups. Instead, a percentage of the credits issued for the emissions reductions will be earmarked. The percentage to be earmarked must be determined based on an objective assessment of the risk of *leakage* due to displacement of immigrant *baseline* activities.

Earmarked credits will have to be hold in a credit account that is not under the control of the project participants and such earmarked credits will not be available for trade. However, the earmarked credits can be transferred to a broader RED program entity, as per option 2, once such a program exists. Transfer can be either in form of credited emission reductions or revenues from their sale, whichever has been agreed between the project entity and the program entity.

Option 3 is useful where conditions required for option 2 are not fully met at the time of validation, but where it is expected that a broader RED program will be implemented in the future.

8.3 Estimation of total leakage

Summarize the result of all significant sources of *leakage* in Table 18 by keeping separate accounting of *carbon stocks* and GHG emissions.

Table 18. Ex ante estimated leakage

Project year	Leakage prevention measures		Activity displacement		$C_{LEAKAGE}$					
					Carbon stock changes		GHG emissions		Total	
	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative	annual	cumulative
	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e
1										
2										
...										
n										

The net anthropogenic GHG emission reduction of a RED *project activity* is calculated as follows:

Where:

$$C_{LEAKAGE} = \text{leakage greenhouse gas emissions; tonnes CO}_2\text{e}$$

Table 19. *Ex ante* net anthropogenic GHG emission reductions (C_{RED})

[illegible]

In the absence of regulatory and methodological guidance on how to quantify carbon credits based on *carbon stock* changes and permanent GHG emission reductions in RED *project activities* no specific methods are given here. Project proponents are encouraged to keep a separate accounting of *carbon stock* changes and permanent emissions and to explore possible approaches to quantify credits by the potential buyers of emission reductions⁴⁹.

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Part 3 – Methodology for verification and re-validation of the *baseline*

The *ex post* methodology (to be implemented immediately after project start) includes two main tasks:

- 1) Monitoring (to be implemented during the *crediting period*); and
- 2) Adjustment of the *baseline* for the subsequent *crediting period* (to be implemented at the end of each *crediting period*).

Task 1: Monitoring

There are four monitoring tasks:

- 1.1 *Baseline* monitoring
- 1.2 Project monitoring
- 1.3 *Leakage* monitoring
- 1.4 *Ex post* calculation of net anthropogenic GHG emission reduction

Prepare a Monitoring Plan describing how these tasks will be implemented. For each task the monitoring plan must include the following sections:

- a) Technical description of the monitoring task.
- b) Data to be collected.
- c) Overview of data collection procedures.
- d) Quality control and quality assurance procedure.
- e) Data archiving.
- f) Organization and responsibilities of the parties involved in all the above.

1.1 Monitoring of the *baseline*

To monitor the *baseline*, do the following:

- Monitor the driver variables used to model the quantity (hectares) of future *deforestation*.
- Generate spatial data sets for the spatial driver variables that are changing, showing how key features such as roads develop over time.
- If a modeling approach has been used to project the baseline deforestation rate, calculate the *post facto baseline deforestation* rate (in hectares) every 5 to 10 years using the observed values for the driver variables. Where an observed change in a driver is due to the *project activity*, ignore that change, and assume it would have happened as predicted in the *baseline* study.

- .
- Calculate the percentage of *post facto baseline deforestation* (in hectares) relative to the *ex ante* estimated *baseline deforestation*, and:
 - If the calculated percentage is $< 80\%$, multiply the *ex ante* calculated *carbon baseline* ($C_{BASELINE}$) for the following five years by the percentage value calculated above;
 - If the calculated percentage is $> 100\%$, conservatively assume that the *ex ante* calculated *carbon baseline* ($C_{BASELINE}$) is still valid (= do nothing).
- At the end of each *crediting period*, revisit the *deforestation* model and make all necessary adjustments to reassess the *carbon baseline* ($C_{BASELINE}$) for the future *crediting period* and *project term*.

1.2 Monitoring of the *project activity*

This task involves:

- 1.2.1 Monitoring of project implementation: measures to reduce *deforestation* and measures to reduce the risk of *leakage*.
- 1.2.2 Monitoring of land-use and land-cover change.
- 1.2.3 Monitoring of *carbon stocks* and non-CO₂ emissions.
- 1.2.4 Monitoring of large natural disturbances.

1.2.1 Monitoring of project implementation

The rationale of monitoring project implementation is to register all project activities implemented by the RED *project activity* (including *leakage* prevention measures) that could cause an increase in GHG emissions compared to the without project case.

Do the following:

- Describe, date and geo-reference, as necessary, all measures implemented by the *project activity*.
- Where applicable, collect all relevant data to estimate *carbon stock* changes due to *forest management* and displacement of *baseline activities*, as well as GHG emissions due to *leakage* prevention measures. Refer to Part 2 of the methodology for the variables to be measured.
- State whether the measures are implemented according to those described in the PDD;
- Record and justify any deviation to the interventions planned.

1.2.2 Monitoring of land-use and land-cover change

Monitoring of land-use and land-cover change has a twofold objective:

- 1) To measure actual *deforestation* so that the net anthropogenic greenhouse gas emission reductions of a *monitoring period* can be quantified and verified *ex post*; and
- 2) To collect data that will be necessary to revisit the *baseline* for the subsequent *crediting period*.

The following guidance is given:

- Record all changes in the polygon boundaries of *forest classes* within the *project area* using remotely sensed and/or GPS data and report such changes for each *monitoring period*.
- To renew the *baseline* for the subsequent *crediting period*, data on changes in the polygon boundaries of *forest classes* within the *reference region* must be collected for at least three time points (beginning, middle and end of the *crediting period*). For periodical verifications within a *crediting period* only the *project area* must be monitored.
- Where remotely sensed data are collected and analyzed, the data should be of the same type and source of those that were used to establish the *baseline*. Within a *crediting period*, data analysis methods should be those described in the methodology annex of the PDD⁵⁰.
- In case of an improvement of the quality of data and data analysis methods, these must be either: announced at validation and described in the monitoring plan, or they can only be used for the subsequent *crediting periods* subject to validation by an operational entity.
- In case of a change in data and/or methods, redo the analysis of the past period using the new data and data analysis methods and record all changes by updating the methodology document in the annex to the PDD in order to ensure that future monitoring will use the new data and methods.

1.2.3 Monitoring of *carbon stock* changes and non-CO₂ emissions

In principle, the *ex ante* estimated average *carbon densities* per *LU/LC class* and *emission factors* per *LU/LC change category* should not be changed during a *crediting period*. Monitoring of *carbon stocks* will therefore not be necessary in most cases.

However, when new and more accurate *carbon stock* data become available, these can be used to estimate the net anthropogenic GHG emission reduction of the subsequent *crediting period*. For the current *crediting period*, new data on *carbon stocks* can only be used if they are

⁵⁰ Emission reductions of a *monitoring period* should be calculated using a consistent methodology within a crediting period. If a change in methods during a crediting period is accepted by the verifying operational entity, the *baseline* must be re-assessed with the new methodology.

validated by the operational entity that verifies the *project activity*. If new data are used in the current *crediting period*, the *baseline* must be recalculated using the new data.

Carbon stocks may be subject to monitoring under the following circumstances:

- *Carbon stock* data used in *ex ante* estimations were of low precision, which leads to small *emission factors* due to the conservative principle. With new and more precise (and accurate) data it is expected that *emission factors* will increase significantly.
- During the current *crediting period*, certain *forest* polygons are expected to change *carbon density* and convert to *forest classes* that did not exist at the beginning of the project (e.g. due to aging of secondary or planted *forests*, or *forest management*).

Where *carbon stocks* are monitored, follow the guidance on sampling and measuring *carbon stocks* of Appendix 3.

Non-CO₂ emissions must be subject to monitoring under the following circumstances:

- Emissions from *forest* fire were included in the *baseline*. In this case, under the *project scenario* it will be necessary to monitor the variables of Table 12 within the *project area*.
- Some *leakage* prevention measures are implemented within the *project area* and according to the *ex ante* assessment are likely to significantly increase sources of non-CO₂ emissions above the pre-project situation. In this case, it will be necessary to monitor these sources.

1.2.4 Monitoring of natural disturbances

Natural disturbances such as tsunamis, sea level rise, volcanic eruption, landslide, flooding, permafrost melting, pest, disease, etc. can impact on the area, *carbon stocks* and non-CO₂ GHG emissions of a *forest*⁵¹. Such changes can be abrupt or gradual and when significant, they should be factored-out from the estimation of *ex post* net anthropogenic GHG emission reductions.

- Where natural disturbances reduce the area of *forest*, measure the boundary of the polygons of lost *forest* and exclude the area within such polygons from the *project area* in both, the *baseline* and *project scenarios*.
- Where natural disturbances have an impact on *carbon stocks*, measure the boundary of the polygons where such changes happened and the change in *carbon stock* within

⁵¹ When the 1997-1998 El Niño episode provoked severe droughts in the Amazon and Indonesia, large areas of tropical forest burned, releasing 0.2 to 0.4 Gt of carbon to the atmosphere (de Mendonça *et al.*, 2004; Siegert *et al.*, 2001; Page *et al.*, 2002). If droughts become more severe in the future through more frequent and severe el Niño episodes (Trenberth and Hoar, 1997; Timmermann *et al.*, 1999), or the dry season becomes lengthier due to deforestation-induced rainfall inhibition (Nobre *et al.*, 1991; Silva-Dias *et al.*, 2002) or there are rainfall reductions due to climate change (White *et al.*, 1999; Cox *et al.*, 2000), then substantial portions of the 200 Gt of carbon stored globally on tropical forest trees could be transferred to the atmosphere in the coming decades (Santilli *et al.*, 2005).

each polygon. Assume that a similar *carbon stock* change would have happened in the *forest* under the *baseline* case (if the polygon is already deforested in the *baseline*, assume no *carbon stock* change in the *baseline*).

- Where gradual changes in *carbon stocks* are likely to be significant (e.g. due to the effects of climate change), monitor *carbon stocks* in permanent sample plots located in the *LU/LC classes* expected to change. Factoring-out would then imply changing the *ex ante* estimated *carbon densities* and *emission factors*. Such changes are subject to verification by an independent operational entity.

1.3 Monitoring of *leakage*

All sources of *leakage* identified as significant in the *ex ante* assessment are subject to monitoring. Two sources of *leakage* are potentially subject to monitoring:

- 1.3.1 Increase in GHG emissions associated with *leakage* prevention measures;
- 1.3.2 Increased *deforestation* outside the project boundary due to displacement of *baseline* activities.

1.3.1 Monitoring of GHG emissions associated with *leakage* prevention measures

Monitoring of the sources of emissions associated to *leakage* prevention measures must happen with the methods and tools described in Part 2 of the methodology.

1.3.2 Monitoring of *deforestation* outside the project boundary due to displacement of *baseline* activities

Leakage due to displacement of *baseline activities* of endogen *deforestation* agent's group, when detected as significant in the *ex ante* assessment, must be monitored using the methods described in Appendix 6.

Leakage due to displacement of *baseline activities* implemented by immigrant *deforestation* agent's group need not to be monitored under this methodology.

1.4 *Ex post* net anthropogenic GHG emission reductions

The calculation of *ex post* net anthropogenic GHG emission reductions is similar to the *ex ante* calculation with the only difference that *ex post* measured emissions must be used in the case of the *project scenario* and *leakage*.

In case of *post facto* adjusted carbon baselines, *ex post* improvements of *carbon stock* estimates, or factoring-out of the impact of natural disturbances, the *ex ante* estimated *baseline* must be replaced by a *post facto baseline*.

Task 2: Revisiting the *baseline* projections for future *crediting periods*

Baselines must be revisited over time because agents, drivers and underlying causes of *deforestation* change dynamically. Frequent and unpredicted updating of the *baseline* can create serious market uncertainties. Therefore, the procedure used to update the *baseline* should be transparent, the periodicity of the updates defined *ex ante* and not less than 5 years or more than 10 years.

Tasks involved in revisiting the *baseline* are:

- 2.1 Update information on agents, drivers and underlying causes of *deforestation*
- 2.2 Adjust the land-use and land-cover change component of the *baseline*
- 2.3 Adjust, as needed, the carbon component of the *baseline*

2.1 Update of the information on agents, drivers and underlying causes of *deforestation*

Information on agents, drivers and underlying causes in the *reference region* and *project area* must be collected periodically, as these are essential for improving future *deforestation* projections and the design of the *project activity*.

- Collect information that is relevant to understand *deforestation* agents, drivers and underlying causes.
- Redo step 3 of the *ex ante* methodology.
- When new data on the spatial driver variables (SDV_i) used to model *deforestation* risk become available, collect these data and create update spatial datasets in order to update the “Distance Maps” for the subsequent *crediting period*.

2.2 Adjustment of the land-use and land-cover change component of the *baseline*

LU/LC-change is the component of the *baseline* that is more likely to change over time. Two components need to be adjusted:

- 2.2.1 The *deforestation* rate; and
- 2.2.2 The location of *deforestation*.

2.2.1 Adjustment of the quantity of future *deforestation*

At the end of each *crediting period*, the *baseline deforestation* rate of the *reference region*, *leakage belt* and *project area* need to be revisited and eventually adjusted for the subsequent *crediting period*. The adjusted *baseline rates* must be submitted to an independent validation.

Adjustments are made using the methods described in part 2 of the methodology and using the data obtained from monitoring LU/LC changes in the *reference region* during the past *crediting period* and updated information on *deforestation* agents, drivers and underlying cases of *deforestation* including (spatial) and non-spatial driver variables.

2.2.2 Adjustment of the location of future *deforestation*

Using the quantity of future *baseline deforestation* (as adjusted according to 2.2.1 above) and the methods explained in part 2 of the methodology, the location of future *baseline deforestation* must be reassessed and adjusted, as needed.

2.3 Adjustment of the carbon component of the *baseline*

Adjusting the carbon component of the *baseline* involves improving the estimation of the average *carbon densities* of *LU/LC classes* and adjusting *emission factors* accordingly. See task 1.2.3 on this topic.

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Appendix 1 - Definitions

For the purposes of this methodology, the following terms⁵² are defined as indicated. Defined terms are underlined within the body of the methodology.

Activity Data is the area (ha) of a *category of LU/LC-change* for a given period of time.

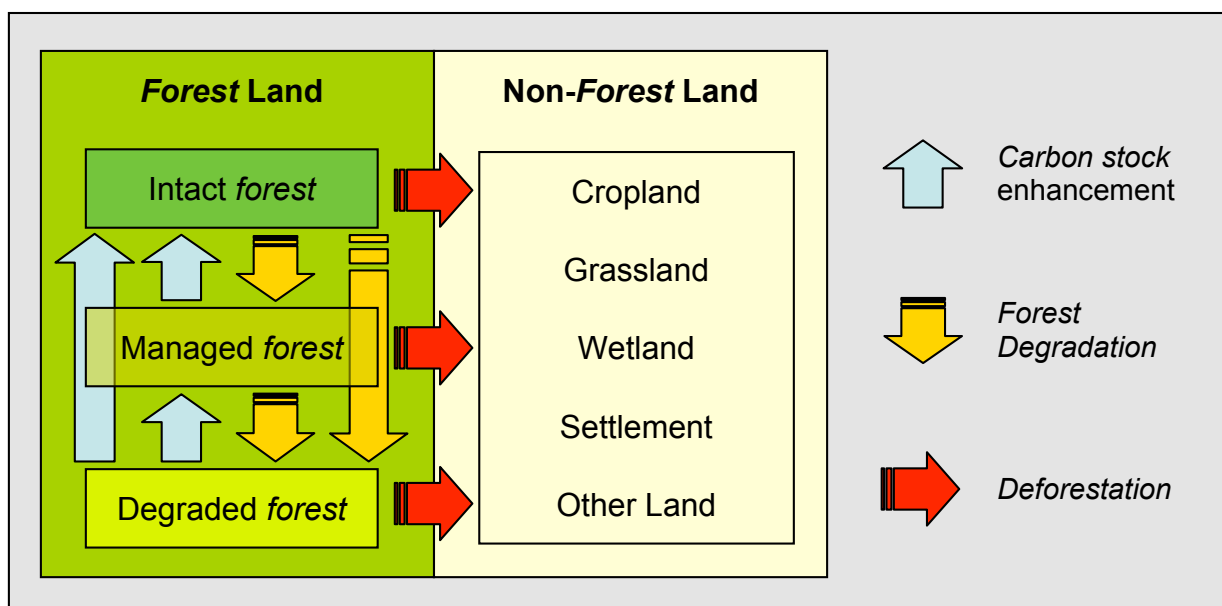
Actual Emission Level is the sum of *carbon stock* changes that occurs within the boundary of the *project area* under the proposed RED *project activity*.

Baseline Scenario is the expected change in land use and land cover (LU/LC) within the boundary of the *project area* in the absence of any *project activity* designed to reduce emissions from *deforestation, forest degradation, or enhance carbon stocks*.

Baseline is the sum of *carbon stock* changes that would occur within the boundary of the *project area* in the absence of the proposed RED *project activity*.

Broad Category is the term used in this methodology to identify three main *categories* of LU/LC-change: *deforestation, forest degradation and forest regeneration* (Figure A1-1):

Figure A1-1. Broad categories of land-use and land-cover change



Carbon Density is the amount of carbon (as CO₂e) per hectare (ha⁻¹) estimated to be present in the accounted carbon pools of a *LU/LC Class*.

⁵² With ongoing political discussion and negotiations on a possible future REDD mechanism, many terms, definitions and key methodological issues have not yet been decided. This methodology adopts the definitions outlined below, which are subject to revision as the international political, regulatory and methodological framework evolves.

Carbon Stock is the *carbon density* of an area times the number of hectares in the area.

Category of LU/LC-Change (or simply “*category*”) is the change from one *LU/LC class* to another that occurs during a given period of time.

Category is the term used in IPCC reports to refer to specific sources of emissions or removals of greenhouse gases. Under the AFOLU sector, “categories” are land-use / land-cover (LU/LC) transitions. RED methodologies deal with the following categories:

- (a) *Forest Land to Forest Land* (degradation and regeneration of *forest land* remaining *forest land*)
- (b) *Forest Land to Crop Land* (*deforestation* followed by agriculture)
- (c) *Forest Land to Grassland* (*deforestation* followed by pasture)
- (d) *Forest Land to Settlements* (*deforestation* followed by settlements)
- (e) *Forest Land to Wetlands* (*deforestation* followed by wetlands)
- (f) *Forest Land to Other Land* (*deforestation* followed by other land)

Activities that convert non-*forest* land back to *forest* (Crop Land to *Forest Land*, Grassland to *Forest Land*, etc.) are considered afforestation and reforestation and are excluded from RED methodologies.

Class. See *LU/LC Class*.

Crediting Period is the renewable period of time over which *baseline* and crediting calculations will be undertaken, defined as up to 10 years in this methodology. The *crediting period* is the period of time during which a *baseline* does not need to be updated, actual changes are monitored, and credits are eventually issued for *ex post* verified emission reductions. The *crediting period* should be up to 10 years (De Jong *et al.*, 2005; Brown *et al.*, 2007b) and is renewable as long as a demonstrable *deforestation* threat exists within the *project area* but at which time the *baseline* would need to be re-visited to see if the rate of *deforestation* in the *reference region* and associated drivers has changed.

Deforestation is the direct, human-induced and long-term (or permanent) conversion of *forest* land to non-*forest* land⁵³. It occurs when at least one of the parameter values used to define “*forest land*” is reduced from above the threshold for defining “*forest*” to below this threshold for a period of time that is longer than the period of time used to define “*temporarily un-stocked*”⁵⁴. For example, if a country defines a *forest* as having a

⁵³ Forest area and carbon stock losses due to natural disturbances (landslides, consequences of volcanic eruptions, and sea level rise, among other) are not considered “deforestation”.

⁵⁴ According to IPCC (GPG LUUCF, 2003, Chapter 4.2.6.2.) “The identification of units of land subject to deforestation activities requires the delineation of units of land that:

- (a) Meet or exceed the size of the country’s minimum forest area (i.e., 0.05 to 1 ha); and
- (b) Have met the definition of forest on 31 December 1989; and
- (c) Have ceased to meet the definition of forest at some time after 1 January 1990 as the result of direct human-induced deforestation.”

crown cover greater than 30% and “temporarily un-stocked” as a maximum period of 3 years, then *deforestation* would not be recorded until the crown cover is reduced below 30% for at least three consecutive years⁵⁵. Country should develop and report criteria by which temporary removal or loss of tree cover can be distinguished from *deforestation*.

Eligible Land. To avoid double counting of emission reductions, land areas registered under the CDM or under any other carbon trading scheme (both voluntary and compliance-oriented) should be transparently reported and excluded from the *project area*.

Emission Factor is the difference between the *carbon density* of the two *LU/LC classes* describing a *category of LU/LC-change*.

Forest is a land with woody vegetation consistent with the thresholds used to define “forest land” in the country where the RED *project activity* will be implemented. Where the country has adopted a *forest* definition for the Kyoto Protocol, the minimum thresholds of the vegetation indicators (minimum area, tree crown cover and height)⁵⁶ used for defining “forests”, as communicated by the DNA⁵⁷ consistent with decision 11/CP.7 and 19/CP.9, should be used. Otherwise, the definition used to define “Forest Land” in the national GHG inventory should be used.

Land defined as “forest land” can include areas that do not, but at maturity *in situ* could potentially reach, the thresholds used to define “forest land”. To distinguish between “non-forest” (and hence “deforested”) and “temporarily un-stocked” areas in managed *forests*, the definition of “forest” should include the maximum period of time that the woody vegetation can remain below the thresholds used to define “forest land”. This maximum period can be specific for each *category* of land-use / land-cover change (LU/LC-change). For instance, it could be zero years for conversion from “forest land to crop land”, but up to 5 or more years for transitions between *forest* classes (e.g. age classes)⁵⁸.

⁵⁵ Deforestation can be the result of an abrupt event (deforestation = forest → non-forest), in which case the change in land-cover and land-use occurs immediately and simultaneously; or of a process of progressive degradation (deforestation = forest → degraded forest → non-forest), in which case the change in land-cover occurs when one of the parameters used for defining “forest land” falls below its minimum threshold, but the change in land-use may have already occurred or will occur later (e.g. use of the land for the production of crops or grazing animals). Land-use is thus not a reliable indicator for identifying a forest class or for defining a category of change.

⁵⁶ “Forest is a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 metres at maturity *in situ*. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high portion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 – 30 per cent or tree height of 2 – 5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily un-stocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest”.

⁵⁷ DNA = Designated National Authority of the Clean Development Mechanism.

⁵⁸ Project proponents should report on how they distinguish between deforestation and areas that remain forests but where tree cover has been removed temporarily, notably areas that have been harvested or have been subject to other human or natural disturbance but for which it is expected that forest will be replanted or regenerate naturally. See IPCC GPG LULUCF, 2003, Chapter. 4.2.6.2.1 for further guidance on this issue.

Areas covered with planted *forests* as well as with any other anthropogenic vegetation type that meet the definition of “*forest*” since the earliest date of the *historical reference period* used to assess *deforestation* can be considered “*forest land*”. Hence, “*forests*” can be natural, semi-natural, or anthropogenic and they may include primary or old-growth *forests* (intact or logged), secondary *forests*, planted *forests*, agro-forestry and silvo-pastoral systems.

Forest degradation is “*forest land remaining forest land*” but gradually losing *carbon stocks* as a consequence of direct-human intervention (e.g. logging, fuel-wood collection, fire, grazing, etc.)⁵⁹. Units of *forest land* subject to degradation are allocated to different *forest classes* over time, with each successive *class* having a lower *carbon density* than the previous one. The difference in average *carbon density* between two contiguous *forest classes* should be at least 10%. The difference refers to the upper and lower levels of the confidence intervals of the two contiguous *forest classes* in the degradation sequence (Figure A1-2).

Forest management. Areas subject to sustainable *forest management* (with logging activities) represent a particular *class* of “*degraded forest*”. An undisturbed natural *forest* that will be subject to sustainable *forest management* will lose part of its carbon, but the loss will partially recover over time. In the long-term, a sustainable harvesting and re-growth cycle will maintain a constant average *carbon density* in the *forest*. Since this average *carbon density* is lower than in the original *forest*, sustainably managed *forests* can be considered a degraded *forest class*.

Depending on the magnitude and timeframe of the *carbon stock* changes, managed *forests* could be classified into one single “*managed forest*” *class* (with a *carbon density* equivalent to the average of the entire management cycle) or to different sub-*classes* representing different average carbon densities (Figure A1-2).

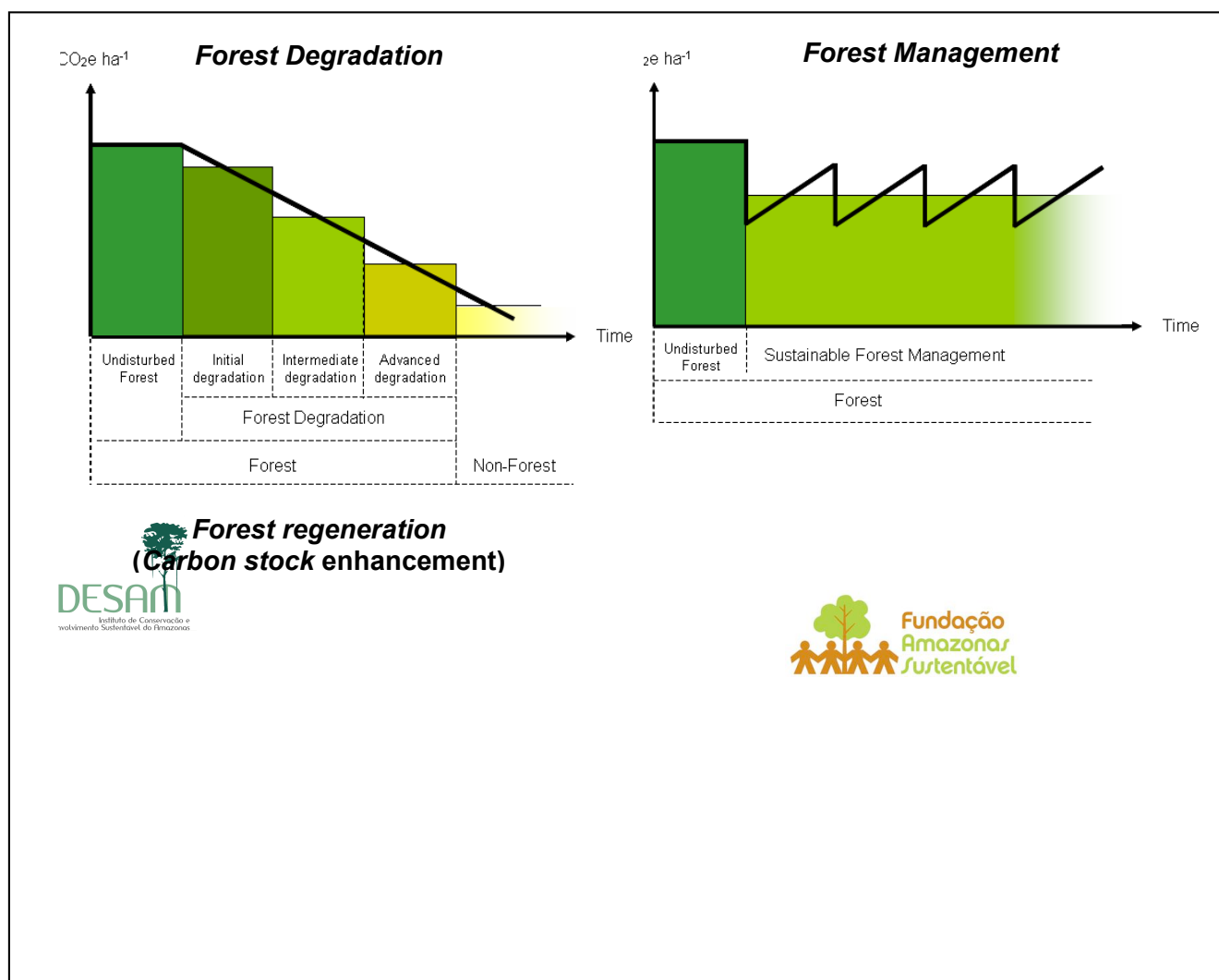
Forest Regeneration is “*forest land remaining forest land*” but gradually enhancing its *carbon stock* as a consequence of direct-human intervention. Units of *forest land* subject to regeneration are allocated to different *forest classes* over time, with each successive *forest class* having a higher *carbon density* than the previous one. The difference in average *carbon density* between two contiguous *forest classes* should be at least 10%. The difference refers to the upper and lower levels of the confidence intervals of the two *forest classes*.

Frontier Deforestation is the conversion of *forest land* to non-*forest land* occurring when the agricultural frontier expands as a result of improved access to *forest* into areas with relatively little human activity.

⁵⁹ According to IPCC GPG LULUCF “*forest degradation*” is “a direct, human-induced, long-term (persisting for *X* years or more) or at least *Y*% of forest carbon stock [and forest values] since time *T* and not qualifying as *deforestation*”. Note that *X*, *Y*% and *T* are not quantified. See IPCC 2003 (Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types, Chapter 2.2) for a discussion on the definition of “*forest degradation*”, in particular Table 2.1 for alternative definitions of direct human-induced *forest degradation*.

Historical Reference Period is a time period preceding the starting date of the proposed RED project activity. It is analyzed to determine the magnitude of *deforestation* and *forest degradation* in the *reference region* and to identify agents and drivers of DD and the chain of events leading to land-use / land-cover change. In order to be useful for understanding recent and likely future DD trends, the starting date of the *historical reference period* should be selected between 10 and 15 years in the past, and the end date as close as possible to present.

Figure A1-2. Carbon density in “forest land remaining forest land”(living tree biomass)



Leakage is the decrease in *carbon stocks* and the increase in GHG emissions attributable to the implementation of the RED *project activity* that occurs outside the boundary of the *project area*.

Leakage belt is the geographical area where *baseline* activities could be displaced as a consequence of the implementation of the RED *project activity* and the area where such activity displacement will be monitored.

LU/LC Class (or simply “*class*”) is a unique combination of land use and land cover having a specific *carbon density*.

LU/LC Polygon is a discrete area falling into a single *LU/LC class*.

Monitoring period is the period of time (in years) between two monitoring and verification events. Typically it is a fraction of the *crediting period*. The minimum duration is one year and the maximum is the duration of the *crediting period*.

Mosaic Deforestation is the conversion of *forest* land to non-*forest* land occurring in a patchy pattern where human population and associated agricultural activities and infrastructure (roads, towns, etc.) are spread out across the landscape and most areas of *forest* within such a configured region or country are practically already accessible.

Planned Deforestation is the legally authorized conversion of *forest* land to non-*forest* land occurring in a discrete area of land. *Deforestation* within an area can be planned (designated and sanctioned) or unplanned (unsanctioned). *Planned deforestation* can include a wide variety of activities such as national resettlement programs from non-forested to forested regions; a component of a national land plan to reduce the *forest* estate and convert it to other industrial-scale production of goods such as soybeans, pulpwood plantations, and oil palm plantations; or plans to convert well-managed community-owned *forests* to other non-*forest* uses. Other forms of *planned deforestation* could also include decisions by individual land owners, whose land is legally zoned for agriculture, to convert their say selectively logged *forest* to crop production. These *planned deforestation* activities would be a component of some land planning or management document and could be readily verified.

Project Activity is the series of planned steps and activities by which the proponent intends to reduce *deforestation* and *forest degradation* and/or enhance *forest regeneration*.

Project Area is the area or areas of land on which the proponent will undertake the *project activities*. No lands on which the *project activity* will not be undertaken can be included in the *project area*.

Project Scenario is the expected change in land use and land cover within the boundary of the *project area* resulting from the undertaking of the *project activity*.

Project Term is the period of time over which the proponents plan to undertake the *project activity* on the *project area*. The *project term* will be chosen by the proponents, typically as a multiple of the *crediting period*.

Reference Region is the spatial delimitation of the analytic domain from which information about *deforestation* and degradation agents, drivers and LU/LC-change is obtained, projected into the future and monitored. The *reference region* includes the *project*

*area*⁶⁰ and is defined by the project proponent using transparent criteria. It must contain *LU/LC classes* and *deforestation* agents and drivers similar to those found in the *project area* under the *baseline* and *project scenarios*.

Stand Model is the term used in approved A/R CDM methodologies to describe the unique combination of the natural features of a *forest* stand, such as its species composition and growth, and the management applied to it during its life cycle.

⁶⁰ The methodology thus adopts a so called “Stratified Regional *Baseline*” (SRB) approach, which has been recommended in recent literature (Sathaye and Andrasko, 2007; Brown *et al.*, 2007a)

Appendix 2 - Tables

Table 1. Guidance on carbon pool selection depending on the *land-use / land-cover change category* considered⁶¹

Type of land-use / land-cover transition	Living biomass (trees)		Dead organic matter			Soil
	Above-ground	Below-ground	Wood products	Dead wood	Litter	Organic matter
<i>Forest to cropland</i>	+++	++	+	+	+	+
<i>Forest to pasture</i>	+++	++	+	+	+	
<i>Forest to shifting cultivation</i>	+++	++		+		
<i>Forest to degraded forest</i>	+++	++	+			
+++ = include always; ++ = inclusion recommended; + = inclusion possible						

Table 2. Present availability of optical mid-resolution (10-60m) sensors (Brown *et al.*, 2007a)

Nation	Satellite & sensor	Resolution & coverage	Cost (archive ⁶²)	Feature
U.S.A.	Landsat-5 TM	30 m 180×180 km ²	600 US\$/scene 0.02 US\$/km ²	Images every 16 days to any satellite receiving station. Operating beyond expected lifetime.
U.S.A.	Landsat-7 ETM+	30 m 60×180 km ²	600 US\$/scene 0.06 US\$/km ²	On April 2003 the failure of the scan line corrector resulted in data gaps outside of the central portion of images, seriously compromising data quality
U.S.A./Japan	Terra ASTER	15 m 60×60 km ²	60 US\$/scene 0.02 US\$/km ²	Data is acquired on request and is not routinely collected for all areas
India	IRS-P2 LISS-III & AWIFS	23.5 & 56 m		Experimental craft shows promise, although images are hard to acquire
China/Brazil	CBERS-2 HRCCD	20 m		Experimental; Brazil uses on-demand images to bolster their coverage.
Algeria/China/Nigeria/Turkey/U.K.	DMC	32 m 160×660 km ²	3000 €/scene 0.03 €/km ²	Commercial; Brazil uses alongside Landsat data
France	SPOT-5 HRVIR	5-20 m 60×60 km ²	2000 €/scene 0.5 €/km ²	Commercial Indonesia & Thailand used alongside Landsat data

⁶¹ Modified from Brown, S., F. Achard, R. de Fries, G. Grassi, N. Harris, M. Herold, D. Mollicone, D. Pandey, T. Pearson, D. Shoch, 2007. Reducing Greenhouse Gas emission from deforestation and Degradation in Developing Countries: A Sourcebook of Methods and Procedures for Monitoring, Measuring and Reporting (Draft Version, 10.November, 2007).

⁶² Some acquisitions can be programmed (e.g., DMC, SPOT). The cost of programmed data is generally at least twice the cost of archived data.

Table 3. Example of a potential land use-change matrix

Final \ Initial		Forest land				
		Class 1	Class 2	Class 3	Class 4	Class 5
Forest Land	Class 1	Category 1/1	Category 2/1	Category 3/1	Category 4/1	Category 5/1
	Class 2	Category 1/2	Category 2/2	Category 3/2	Category 4/2	Category 5/2
	Class 3	Category 1/3	Category 2/3	Category 3/3	Category 4/3	Category 5/3
	Class 4	Category 1/4	Category 2/4	Category 3/4	Category 4/4	Category 5/4
	Class 5	Category 1/5	Category 2/5	Category 3/5	Category 4/5	Category 5/5
Grassland	Class 6	Category 1/6	Category 2/6	Category 3/6	Category 4/6	Category 5/6
Cropland	Class 7	Category 1/7	Category 2/7	Category 3/7	Category 4/7	Category 5/7
Wetland	Class 8	Category 1/8	Category 2/8	Category 3/8	Category 4/8	Category 5/8
Settlement	Class 9	Category 1/9	Category 2/9	Category 3/9	Category 4/9	Category 5/9
Other Land	Class 10	Category 1/10	Category 2/10	Category 3/10	Category 4/10	Category 5/10

Table 4. Example of a land-use / land-cover change matrix

<div>Final \ Initial</div>			Forest land											Final area
			Old growth forests		Degraded old growth forest			Secondary forest			Plantations			
			Intact	managed	initial	intermediate	advanced	initial	intermediate	advanced	young	mid	mature	
Forest Land	Old-growth	Intact	100											100
		managed	1	5										6
	Degraded	Initial	1		2									3
		intermediate			2	1								3
		advanced				2	3							5
	Secondary	Initial						2						2
		intermediate						1	3					4
		advanced							1	1				2
	Plantations	Young					1	1	1		1		1	5
		Mid									1	2		3
		Mature											1	1
Grassland		unimproved	1	1	1	2		1	1	1				8
		improved				1	1							2
Cropland				1		1		2	3	3				10
Wetland														0
Settlement														0
Other Land														0
Initial Area			103	7	5	7	5	7	9	5	2	2	2	154
Net Change			-3	-1	-2	-4	0	-5	-5	-3	3	1	-1	0

Notes:

- Numbers represent hectares or *activity data* (in this case numbers are for illustrative purposes only, they do not represent any real case).
- Column and rows totals show net conversion of each LU/LC-class.
- “Initial” indicates the area of the LU/LC-class at the starting date of the period assessed, and “Final” the area of the class at the end date of the assessment period.
- Net changes (bottom rows) are the final area minus the initial area for each of the LU/LC-classes shown at the head of the corresponding column.
- Blank entries indicate no LU/LC-change the period assessed.

**Table 5. Approximate values of daily biomass intake (d. m. – dry mass)
for different type of animals⁶³**

Animal Type		Daily Feed Intake (MJ head ⁻¹ day ⁻¹)	Daily Biomass Intake (kg d. m. head ⁻¹ day ⁻¹)
Sheep	Developed Countries	20	2.0
	Developing Countries	9	1.3
Goats	Developed Countries	14	1.4
	Developing Countries	14	1.4
Mules/Asses	Developed Countries	60	6.0
	Developing Countries	60	6.0
Sources: Feed intake from Crutzen <i>et al.</i> (1986).			

⁶³ Taken from AR-AM0003 version 2

Box 1: Geomod

Geomod is a land-use land-cover change simulation model implemented in Idrisi, a GIS software developed by Clark University (Pontius *et al.*, 2001; Brown *et al.*, 2007). Geomod has been used frequently to analyze *baseline scenarios* of deforestation at continental scale for Africa, Asia and Latin America; at the country scale for Costa Rica and India; and at local scale within India, Egypt, United States and several countries in Latin America (Pontius and Chen, 2006).

Geomod is a grid-based model that predicts the transition from one *LU/LC class* to another *LU/LC class*, i.e. the location of grid cells that change over time from *class 1* to *class 2*. Hence, Geomod can be used to predict areas likely to change from *forest class 1* to non-forest *class 2* (*deforestation*) over a given time.

Geomod creates the LU/LC-change risk map empirically, by using several driver images and the land-cover map from the beginning time. For example, Geomod's *deforestation* risk maps have relatively high values at location that have biogeophysical attributes similar to those of the deforested land (= "developed land" in Geomod's jargon) of the beginning time, and has relatively low values at locations that have biogeophysical attributes similar to those of forested land ("non-developed" land) of the beginning time.

Box 2. Example of Simple Error Propagation analysis (Tier 1 method) (Taken from Brown *et al.*, 2007)

Carbon pool	Average carbon stock t C ha ⁻¹	95% CI t C ha ⁻¹
Above-ground biomass	113	11
Dead wood	18	3
Litter	7	2

Therefore the total stock is 138 t C/ha and the uncertainty = $\sqrt{11^2 + 3^2 + 2^2} = 11.6 \text{ tC / ha}$

	Mean	95% CI	Uncertainty %
Area (ha)	8564	1158	14
Carbon stock (tC ha ⁻¹)	138	11,6	8

Therefore the total carbon stock over the stratum is: $8564 * 138 = 1,181,832 \text{ t C}$

And the uncertainty = $\sqrt{14^2 + 8^2} = 15.9\%$

15.9% of 1,181,832 = 188,165 t C

Appendix 3 – Methods to estimate *carbon stocks*

Sampling framework

The sampling framework, including sample size, plot size, plot shape and plot location should be specified in the PDD.

Areas to be sampled in *forest classes* should be at locations expected to be deforested according to the baseline projections.

The sampling areas for *non-forest classes* should be selected within the *reference region* at locations that represent a chrono-sequence of 10 to 30 years since the *deforestation* date.

Temporary or permanent plots

Plots can be temporary or permanent depending on the specific project circumstances, interests and needs, but in general temporary plots should be sufficient.

Where changes in *carbon stocks* are to be monitored, permanent sampling plots are recommended. Permanent sample plots are generally regarded as statistically efficient in estimating changes in *forest carbon stocks* because typically there is high covariance between observations at successive sampling events. However, it should be ensured that the plots are treated in the same way as other lands within the project boundary, e.g., during logging operations, and should not be destroyed over the monitoring interval. Ideally, staff involved in *forest management* activities should not be aware of the location of monitoring plots. Where local markers are used, these should not be visible.

Permanent plots may also be considered to reduce the uncertainty of the average *carbon density* of a *forest class* undergoing *carbon stock* changes due to management and to detect changes in *carbon stocks* induced by climate change or large-scale natural disturbances.

Definition of the sample size and allocation among *LU/LC-classes*

The number of sample plots is estimated as dependent on accuracy, variability of the parameter to estimate in each class and costs. Where at the beginning of a RED *project activity* accurate data for sample size estimation and allocation are not available, the sampling size can initially be estimated by using a desired level of accuracy (10% of sampling error at 95% confidence level), and by allocating the estimated sample size proportionally to the area of each *class*⁶⁴, using respectively equations 1, and 2. Then, once data on *carbon stock* variability within each *class* become available, the sample size and allocation is recalculated using the methodology described by Wenger (1984), which also accounts for the cost of sampling (see equations 3 and 4).

Equation 1 was chosen because it works with percentages rather than absolute units (biomass, carbon, or CO₂), and coefficient variation data could be easier to find in the literature at the beginning of a *project activity*. The initial allocation of the sample plots shall be proportional

⁶⁴ Loetsch, F. and Haller, K. 1964. Forest Inventory. Volume 1. BLV-VERLAGS GESE LLSCHAFT, München.

to the area of the *LU/LC-classes*, but with minimum of 5 plots per class. The t-student for a 95% confidence level is approximately equal to 2 when the number of sample plot is over 30. As the first step, use 2 as the t –student value, and if the resulting “*n*” is less than 30, use the new “*n*” to get a new t-student value and conduct the new estimation of the sample size. This process can be repeated until the calculated *n* is stabilized.

$$n = \frac{t_{st}^2 \cdot (CV\%)^2}{(E\%)^2 + \frac{t_{st}^2 \cdot (CV\%)^2}{N}} \quad (A3-1)$$

$$n_i = n \cdot \frac{N_i}{N} \quad (A3-2)$$

Where:

- i* = 1, 2, 3, *L LU/LC classes*
- L* = Total number of *LU/LC classes*
- t_{st}* = t-student value for a 95% confidence level (initial value *t* = 2)
- n* = total number of sample units to be measured (in all *LU/LC classes*)
- E%* = allowable sample error in percentage ($\pm 10\%$)
- CV%* = the highest coefficient of variation (%) reported in the literature from different volume or biomass *forest* inventories in *forest* plantations, natural *forest*, agro-forestry and/or silvo-pastoral systems
- n_i* = number of samples units to be measured in *LU/LC class i* that is allocated proportional to the size of the class. If estimated *n_i* < 3, set *n_i* = 3.
- N_i* = maximum number of possible sample units for *LU/LC class i*, calculated by dividing the area of *class i* by the measurement plot area
- N* = population size or maximum number of possible sample units (all *LU/LC classes*), $N = \sum_{i=1}^{m_p} N_i$

In equation 3 the standard deviation of each *LU/LC class* (*S_i*) shall be determined using the actual data from the latest field measurement. The allowable error is an absolute value, and can be estimated as $\pm 10\%$ of the observed overall average *carbon stock* per hectare. It is possible to reasonably modify the *LU/LC class* limits and the sample size after each monitoring event based on the actual variation of the *carbon stock* changes determined from taking “*n*” sample plots. Where costs for selecting and measuring plots are not a significant consideration then the calculation and allocation of the sample size can be simplified by setting *C_i* equal to 1 across all *LU/LC classes*.

$$n = \left(\frac{t_{st}}{E} \right)^2 \left[\sum_{i=1}^{m_p} W_i \cdot S_i \cdot \sqrt{C_i} \right] \cdot \left[\sum_{i=1}^{m_p} W_i \cdot S_i / \sqrt{C_i} \right] \quad (A3-3)$$

$$n_i = n \cdot \frac{W_i \cdot S_i / \sqrt{C_i}}{\sum_{i=1}^{m_p} W_i \cdot S_i / \sqrt{C_i}} \quad (\text{A3-4})$$

Where:

- i = 1, 2, 3, ... L *LU/LC classes*
- L = total number of *LU/LC classes*
- t_{st} = t-student value for a 95% confidence level, with $n-2$ degrees of freedom
- E = allowable error ($\pm 10\%$ of the mean)
- S_i = standard deviation of *LU/LC class i*
- n_i = number of samples units to be measured in *LU/LC class i* that is allocated proportional to $W_i \cdot S_i / \sqrt{C_i}$. If $n_i < 3$, set $n_i = 3$
- W_i = N_i/N
- n = total number of sample units to be measured (in all *LU/LC classes*)
- N_i = maximum number of possible sample units for *LU/LC class i*, calculated by dividing the area of *LU/LC class i* by the measurement plot area
- N = population size or maximum number of possible sample units (all strata),

$$N = \sum_{i=1}^{m_p} N_i$$
- C_i = cost to select and measure a plot of the *LU/LC class i*

Sample plot size

The plot area a has major influence on the sampling intensity, time and resources spent in the field measurements. The area of a plot depends on the stand density. Therefore, increasing the plot area decreases the variability between two samples. According to Freese (1962), the relationship between coefficient of variation and plot area can be denoted as follows:

$$CV_2^2 = CV_1^2 \sqrt{(a_1 / a_2)} \quad (\text{A3-5})$$

Where a_1 and a_2 represent different sample plot areas and their corresponding coefficient of variation (CV). Thus, by increasing the sample plot area, variation among plots can be reduced permitting the use of small sample size at the same precision level. Usually, the size of plots is between 100 m² for dense stands and 1000 m² for open stands⁶⁵.

Plot location

⁶⁵ It is recommended to use sample plots of equal area for the strata. This methodology can not be used if sample plots area varies within the same stratum. The density of trees to be considered is the one at maturity of the trees.

To avoid subjective choice of plot locations (plot centers, plot reference points, movement of plot centers to more “convenient” positions), the permanent sample plots shall be located systematically with a random start, which is considered good practice in IPCC GPG-LULUCF. This can be accomplished with the help of the project GIS platform and a GPS in the field. The geographical position (GPS coordinate), administrative location, stratum and stand, series number of each plots shall be recorded and archived.

Also, it is to be ensured that the sampling plots are as evenly distributed as possible. For example, if one stratum consists of three geographically separated sites, and then it is proposed to

- Divide the total stratum area by the number of plots, resulting in the average area represented by each plot;
- Divide the area of each site by this average area per plot, and assign the integer part of the result to this site. e.g., if the division results in 6.3 plots, then 6 plots are assigned to this site, and 0.3 plots are carried over to the next site, and so on.

Estimation of *carbon stocks*

The total average *carbon stock* per hectare (= *carbon density*) in a *LU/LC class* is estimated by the following equation:

$$C_l = C_{l,AB} + C_{l,BB} + C_{l,DW} + C_{l,L} + C_{l,SOC} \quad (A3-6)$$

Where:

- C_l = Average *carbon stock* per hectare in the carbon pools of the *LU/LC-class l*; tonnes CO₂e ha⁻¹
- $C_{l,AB}$ = Average *carbon stock* per hectare in the above-ground biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹
- $C_{l,BB}$ = Average *carbon stock* per hectare in the below-ground biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹
- $C_{l,DW}$ = Average *carbon stock* per hectare in the dead wood carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹
- $C_{l,L}$ = Average *carbon stock* per hectare in the litter carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹
- $C_{l,SOC}$ = Average *carbon stock* per hectare in the soil organic carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

Note: Of all the abovementioned carbon pools, only $C_{l,AB}$ (above-ground biomass) is mandatory.

Estimation of *carbon stocks* in the living biomass carbon pools ($C_{l,AB}$ and $C_{l,BB}$)

In a *forest* most of the carbon is stored in the tree component of the living biomass. Hence, for a majority of *forest* classes it is sufficient to estimate the *carbon stock* in the tree component and to ignore the *carbon stock* in the non-tree vegetation component.

However, there might be situations where *carbon stocks* in the non-tree vegetation component are significantly increased in the *LU/LC-classes* adopted after *deforestation* (e.g. coffee plantations). Under such circumstances, *carbon stocks* in the non-tree vegetation component should be estimated⁶⁶.

The living biomass components that are measured and the minimum diameter at breast height (DBH) above which trees are measured should be specified in the PDD.

Carbon stocks in the living biomass are given by the following equations:

$$C_{l,AB} = C_{l,AB,tree} + C_{l,AB,non-tree} \quad (A3-7)$$

$$C_{l,BB} = C_{l,BB,tree} + C_{l,BB,non-tree} \quad (A3-8)$$

Where:

$C_{l,AB}$ = Average *carbon stock* per hectare in the above-ground biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,AB,tree}$ = Average *carbon stock* per hectare in the above-ground tree biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,AB,non-tree}$ = Average *carbon stock* per hectare in the above-ground non-tree biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,BB}$ = Average *carbon stock* per hectare in the below-ground biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,BB,tree}$ = Average *carbon stock* per hectare in the below-ground tree biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,BB,non-tree}$ = Average *carbon stock* per hectare in the below-ground non-tree biomass carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

Tree component ($C_{l,AB,tree}$ and $C_{l,BB,tree}$)

The *carbon stock* of trees can be estimated using: (a) Existing *forest* inventory data; or (b) Direct field measurements.

(a) Estimations using *forest* inventory data

(See the GOFC-GOLD sourcebook on REDD (Brown *et al.*, 2007a) for more details)

Forest inventory data typically comes in two different forms: (1) Stand tables and (2) Stock tables.

⁶⁶ The same carbon pools are to be estimated for the two classes of a LU/LC-change category.

- (a.1) Stand tables provide the number of trees in diameter (DBH) classes. The method basically involves estimating the biomass per average tree of each diameter class of the stand table, multiplying by the number of trees in the class, and summing across all classes. The mid-point diameter of a diameter class should be used in combination with an allometric biomass regression equation (explained later).

Stand tables often include trees with a minimum diameter of 30 cm or more, which essentially ignores a significant amount of carbon particularly for younger *forests* or heavily logged. To overcome this problem Gillespie *et al.* (1992) developed a technique that can be used to estimate the number of trees in lower diameter classes (see Box 1).

Box 1. Adding diameter classes to truncated stand tables

DBH-Class	Midpoint Diameter	Number of Stems per ha
cm	cm	Nr
10-19	15	-
20-29	25	-
30-39	35	35.1
40-49	45	11.8
50-59	55	4.7
...

DBH class 1 = 30-39 cm, DBH class 2 = 40-49 cm

Ratio = $35.1/11.8 = 2.97$

Therefore, the number of trees in the 20-29 cm class is:

$2.97 \times 35.1 = 104.4$

To calculate the 10-19 cm class:

$104.4/35.1 = 2.97$,

$2.97 \times 104.4 = 310.6$

- (a.2) Stock tables indicate the volume of merchantable timber by diameter class or total per hectare. If volume data are just for commercial species do not use them for estimating *carbon stocks*, because a large and unknown proportion of the total volume is excluded.

The biomass density can be calculated from Volume Over Bark (*VOB*) by multiplying this value with the Biomass Conversion and Expansion Factor (*BCEF*). When using this approach and default values of the *BCEF* provided in the IPCC GL AFOLU, it is important that the definitions of *VOB* match. The values of *BCEF* for tropical *forests* in the AFOLU report are based on a definition of *VOB* as follows:

“Inventoried volume over bark of free bole, i.e. from stump or buttress to crown point or first main branch. Inventoried volume must include all trees, whether presently commercial or not, with a minimum diameter of 10 cm at breast height or above buttress if this is higher”.

Values of the *BCEF* are given in Table 4.5 of the IPCC FL AFOLU guidelines, and those relevant to tropical humid broadleaf and pine *forests* are shown in the Table 1.

Table 1. Values of *BCEF* for application to volume data
(Modified by Brown *et al.* (2007a) from Table 4.5 in IPCC GL AFOLU)

Forest type	Growing stock volume –average and range (<i>VOB</i> , m ³ /ha)						
	<20	21-40	41-60	61-80	80-120	120-200	>200
Natural broadleaf	4.0 2.5-12.0	2.8 1.8-304	2.1 1.2-2.5	1.7 1.2-2.2	1.5 1.0-1.8	1.3 0.9-1.6	1.0 0.7-1.1
Conifer	1.8 1.4-2.4	1.3 1.0-1.5	1.0 0.8-1.2	0.8 0.7-1.2	0.8 0.6-1.0	0.7 1.6-0.9	0.7 0.6-0.9

In cases where the definition of *VOB* does not match exactly the definition given above, Brown *et al.* (2007b) recommend the following:

- If the definition of *VOB* also includes stem tops and large branches then the lower bound of the range for a given growing stock should be used;
- If the definition of *VOB* has a large minimum top diameter or the *VOB* is comprised of trees with particularly high basic wood density then the upper bound of the range should be used.

Forest inventories often report volumes for trees above a minimum *DBH*. To include the volume of *DBH* classes below the minimum *DBH*, Brown *et al.* (2007a) propose Volume Expansion Factors (*VEF*). However, due to large uncertainties in the volume of smaller *DBH* classes, inventories with a minimum diameter that is higher than 30 cm should not be used. Volume expansion factors range from about 1.1 to 2.5, and are related to the *VOB*₃₀ as follows to allow conversion of *VOB*₃₀ to a *VOB*₁₀ equivalent:

- For *VOB*₃₀ < 250 m³/ha use the following equation:

$$VEF = \text{Exp}(1.300 - 0.209 * \ln(\text{VOB}_{30})) \quad (\text{A3-9})$$

- For *VOB*₃₀ > 250 m³/ha use *VEF* = 1.9

See Box 2 for a demonstration of the use of the *VEF* correction factor and *BCEF* to estimate biomass density.

Box 2. Use of volume expansion factor (*VEF*) and biomass conversion and expansion factor (*BCEF*)

Tropical broadleaf forest with a *VOB*₃₀ = 100 m³/ha

- (1) Calculate the *VEF*:
 $VEF = \text{Exp}(1.300 - 0.209 * \ln(100)) = 1.40$
- (2) Calculate *VOB*₁₀:
 $VOB_{10} = 100 \text{ m}^3/\text{ha} \times 1.40 = 140 \text{ m}^3/\text{ha}$
- (3) Take the *BCEF* from the table 7 above:
BCEF for tropical hardwood with growing stock of 140 m³/ha = 1.3

- (4) Calculate above-ground biomass density:
= $1.3 \times 140 = 182 \text{ t/ha}$

Below-ground tree biomass (roots) is almost never measured, but instead is included through a relationship to above-ground biomass (usually a root-to-shoot ratio). If the vegetation strata correspond with tropical or subtropical types listed in Table 2 (modified by Brown *et al.*, 2007a from Table 4.4 in IPCC GL AFOLU to exclude non-forest or non-tropical values and to account for incorrect values) then it makes sense to include roots.

Table 2. Root to shoot ratios
(Modified by Brown *et al.* (2007a) from Table 4.4. in IPCC GL AFOLU)

Domain	Ecological Zone	Above-ground biomass	Root-to-shoot ratio	Range
Tropical	Tropical rainforest	<125 t.ha ⁻¹	0.20	0.09-0.25
		>125 t.ha ⁻¹	0.24	0.22-0.33
	Tropical dry forest	<20 t.ha ⁻¹	0.56	0.28-0.68
		>20 t.ha ⁻¹	0.28	0.27-0.28
Subtropical	Subtropical humid forest	<125 t.ha ⁻¹	0.20	0.09-0.25
		>125 t.ha ⁻¹	0.24	0.22-0.33
	Subtropical dry forest	<20 t.ha ⁻¹	0.56	0.28-0.68
		>20 t.ha ⁻¹	0.28	0.27-0.28

(b) Estimations using direct field measurements

Two methods are available to estimate the *carbon stock* of trees: (1) Allometric Equations method, and (2) Biomass Expansion Factors (*BEF*). The Allometric Equations method should be favored over the *BEF* method. However, if no biomass equations are available for a given species or *forest type*, the *BEF* method shall be used.

(b.1) Allometric method

1. In the sample plots, identify the plot unique identification number and record the measurement date. Then identify the tree species and identification numbers and measure the diameter at breast height (*DBH*, at 1.3 m above ground), and possibly, depending on the form of the allometric equation, the height of all the trees above a minimum *DBH*.
2. Choose or establish the appropriate allometric equations for each species or species group *j*.

$$TB_{ABj} = f_j(DBH, H)_{AB} \quad (A3-10)$$

Where:

TB_{ABj} = above-ground biomass of a tree of species *j*, kg tree⁻¹

$f_j(DBH, H)_{AB}$ = an allometric equation for species *j*, linking above-ground tree biomass (in kg tree⁻¹) to diameter at breast height (*DBH*) and possibly tree height (*H*).

The allometric equations are preferably local-derived and species-specific. When allometric equations developed from a biome-wide database, such as those in Annex 4A.2, Tables 4.A.1 and 4.A.2 of GPG LULUCF, are used, it is necessary to verify by destructively harvesting, within the project area but outside the sample plots, a few trees of different sizes and estimate their biomass and then compare against a selected equation. If the biomass estimated from the harvested trees is within about ±10% of that predicted by the equation, then it can be assumed that the selected equation is suitable for the project. If this is not the case, it is recommended to develop local allometric equations for the project use. For this, a sample of trees, representing different size classes, is destructively harvested, and its total biomass is determined. The number of trees to be destructively harvested and measured depends on the range of size classes and number of species: the greater the heterogeneity the more trees are required. If resources permit, the carbon content can be determined in the laboratory. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as tree diameter and total height (see Chapter 4.3 in GPG LULUCF). Also generic allometric equations can be used, as long as it can be proven that they are conservative.

3. Estimate the *carbon stock* in the above-ground biomass of all trees measured in the permanent sample plots using the allometric equations selected or established for each

species or group of species.

$$TC_{AB,tr} = TB_{AB,tr} \cdot CF_j \quad (A3-11)$$

Where:

$$\begin{aligned} TC_{AB,tr} &= \text{Carbon stock in above-ground biomass of tree } tr; \text{ kg C tree}^{-1} \\ TB_{AB,tr} &= \text{Above-ground biomass of tree } tr; \text{ kg tree}^{-1} \\ CF_j &= \text{Carbon fraction for tree } tr, \text{ species } j; \text{ tonnes C (tonne d. m.)}^{-1} \end{aligned}$$

4. Calculate the *carbon stock* in above-ground biomass per plot on a per area basis. Calculate by summing the *carbon stock* in above-ground biomass of all trees within each plot and multiplying by a plot expansion factor that is proportional to the area of the measurement plot. This is divided by 1,000 to convert from kg to tonnes.

$$PC_{AB,p} = \frac{\left(\sum_{tr=1}^{TR_p} TC_{AB,tr} \cdot XF \right)}{1000} \quad (A3-12)$$

$$XF = \frac{10,000}{AP} \quad (A3-13)$$

Where:

$$\begin{aligned} PC_{AB,p} &= \text{Carbon stock in above-ground biomass in plot } p; \text{ tonnes C ha}^{-1} \\ TC_{AB,tr} &= \text{Above-ground biomass of tree } tr; \text{ kg tree}^{-1} \\ XF &= \text{Plot expansion factor from per plot values to per hectare values} \\ AP &= \text{Plot area; m}^2 \\ tr &= 1, 2, 3, \dots TR_p \text{ number of trees in plot } p; \text{ dimensionless} \end{aligned}$$

5. Calculate the average *carbon stock* by averaging across all plots within a *LU/LC class*.

$$C_{l,AB} = 44/12 * \frac{\sum_{p=1}^{PL_l} PC_{AB,p}}{PL_l} \quad (A3-14)$$

Where:

$$\begin{aligned} C_{l,AB} &= \text{Average carbon stock in above-ground biomass in LU/LC class } l; \text{ tonnes CO}_2\text{e ha}^{-1}. \\ PC_{AB,p} &= \text{carbon stock in above-ground biomass in plot } p; \text{ tonnes C ha}^{-1} \\ 44/12 &= \text{Ratio converting C to CO}_2\text{e} \\ pl &= 1, 2, 3, \dots PL_l \text{ plots in LU/LC class } l; \text{ dimensionless} \\ PL_l &= \text{Total number of plots in LU/LC class } l; \text{ dimensionless} \end{aligned}$$

6. Estimate the *carbon stock* in the below-ground biomass of tree *tr* using root-shoot ratios and above-ground *carbon stock* and apply steps 4 and 5 to below-ground biomass.

$$TC_{BB,tr} = TC_{AB,tr} \cdot R_j \quad (A3-15)$$

$$PC_{BB,p} = \frac{\left(\sum_{tr=1}^{TR} TC_{BB,tr} \cdot XF \right)}{1000} \quad (A3-16)$$

$$C_{l,BB} = \frac{\sum_{pl=1}^{PL_l} PC_{BB,p}}{PL_l} \quad (A3-17)$$

Where:

$TC_{BB,tr}$	=	Carbon stock in below-ground biomass of tree <i>tr</i> ; kg C tree ⁻¹
$TC_{AB,tr}$	=	Carbon stock in above-ground biomass of tree <i>tr</i> ; kg C tree ⁻¹
R_j	=	Root-shoot ratio appropriate for species <i>j</i> ; dimensionless
$PC_{BB,p}$	=	Carbon stock in below-ground biomass in plot <i>p</i> ; tonnes C ha ⁻¹
XF	=	Plot expansion factor from per plot values to per hectare values
AP	=	Plot area; m ²
<i>tr</i>	=	1, 2, 3, ... TR_p number of trees in plot <i>p</i> ; dimensionless
$C_{l,BB}$	=	average <i>carbon stock</i> in below-ground biomass in LU/LC class <i>l</i> ; tonnes CO ₂ e ha ⁻¹ .
44/12	=	Ratio converting C to CO ₂ e
<i>pl</i>	=	1, 2, 3, ... PL_l plots in LU/LC class <i>l</i> ; dimensionless
PL_l	=	total number of plots in LU/LC class <i>l</i> ; dimensionless

(b.2) Biomass Expansion Factor (BEF) Method

1. In the sample plots, identify the plot unique identification number and record the measurement date. Then identify the tree species and identification numbers and measure the diameter at breast height (*DBH*, at 1.3 m above ground), and possibly, depending on the form of the volume equation, the height of all the trees above a minimum *DBH*.
2. Estimate the volume of the commercial component per each tree based on locally derived equations by species or species group. Then, sum for all tree within a plot, and express it as commercial volume per unit of area (m³ ha⁻¹). It is also possible to combine step b.1 and step b.2 if there are available field instruments that measure volume per hectare directly (e.g. a Bitterlich relascope). The volume per plot is an ancillary variable, and it may be needed in some cases to estimate the proper biomass expansion factor or

the root-shoot ratio.⁶⁷

$$V_{tr} = f_j(DBH, H)_V \quad (A3-18)$$

$$V_p = \sum_{tr=1}^{TR} V_{tr} \cdot XF \quad (A3-19)$$

$$XF = \frac{10,000}{AP} \quad (A3-20)$$

Where:

- V_{tr} = commercial volume of tree tr ; $m^3 \text{ tree}^{-1}$
- $f_j(DBH, H)_V$ = a commercial volume equation for species or species group j , linking commercial volume to diameter at breast height (DBH) and possibly tree height (H).
- tr = 1, 2, 3, ... TR_p number of trees in plot p ; dimensionless
- XF = Plot expansion factor from per plot values to per hectare values
- AP = plot area; m^2

3. Choose a biomass expansion factor (BEF) and a root-shoot ratio (R). The BEF and root-shoot ratio vary with local environmental conditions, species and age of trees, and the volume of the commercial component of trees, therefore, they should be calculated for each plot in a given *LU/LC class*. Use the result from '2' to choose them.

These parameters can be determined by either developing a local regression equation or selecting from national inventory, Annex 3A.1 Table 3A.1.10 of GPG LULUCF, or from published sources.

If a significant amount of effort is required to develop local $BEFs$ and root-shoot ratio, involving, for instance, harvest of trees, then it is recommended not to use this method but rather to use the resources to develop local allometric equations as described in the allometric method above (refers to Chapter 4.3 in GPG LULUCF). If that is not possible either, national species specific defaults for BEF and R can be used. Since both BEF and the root-shoot ratio (R) are age or stand density dependent, it is desirable to use age-dependent or stand density-dependent equations (for example, volume per hectare). Stem wood volume can be very small in young stands and BEF can be very large, while for old stands BEF is usually significantly smaller. Therefore using average BEF value may result in significant errors for both young stands and old stands. It is preferable to use allometric equations, if the equations are available, and as a second best solution, to use age-dependent or stand density-dependent $BEFs$ (but for very young trees, multiplying a small number for stem wood with a large number for the BEF can result in significant error).

4. Convert the volume of the commercial component of each tree in a plot into *carbon*

⁶⁷ See for example: Brown, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A primer. FAO Forestry Paper 134, UN FAO, Rome.

stock in above-ground biomass and below-ground biomass per tree via basic wood density, BEF, root-shoot ratio and carbon fraction (applicable to the species):

$$TC_{AB,tr} = V_{tr} \cdot D_j \cdot BEF_p \cdot CF_j \quad (A3-21)$$

$$TC_{BB,tr} = TC_{AB,tr} \cdot R_{j,p} \quad (A3-22)$$

Where:

- $TC_{AB,tr}$ = Carbon stock in above-ground biomass of tree *tr*; kg C tree⁻¹
- $TC_{BB,tr}$ = Carbon stock in below-ground biomass of tree *tr*; kg C tree⁻¹
- V_{tr} = Commercial volume of tree *tr*; m³ tree⁻¹
- D_j = Wood density for species *j*; tonnes d. m. m⁻³ (See IPCC GPG-LULUCF, 2003 Table 3A.1.9 or USDA wood density table⁶⁸)
- BEF_p = Biomass expansion factor for converting volumes of extracted round wood to total above-ground biomass (including bark), applicable to tree *tr*, in plot *p*; dimensionless
- CF_j = Carbon fraction applicable to tree *tr* of species *j*; tonnes C (tonne d. m.)⁻¹.
- $R_{j,p,t}$ = Root-shoot ratio, applicable to tree *tr* of species *j* in plot *p*; dimensionless

5. Continue with step a.4 of the allometric equation method to calculate the *carbon stock* in above-ground and below-ground biomass by aggregating successively at the tree, plot, and *LU/LC class* levels.

Non-tree component ($C_{l,AB,non-tree}$ and $C_{l,BB,non-tree}$)

In tropical *forests* non-tree vegetation includes palms, shrubs, herbaceous plants, lianas and other epiphytes. These types of plants are difficult to measure. Unless they form a significant component of the ecosystem, they should not be measured, which is conservative as their biomass is usually much reduced in the *LU/LC classes* adopted after *deforestation*.

Carbon stock estimations for the non-tree vegetation components are usually based on destructive harvesting, drying and weighting. These methods are described in the Sourcebook for LULUCF projects (Pearson *et al.*, 2006) from which most of the following explanations are taken.

For herbaceous plants, a square frame (30cm x 30 cm) made from PVC pipe is sufficient for sampling. For shrubs and other large non-tree vegetation, larger frames should be used (about 1-2 m², depending on the size of the vegetation). For specific *forest* species (e.g. bamboo) or crop types (e.g. coffee) it is also possible to develop allometric equations.

When using destructive sampling, apply the following steps:

⁶⁸ Reyes *et al.*, 1992. Wood densities of tropical tree species. USDA.

- a. Place the clip frame at the sampling site. If necessary, open the frame and place around the vegetation.
- b. Clip all vegetation within the frame to ground level. Cut everything growing within the quadrat (ground surface not three-dimensional column) and sample this.
- c. Weigh the sample and remove a well-mixed sub-sample for determination of dry-to-wet mass ratio. Weight the sub-sample in the field, then oven-dry to constant mass (usually at ~ 70 °C).
- d. Calculate the dry mass of each sample. Where a sub-sample was taken for determination of moisture content use the following equation:

$$\text{Dry mass} = \left(\frac{\text{subsample dry mass}}{\text{subsample fresh mass}} \right) * \text{fresh mass of whole sample} \quad (\text{A3-23})$$

- e. The *carbon stock* in the above-ground non-tree biomass per hectare is calculated by multiplying the dry mass by an expansion factor calculated from the sample-frame or plot size and then by multiplying by the carbon fraction and CO₂/C ratio. For calculating the average *carbon stock* per LU/LC class, average over all samples:

$$C_{l,AB,non-tree} = \frac{\sum_{pl=1}^{PL_l} DM_{pl} * EF * CF_{pl} * 44/12}{PL_l} \quad (\text{A3-24})$$

Where:

$C_{l,AB,non-tree}$ = Average *carbon stock* per hectare in the above-ground non-tree biomass carbon pool of the LU/LC class l ; tonnes CO₂e ha⁻¹

DM_{pl} = Dry mass of sample pl ; tonnes of d.m.

EF = Plot expansion factor = [10.000 / Plot Area (m²)]; dimensionless

CF_{pl} = Carbon fraction of sample pl ; tonnes C (tonne d. m.)⁻¹

44/12 = Ratio converting C to CO₂e

pl = 1, 2, 3, ... PL_l plots in LU/LC class l ; dimensionless

PL_l = total number of plots in LU/LC class l ; dimensionless

- f. The *carbon stock* per hectare of the below-ground non-tree biomass is calculated by multiplying the estimated above-ground estimate by and appropriate root to shoot ratio.

Estimation of *carbon stocks* in the dead wood carbon pool ($C_{l,DW}$)

Carbon stocks in the dead wood carbon pool is insignificant or zero in most agricultural and pastoral *LU/LC classes* but can be significant in *forest classes*. Therefore, in most cases it will be conservative to ignore the dead wood carbon pool.

Deadwood comprises two types: standing dead wood and lying dead wood. Different sampling and estimation procedures are used to estimate the *carbon stocks* of the two components.

$$C_{l,DW} = C_{l,SDW} + C_{l,LDW} \quad (A3-25)$$

Where:

$C_{l,DW}$ = Average *carbon stock* per hectare in the dead wood carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,SDW}$ = Average *carbon stock* per hectare in the standing dead wood carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{l,LDW}$ = Average *carbon stock* per hectare in the lying dead wood carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

Dead wood shall be measured using the sampling criteria and monitoring frequency used for measuring live trees. The following description of methods to measure and estimate *carbon stocks* in the dead wood carbon pool are taken from the Sourcebook for LULUCF projects Pearson *et al.* (2006).

Standing dead wood ($C_{l,SDW}$)

- a. Within the plots delineated for live trees, the diameter at breast height (*DBH*) of standing dead trees can also be measured. In addition, the standing dead wood is categorized under the following four decomposition classes:
 1. Tree with branches and twigs that resembles a live tree (except for leaves);
 2. Tree with no twig, but with persistent small and large branches;
 3. Tree with large branches only;
 4. Bole (trunk) only, no branches.
- b. For classes 2, 3 and 4, the height of the tree (*H*) and the diameter at ground level should be measured and the diameter at the top should be estimated. Height can be measured using a clinometer.
- c. Top diameter can be estimated using a relascope or through the use of a transparent measuring ruler. Hold the ruler approximately 10-20 cm from your eye and record the apparent diameter of the top of the tree. The true diameter is the equal to:

$$\text{True diameter} - (m) = \frac{\text{Distance eye to tree} (m)}{\text{Distance eye to ruler} (m)} * \text{Ruler measurement} (m) \quad (A3-26)$$

Distance can also be measured with a laser range finder.

- d. For decomposition class 1 the carbon content of each dead tree is estimated using the allometric or *BEF* methods applied for live trees and by subtracting out the biomass of leaves (about 2-3% of the above-ground biomass for hardwood/broadleaf species and 5-6% for softwood/conifer species).
- e. For classes 2, 3 and 4, where it is not clear what proportion of the original biomass has been lost, it is conservative to estimate the biomass of just the bole (trunk) of the tree.

The volume is calculated using *DBH* and height measurements and the estimate of the top diameter. It is then estimated as the volume of a truncated cone:

$$Volume (m^3) = 1/3 * \pi * H * (r_1^2 + r_2^2 + r_1 * r_2) \quad (A3-27)$$

Where:

- H = Height of the tree; meters
- r_1 = Radius at the base of the tree; meters
- r_2 = Radius at the top of the tree; meters

The volume is converted to dry biomass using the appropriate wood density D_j and the to carbon dioxide equivalents using the carbon fraction CF_j and CO_2/C ratio (44/12), as in the *BEF* method, but ignoring the Biomass Expansion Factor.

- f. To aggregate the *carbon stock* of each standing dead tree at the plot level and then at the *LU/LC class* level, continue with step a.4 of the allometric equation method.

Lying dead wood ($C_{L,LDW}$)

Lying dead wood is most efficiently measured using the line-intersect method. Only coarse dead wood above a predefined minimum diameter (e.g. > 10 cm) is measured with this method – dead wood with smaller diameter is measured with litter.

- a. At each plot location, lay out two lines of 50 meters either in a single line or at right angles. The lines should be outside the boundaries of the plot to avoid damage to seedlings in the plots during measurement, and also to biasing the dead wood pool by damaging during tree measurement.
- b. Along the length of the lines, measure the diameter of each intersecting piece of coarse dead wood above a predefined minimum diameter (e.g. > 10 cm). Calipers work best for measuring the diameter. A piece of dead wood should only be measured if: (a) more than 50% of the log is above-ground and (b) the sampling line crosses through at least 50% of the diameter of the piece. If the log is hollow at the intersection point, measure the diameter of the hollow: the hollow portion in the volume estimates should be excluded.
- c. Assign each piece of dead wood to one of the three following density classes:
 - 1. Sound
 - 2. Intermediate

3. Rotten

To determine what density class a piece of dead wood fits into, each piece should be struck with a machete. If the blade does not sink into the piece (that is, it bounces off), it is classified as sound. If it sinks partly into the piece and there has been some wood loss, it is classified as intermediate. If the blade sinks into the piece, there is more extensive wood loss and the piece is crumbly, it is classified as rotten.

- d. Representative dead wood samples of the three density classes, representing a range of species present, should be collected for density (dry weight per green volume) determination. Using a chainsaw or a handsaw, cut a complete disc from the selected piece of dead wood. The average diameter and thickness of the disc should be measured to estimate volume. The fresh weight of the disc does not have to be recorded. The disc should be oven-dried to a constant weight.
- e. Calculate the wood density for each density class (sound, intermediate, rotten) from the pieces of dead wood collected. Density is calculated by the following equation:

$$\text{Density (g / m}^3\text{)} = \frac{\text{Mass (g)}}{\text{Volume (m}^3\text{)}} \quad (\text{A3-28})$$

Where:

Mass = The mass of oven-dried sample

Volume = $\pi * (\text{average diameter} / 2)^2 * (\text{average width of the sample})$

Average the densities to get a single density value for each class.

- f. For each density class, the volume is calculated separately as follows:

$$\text{Volume (m}^3 \text{ / ha)} = \pi^2 * \left(\frac{d_1^2 + d_2^2 + \dots d_n^2}{8 * L} \right) \quad (\text{A3-29})$$

Where:

d_1, d_2, \dots, d_n = Diameters of intersecting pieces of dead wood; cm

L = Length of the line; meters

- g. The per hectare *carbon stock* in the lying dead wood carbon pool of each *LU/LC class* is calculated as follows:

$$C_{ILDW} = \frac{\sum_{pl=1}^{PL_l} \left(\sum_{dc=1}^{DC} \text{Volume}_{dc} * D_{dc} * CF * 44 / 12 \right)}{PL_l} \quad (\text{A3-30})$$

Where:

C_{ILDW} = Average *carbon stock* per hectare in the lying dead wood carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

Volume_{dc} = Volume of laying dead wood in the density class *dc*; m³

D_{dc}	=	Dead wood density of class dc ; tonnes d. m. m^{-3}
CF	=	Carbon fraction; tonnes C (tonne d. m.) $^{-1}$
44/12	=	Ratio converting C to CO_2e
pl	=	1, 2, 3, ... PL_l plots in LU/LC class l ; dimensionless
PL_l	=	Total number of plots in LU/LC class l ; dimensionless
dc	=	1, 2, 3 dead wood density classes
DC	=	Total number of density classes (3)

Estimation of *carbon stocks* in the litter carbon pool ($C_{l,L}$)

In some *forest* ecosystem litter *carbon stocks* in the litter carbon pool can be a significant component of the total *carbon stock* while in anthropogenic ecosystem, particularly in agricultural or pastoral systems, litter is almost absent.

Litter is defines as all dead organic surface material on top of the mineral soil not considered in the lying dead wood pool. Some of this material is recognizable (for example dead leaves, twigs, dead grasses and small branches) and some is unidentifiable (decomposed fragments of different components of originally live biomass. To differentiate small woody debris from the laying dead wood it is necessary to define a diameter (i.e. 10 cm) below which small dead wood pieces are classified as litter and above which they are considered dead wood.

If litter is measured, it should be sampled at the same time of the year at each monitoring event in order to eliminate seasonal effects. The sampling technique is similar to the one used for non-tree vegetation: a square frame (30cm x 30cm) made from PVC pipe can be used. The following description of the sampling and data analysis techniques is taken from the Sourcebook for LULUCF projects (Pearson *et al.*, 2006).

- Place the sampling frame at the sample site.
- Collect all the litter inside the frame. A knife can be used to cut pieces that fall on the border of the frame. Place all the litter on a tarpaulin beside the frame
- Weigh the sample on-site, then oven-dry to a constant weight.
- Where sample bulk is excessive, the fresh weight of the total sample should be recorded in the field and a sub-sample of manageable size (approximately 80-100 g) taken for moisture content determination, from which the total dry mass can be calculated.
- Calculate the dry mass of the sample. Where a sub-sample was taken for determination of the moisture content use equation 30 to estimate the dry mass of the whole sample.
- The *carbon stock* per hectare in the litter carbon pool is calculated by multiplying the dry mass by an expansion factor calculated from the sample-frame or plot size and then by multiplying by the carbon fraction and CO_2/C ratio. For calculating the average *carbon stock* per LU/LC class, average over all samples (see equation 31).

Estimation of *carbon stocks* in soil organic carbon pool ($C_{l,soc}$)

Methods to estimate *carbon stocks* in the soil organic carbon pool are described in the Sourcebook for LULUCF projects (Pearson *et al.*, 2006) from which the following explanations have been taken.

Three types of variables must be measured to estimate soil organic *carbon stocks*: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample.

The sample depth should be constant, 30 cm is usually a sufficient sampling depth.

- a. Steadily insert the soil probe to a 30 cm depth. If the soil is compacted, use a rubber mallet to fully insert. If the probe will not penetrate to the full depth, do not force it as it is likely a stone or root that is blocking its route and, if forced, the probe will be damaged. Instead, withdraw the probe, clean out any collected soil and insert in a new location.
- b. Carefully extract the probe and place the sample into a bag. Because the carbon concentration of organic materials is much higher than that of the mineral soil, including even a small amount of surface material can result in a serious overestimation of soil *carbon stocks*.
- c. To reduce variability, aggregate four samples from each collection point for carbon concentration analysis.
- d. At each sampling point, take two additional aggregated cores for determination of bulk density. When taking the cores for measurements of bulk density, care should be taken to avoid any loss of soil from the cores.
- e. Soil samples can be sent to a professional laboratory for analysis. Commercial laboratories exist throughout the world and routinely analyze plant and soil samples using standard techniques. It is recommended the selected laboratory be checked to ensure they follow commonly accepted standard procedures with respect to sample preparation (for example, mixing and sieving), drying temperatures and carbon analysis methods.

For bulk density determination, ensure the laboratory dries the samples in an oven at 105 °C for a minimum of 48 hours. If the soil contains coarse, rocky fragments, the coarse fragments must be retained and weighted. For soil carbon determination, the material is sieved through a 2 mm sieve, and then thoroughly mixed. The well-mixed sample should not be oven-dried for the carbon analysis, but only air-dried; however, the carbon concentration does need to be expressed on an oven dry basis at 105 °C. The dry combustions method using a controlled temperature furnace (for example, a LECO CHN-2000 or equivalent) is the recommended method for determining total soil carbon, but the Walkley-Black method is also commonly used.

- f. Calculate the bulk density of the mineral soil core:

$$\text{Bulk density (g / cm}^3\text{)} = \frac{\text{oven dry mass (g / cm}^3\text{)}}{\text{core volume (cm}^3\text{)} - \frac{\text{mass of coarse fragments (cg)}}{\text{density of rock fragments (cg / m}^3\text{)}}} \quad (\text{A3-31})$$

Where the bulk density is for the < 2 mm fraction, coarse fragments are > 2 mm. The density of rock fragments is often given as 2.65 g/cm³.

- g. Using the carbon concentration data obtained from the laboratory, the amount of carbon per unit area is given by:

$$C_{\text{SOC},pl}(\text{t / ha}) = [(\text{soil bulk density (g / cm}^3\text{)} * \text{soil depth (cm)} * C)] * 100 \quad (\text{A3-32})$$

In the above equation, C must be expressed as a decimal fraction. For example, 2.2% carbon is expressed as 0.022 in the equation.

- h. The *carbon stock* per hectare in the soil organic carbon pool is calculated by averaging the *carbon stock* estimates per each *LU/LC class*:

$$C_{\text{ISOC}} = \frac{\sum_{pl=1}^{PL_l} C_{\text{SOC},pl}}{PL_l} \quad (\text{A3-33})$$

Where:

C_{ISOC} = Average *carbon stock* per hectare in the soil organic carbon pool of the *LU/LC class l*; tonnes CO₂e ha⁻¹

$C_{\text{SOC},pl}$ = *Carbon stock* per hectare in the soil organic carbon pool estimated for the plot *pl*; tonnes CO₂e ha⁻¹

pl = 1, 2, 3, ... PL_l plots in *LU/LC class l*; dimensionless

PL_l = Total number of plots in *LU/LC class l*; dimensionless

dc = 1, 2, 3 dead wood density classes

DC = Total number of density classes (3)

Appendix 4 – Methods to estimate *leakage* due to displacement of pre-existing agricultural activities

Note: These methods are taken from AR-AM0004.

Leakage through land conversion due to activity displacement should be monitored through sampling the households and communities displaced from land by the project. However, *leakage* due to conversion of land is not attributable to the RED *project activity* if the conversion of land occurs 5 or more years after the displacement of the activity to areas outside the project boundary. *Leakage* estimation includes monitoring households with identifiable areas of land conversion and conservatively applying a *deforestation* area to households with unidentifiable areas of land conversion. The type and schedule of measures to be taken to prevent conversion of land outside the project boundary should be described in the PDD and its implementation monitored.

Leakage due to displacement of agricultural activities can be set as zero ($LK_{conv-area} = 0$) where activities are shifted to land area with a *carbon stock* equal or less than the land from which they are displaced:

$$CS_b \geq CS_{AD} \quad (A4-1)$$

CS_b Carbon stock of baseline (t CO_{2eq} ha⁻¹)
 CS_{AD} Locally derived *carbon stock* (including all 5 measurement pools; t CO_{2eq} ha⁻¹) of area of land on which activities shifted.

Step 0: Determine if *leakage* analysis will take place at the household or community level. Household level analysis should only take place in *project areas* where households have clear land ownership or tenure.

Household level:

T_0 : Before start of project activities:

Step 1: Record the number of households occupying land inside the project boundary (TNHH). Randomly select 10% of the households (or a minimum of 30) to be sampled;

Step 2: Measure area of land within project boundaries each sampled household will be displaced from due to project activities (AD_h);

T_1 : Return one year after activity displacement and record land conversion outside project area:

Step 3: Classify sampled households as either having identifiable or unidentifiable converted lands. Households which have moved from the area or which cannot be found should be placed in the ‘unidentifiable households’ category;

Step 4: Measure area of identifiable land each household has converted since displacement of pre-project activities (IAC_h);

Step 5: Classify each area of identifiable converted land into a pre-conversion land cover stratum;

Step 6: Measure the *carbon stock* (including all 5 pools) in each land cover stratum using methods from IPCC GPG-LULUCF chapter 4.3;

Step 7: Determine the mean conservative *forest* biomass stock for the project region (\overline{AGB}), if no mean regional stock data exists, use mean national stock reported in IPCC GPG-LULUCF (Table 3A.1.4);

Note: In this methodology the regional or national aboveground biomass is converted to a conservative all-measurement-pool value using the root-shoot ratio and a factor of 1.5 to include other pools and to raise the mean stock to a conservative stock.

Step 8: Apply below equations (A4-2) – (A4-3) to estimate the amount of *leakage* due to land conversion, based on area.

Equation (A4-2) is made up of two parts. Part (a) calculates the *leakage* in identifiable areas of conversion. Part (b) estimates the *leakage* in unidentifiable areas.

Equation (A4-2), part (a): To calculate the *leakage* due to identifiable conversion, the product of: the area of each land cover strata converted and the *carbon stock* of that strata, are summed for all strata in that community. This total amount of *leakage* for each community is then multiplied by the scaling factor for that community (SF_c).

4-2), part (b): To estimate the *leakage* in unidentified areas, the area of displaced land that the ‘unidentifiable households’ held is multiplied by a conservative estimate of the *carbon stock* in the region ($\overline{AGB} \cdot (1+R) \cdot 1.5 \cdot 44/12 \cdot 0.5$ (the 0.5 converts biomass to carbon)) and a scaling factor SF_h .

$$LK_{conv-area} = \left(\sum_{h=1}^H \left(\sum_i IAC_{hi} \cdot CS_i \cdot \frac{44}{12} \right) * SF_h \right) + \left(\sum_{h=1}^H AD_h \cdot \overline{AGB} \cdot (1+R) \cdot 1.5 \cdot \frac{44}{12} \cdot 0.5 \cdot SF_h \right) \quad (A4-2)$$

$$SF_h = \frac{TNHH}{SHH} \quad (A4-3)$$

Where:

$LK_{conv-area}$ *Leakage* due to conversion of land to agriculture attributable to displacement (activity shifting), tonnes CO₂-e
 IAC_h Identifiable Areas Converted by displaced household h; hectares
 AD_h Area of land from which household h, classified as ‘unidentifiable’, was

	Displaced due to <i>project activity</i> ; hectares
H	1,2,3.... H , households; dimensionless
I	1,2,3.... I , strata; dimensionless
CS_i	Locally derived <i>carbon stock</i> (including all 5 measurement pools) of stratum i ; t Carbon ha ⁻¹
\overline{AGB}	Mean conservative regional aboveground biomass; t biomass ha ⁻¹
R	Root-shoot ratio; dimensionless
SF_h	Sampling factor of household h ; dimensionless
$TNHH$	Total number of households using project lands in <i>baseline</i> ; dimensionless
SHH	Sampled households, number of households sampled for $LK_{conv-crop}$; dimensionless

T_5 : Return after five years and record land conversion outside project area by repeating Steps 3-8.

Community level:

T_0 : Before start of project activities:

Step 1: Record the number of communities occupying land inside the project boundary. Randomly select 10% of the communities (or a minimum of 10 communities) to be sampled;

Step 2: Measure the area of all project-participating communities (both inside and outside the project boundaries);

Step 3: Measure area of land within project boundaries from which pre-project activities in each sampled community will be displaced (PA_c);

Step 4: Calculate the total number of households within each selected community ($TNHH$);

Step 5: Randomly select 10% of households (or a minimum of 10 households) to be sampled within selected communities;

Step 6: Calculate the average area of land displaced by a household in each selected community (AAD_c).

T_1 : Return one year after activity displacement and record land conversion outside project area:

Step 7: Measure area of identifiable land each sampled community has converted since displacement of pre-project activities (IAC_c);

Step 8: Classify each area of identifiable converted land within the community into a pre-conversion land cover stratum;

Step 9: Measure the *carbon stock* (including all 5 pools) in each land cover stratum using methodology from IPCC GPG LULUCF chapter 4.3 (CS_i);

Step 10: Classify sampled households as either having identifiable or unidentifiable converted lands (XH). Households which have moved from the area or which cannot be found should be placed in the ‘unidentifiable’ category (XH);

Step 11: Determine the mean *forest* biomass stock and root-shoot ratio for the project region (\overline{AGB});

Note: In this methodology the regional or national aboveground biomass is converted to a conservative all-measurement-pool value using the root-shoot ratio and a factor of 1.5 to include other pools and to raise the mean stock to a conservative stock.

Step 12: Apply below equations (A4-4) – (A4-8) to estimate the amount of *leakage* due to land conversion, based on area.

Equation (A4-4) is made up of two parts. Part (a) calculates the *leakage* in identifiable areas of conversion. Part (b) estimates the *leakage* in unidentifiable areas.

Equation (A4-4), Part (a): To calculate the *leakage* due to identifiable conversion, the product of: the area of each land cover strata converted and the *carbon stock* of that strata, are summed for all strata in that community. This total amount of *leakage* for each community is then multiplied by the scaling factor for that community (SF_c). This is then repeated for each community, summed, and multiplied by the total area of displaced activities (TAC). The scaling factor (equation (118), SF_c) allows for the sampling of different sized communities by weighting that community (PA_c) by its size.

Equation (A4-4), Part (b): To estimate the *leakage* in unidentified areas, an estimate of the average amount of displaced land per household is calculated and multiplied by the *carbon stock* and a scaling factor. Equation (A4-5) calculates the ‘average area of land displaced by a household’ in each sampled community. This is then used in equation (A4-6) which multiplies this ‘average area of land displaced by a household’ by the ‘proportion of the sampled households which were displaced to unidentifiable areas’. Therefore, equation (A4-6) estimates the area of unidentifiable land area converted by households. In equation (A4-4), this area (XAC_c) is then multiplied by a conservative estimate of the mean *carbon stocks* in the region ($\overline{AGB} * (1+R) * 1.5 * 44/12 * 0.5$ (the 0.5 converts biomass to carbon)) and a scaling factor SF_{ch} . The scaling factor (equation (A4-8), SF_{ch}) includes the proportion of households sampled in that community ($TNHH_c/SHH_c$) and the scaling factor for that community (SF_c). This estimate of *leakage* for each community is then summed and multiplied by the total area on which pre-project activities were displaced due to the project (TAC).

Part (a) + Part (b)

$$LK_{conv-area} = TAC \cdot \left(\sum_{c=1}^C \left(\sum_{i=1}^I IAC_{ci} \cdot CS_i \cdot \frac{44}{12} \right) \cdot SF_c \right) + TAC \cdot \left(\sum_{c=1}^C XAC_c \cdot \overline{AGB} \cdot (1+R) \cdot 1.5 \cdot \frac{44}{12} \cdot 0.5 \cdot SF_{ch} \right) \quad (A4-4)$$

$$AAD_c = \frac{PA_c}{TNHH_c} \quad (A4-5)$$

$$XAC_c = AAD_c \cdot \frac{XH_c}{SHH_c} \quad (A4-6)$$

$$SF_c = \frac{PA_c}{\sum_{c=1}^C PA_c} \quad (A4-7)$$

$$SF_{ch} = SF_c \cdot \left(\frac{TNHH_c}{SHH_c} \right) \quad (A4-8)$$

Where:

$LK_{conv-area}$	<i>Leakage</i> due to conversion of land to agriculture attributable to displacement (activity shifting); tonnes CO ₂ -e
TAC	Total area of land on which pre-project activities were displaced due to project activities; hectares
IAC_c	Identifiable Areas Converted by displaced community c; hectares
XAC_c	Estimated area of land converted by households with unidentifiable lands in community c; hectares
CS_i	Locally derived <i>carbon stock</i> (including all 5 measurement pools) of stratum i; tonnes carbon ha ⁻¹
\overline{AGB}	Mean aboveground biomass; tonnes d.m. ha ⁻¹
R	Root-shoot ratio; dimensionless
PA_c	Area from which sampled community h was displaced due to project activities; hectares
AAD_c	Average area of land displaced by household in community c; hectares
XH_c	Number of households with unidentifiable converted lands in community c; dimensionless
SF_c	Sampling factor (communities); dimensionless
SF_{ch}	Sampling factor (households in communities); dimensionless
c	1,2,3...C, communities; dimensionless
h	1,2,3....H, households; dimensionless
i	1,2,3....I, strata; dimensionless
$TNHH_c$	Total number of households using project lands in <i>baseline</i> in community c; dimensionless
SHH_c	Sampled households in community c, number of households sampled for <i>leakage</i> by

activity shifting; dimensionless

T₅: Return after five years and record land conversion outside *project area* by repeating Steps 7-12.

Appendix 5 – Methods to estimate emissions from enteric fermentation and manure management

Estimation of CH₄ emissions from enteric fermentation ($E_{l,CH_4,ferm}$)

The amount of methane⁶⁹ emitted by a population of animals is calculated by multiplying the emission rate per animal by the number of animals. To reflect the variation in emission rates among animal types, the population of animals is divided into subgroups, and an emission factor per animal is estimated for each subgroup. As per PCC GPG 2000 and IPCC 2006 Guidelines for AFOLU, use the following equation⁷⁰:

$$E_{l,CH_4,ferm} = EF_1 * Population_l * 0,001 * GWP_{CH_4} \quad (A5-1)$$

$$Population = Producing_{forage} / (DBI * 365) \quad (A5-2)$$

Where:

$E_{l,CH_4,ferm}$	= CH ₄ emissions from enteric fermentation in <i>LU/LC class l</i> ; tonnes CO ₂ e ha ⁻¹ yr ⁻¹
EF_1	= Enteric CH ₄ emission factor for the livestock group; kg CH ₄ head ⁻¹ yr ⁻¹
$Population_l$	= Equivalent number of forage-fed livestock in <i>LU/LC class l</i> ; heads
$Producing_{forage}$	= Production of forage in <i>LU/LC class l</i> ; kg d.m. ha ⁻¹ yr ⁻¹
DBI	= Daily biomass intake; kg d.m. head ⁻¹ day ⁻¹
GWP_{CH_4}	= Global warming potential for CH ₄ (with a value of 23 for the first commitment period); dimensionless
0.001	= Conversion factor of kilograms into tonnes; dimensionless
365	= Number of day per year; dimensionless

The production of forage can be estimated by collecting production rates from the literature that represents the shrub species, climate, soil conditions and other features of the areas in which forage will be produced. Sampling surveys is also a good option.

Country-specific emission factors for enteric CH₄ emissions are documented in peer reviewed literature or can be obtained from national GHG inventories. Default values are given in table

⁶⁹ Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream. Both ruminant animals (e.g., cattle, sheep) and some non-ruminant animals (e.g., pigs, horses) produce CH₄, although ruminants are the largest source since they are able to digest cellulose, due to the presence of specific micro organisms in their digestive tracts. The amount of CH₄ that is released depends on the type, age, and weight of the animal, the quality and quantity of the feed, and the energy expenditure of the animal.

⁷⁰ Refer to equation 10.19 and equation 10.20 in IPCC 2006 GL AFOLU or equation 4.12 and equation 4.13 in GPG 2000 for agriculture.

10.10 and 10.11 in the IPCC 2006 Guidelines for AFOLU. When selecting emission factors it is important to select those from a region that is similar to the *project area*. The tables in Annex 10A.1 of the IPCC 2006 Guidelines for AFOLU specify the animal characteristic such as weight, growth rate and milk production used to estimate the emission factors. These tables should be consulted in order to ensure that the local conditions are similar. In particular, data on average milk production by dairy livestock should be analyzed when selecting an emission factor for dairy livestock. To estimate the emission factor, the data in Table 10 A.1 can be interpolated using the data on the local average milk production.

For data on daily biomass intake use local data or data that are applicable to the local conditions according to peer-reviewed literature or the national GHG inventory. When selecting a value for daily biomass intake, ensure that the chosen data are applicable to both the forage types to be produced and the livestock group (see also Table 5 in Appendix 2).

Estimation of CH₄ emissions from manure management ($E_{l,CH_4,manure}$)⁷¹

The storage and treatment of manure under anaerobic conditions produces CH₄. These conditions occur most readily when large numbers of animals are managed in confined area (e.g. dairy farms, beef feedlots, and swine and poultry farms), and where manure is disposed of in liquid based systems. The main factors affecting CH₄ emissions are the amount of manure produced and the portion of manure that decomposes anaerobically. The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g. in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH₄. The temperature and the retention time of storage greatly affect the amount of methane produced. When manure is handled as a solid (e.g. in stacks or piles), or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH₄ is produced.

CH₄ emissions from manure management for the forage-fed livestock can be estimated using IPCC methods⁷².

$$E_{l,CH_4,manure} = EF_2 * Population_l * 0,001 * GWP_{CH_4} \quad (A5-3)$$

Where:

- $E_{l,CH_4,manure}$ = CH₄ emissions from manure management in *LU/LC class l*; tonnes CO₂e ha⁻¹ yr⁻¹
- EF_2 = Manure management CH₄ emission factor for the livestock group; kg CH₄ head⁻¹ yr⁻¹
- $Population_l$ = Equivalent number of forage-fed livestock in *LU/LC class l*; heads

⁷¹ Taken from AR-AM0006 version 1

⁷² Refer to equation 10.22 in AFOLU volume of the IPCC 2006 Guidelines or equation 4.15 in GPG 2000 for agriculture.

GWP_{CH_4} = Global warming potential for CH₄ (with a value of 23 for the first commitment period); dimensionless

0.001 = Conversion factor of kilograms into tonnes; dimensionless

The best estimate of emissions will usually be obtained using country-specific emission factors that have been published in peer-reviewed literature or in the national GHG inventory. It is recommended that country-specific emission factors be used that reflect the actual duration of storage and type of treatment of animal manure in the management system used. If appropriate country-specific emission factors are unavailable, default emission factors presented in table 10.14-10.16 of IPCC 2006 Guidelines for AFOLU may be used. These emission factors represent those for a range of livestock types and associated management systems, by regional management practices and temperature. When selecting a default factor, be sure to consult the supporting tables in Annex 10A.2 of IPCC 2006 Guidelines for AFOLU, for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches the circumstances of the livestock that are fed forage from the *project area*.

Estimation of N₂O emissions from manure management ($E_{l,N_2O,manure}$)⁷³

Nitrous oxide emissions from manure management vary significantly between the type of management system used, and can also result in indirect emissions due to other forms of nitrogen loss from the system. The N₂O emissions from manure management can be estimated using method provided in the IPCC 2006 Guidelines for AFOLU, or in IPCC GPG 2000⁷⁴

$$E_{l,N_2O,manure} = E_{l,Direct_N_2O,manure} + E_{l,Indirect_N_2O,manure} \quad (A5-4)$$

$$E_{l,Direct_N_2O,manure} = Population_l * Nex * EF_3 * 0,001 * 44 / 28 * GWP_{N_2O} \quad (A5-5)$$

$$E_{l,Indirect_N_2O,manure} = Population_l * Nex * Frac_{gas} * EF_4 * 0,001 * 44 / 28 * GWP_{N_2O} \quad (A5-6)$$

Where:

$E_{l,N_2O,manure}$ = N₂O emissions from manure management in *LU/LC class l*; tonnes CO₂e ha⁻¹ yr⁻¹

$E_{l,Direct_N_2O,manure}$ = Direct N₂O emissions from manure management in *LU/LC class l*; tonnes CO₂e ha⁻¹ yr⁻¹

$E_{l,Indirect_N_2O,manure}$ = Indirect N₂O emissions from manure management in *LU/LC class l*; tonnes CO₂e ha⁻¹ yr⁻¹

$Population_l$ = Equivalent number of forage-fed livestock in *LU/LC class l*; heads

Nex = Annual average N excretion per livestock head; kg N head⁻¹ yr⁻¹

⁷³ Taken from AR-AM0006 version 1.

⁷⁴ Refer to equations 10.25, 10.26 and 10.27 in AFOLU volume of the IPCC 2006 Guidelines and/or equation 4.18 in GPG 2000 for agriculture.

EF_3	= Emission factor for N ₂ O emissions from manure management for the livestock group; kg N ₂ O-N (kg N ⁻¹) head ⁻¹ yr ⁻¹
EF_4	= Emission factor for N ₂ O emissions from atmospheric deposition of forage-sourced nitrogen on soils and water surfaces; kg N ₂ O-N (kg NH ₃ -N and NO _x -N emitted) ⁻¹ head ⁻¹ yr ⁻¹
<u>Note:</u> The use of the IPCC default factor 0.01 is recommended.	
$Frac_{gas}$	= Fraction of managed livestock manure nitrogen that volatilizes as NH ₃ and NO _x in the manure management phase; kg NH ₃ -N and NO _x -N emitted (Kg N) ⁻¹
GWP_{N_2O}	= Global warming potential for N ₂ O (310 for the first commitment period); dimensionless
44/28	= Conversion of N ₂ O-N emissions to N ₂ O emissions
0.001	= Conversion factor of kilograms into tonnes; dimensionless

The best estimate of the annual nitrogen excretion rates for each livestock group will usually be obtained using country-specific rates from published peer reviewed literature or from the national GHG inventory. If country-specific data cannot be collected or derived, or appropriate data are not available from another country with similar conditions, default nitrogen excretion rates can be obtained from table 10.19 of IPCC 2006 Guidelines for AFOLU.

The possible data sources for emission factors are similar. Default emission factors are given in table 10.21 and 11.3 of the IPCC 2006 Guidelines for AFOLU and default values for volatilization of NH₃ and NO_x ($Frac_{gas}$) in the manure management system are presented in table 10.22 of the same IPCC 2006 Guidelines. For EF_4 the IPCC default value 0.01 is recommended (equation 10.27, IPCC 2006 Guidelines for AFOLU).

Appendix 6 – Methods to estimate emissions associated to displacement of *baseline* activities of pre-existing local communities and individuals

Where project proponents estimate that *baseline activities* of communities and individuals living inside or near the *project area* (endogen *deforestation* agents) are likely to be displaced and cause a significant loss of *carbon stocks* in the *forests* located outside the boundary of the *project activity*, it will be necessary to estimate this source of *leakage ex ante* and, if the significance of the GHG emission is confirmed, to monitor it *ex post*.

Emissions of GHG (other than *carbon stock* changes) associated to the displaced activities are ignored because in the worst case scenario they would be similar to *baseline* emissions, which are conservatively ignored in this methodology. However, where emissions from *forest* fires are included in the *baseline*, non-CO₂ emissions from biomass burning⁷⁵ caused by the displaced activities must be included, where significant, in the estimation of *leakage* due to displacement of *baseline* activities. Such emissions are estimated using the methods explained in step 6.2.

1 *Ex ante* methodology steps

As per the applicability conditions of this methodology, the following types of *baseline* activities could be displaced: grazing activities, agricultural activities, collection of fuel-wood, and production of charcoal and other short-lived wood products.

To estimate the possible impact of activity displacement on *carbon stocks* outside the project boundary and set the reference for future *leakage* monitoring, estimate the following potential sources of *leakage*, as applicable:

- 1.1 Decrease in *carbon stocks* due to displacement of grazing activities
- 1.2 Decrease in *carbon stocks* due to displacement of agricultural activities
- 1.3 Decrease in *carbon stocks* due to increased use of non-renewable biomass
- 1.4 Total significant decrease in *carbon stocks* due to activity displacement
- 1.5 Reference against which *leakage* due to activity displacement will be monitored

1.1 Decrease in *carbon stocks* due to displacement of grazing activities

Where grazing activities could be displaced, use the most recent version of the CDM-EB approved “Tool for estimation of GHG emissions related to displacement of grazing activities in A/R CDM project activities”⁷⁶. Note that this tool includes methods to estimate increases in non-CO₂ gas emissions, which should be ignored in this methodology, as explained above.

⁷⁵ Emissions associated to the conversion of *forest* to non-*forest*.

⁷⁶ Available at: http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

1.2 Decrease in *carbon stocks* due to displacement of agricultural activities

Where agricultural activities could be displaced, use the most recent version of the CDM-EB approved methodology for “Reforestation or afforestation of land currently under agricultural use” (AR-AM0004, Section on “Estimation of *leakage* due to conversion of land to crop land, based on area of conversion”, as copied in Appendix 4)⁷⁷. If the CDM-EB approves a new tool to calculate *carbon stock* changes related to displacement of agricultural activities, use this tool instead AR-AM0004.

1.3 Decrease in *carbon stocks* due to increased use of non-renewable biomass

Where collection of fuel-wood, production of charcoal and other short-lived wood products could be displaced and cause an increased use of non-renewable biomass outside the project boundary, use the most recent version of the CDM-EB approved tool for the “Calculation of GHG emissions due to *leakage* from increased use of non-renewable woody biomass attributable to an A/R CDM *project activity*”⁷⁸.

1.4 Total estimated significant decreases in *carbon stocks* due to activity displacement

Summarize the results of the previous estimations in Table 17, where only significant decreases in *carbon stocks* must be reported.

Table 17. *Leakage* due to displacement of *baseline* activities

Project year	Carbon stock decrease due to displacement of						Total decrease of <i>carbon stocks</i> due to activity displacement	
	grazing activities		agricultural activities		use of non-renewable biomass		annual	cumulative
	annual	cumulative	annual	cumulative	annual	cumulative		
	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e	tCO ₂ e
1								
2								
...								
n								
Total	Sum		Sum		Sum		Sum	

1.5 Reference against which *leakage* due to activity displacement will be monitored

The numbers in table 17 are an *ex ante* estimate of *leakage* due to activity displacement. *Ex post*, activity displacement will be monitored against the *baseline* of the *leakage belt*. Thus, a *leakage belt* must be defined near or around the *project area*. The *leakage belt* represents the

⁷⁷ Available at: http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

⁷⁸ Available at: http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html

geographical area where activity displacement is likely to happen and where it will be monitored. If *carbon stocks* in the *leakage belt* will decrease more than estimated *ex ante*, this will be an indication that *leakage* due to displacement of *baseline activities* has occurred.

Thus, to finalize this sub-step, calculate *baseline carbon stock* changes for the *leakage belt* following the methods explained in steps 4 to 6 and report the results in tables similar to tables 7 to 11.

2 Monitoring of *deforestation* outside the project boundary due to displacement of *baseline activities*

Deforestation in the *leakage belt* must be monitored and when it is above the *baseline* of the *leakage belt*, it will be considered attributable to activity displacement caused by the *project activity*.

Use the methods described in Part 2 of the methodology to identify the polygons deforested above the *baseline* and to estimate the changes in *carbon stocks*.

Where strong evidence exists that the increased *deforestation* in the *leakage belt* is attributable to *deforestation* agents that are not linked to the *project area*, the increased *deforestation* may not be attributed to the *project activity*. The operational entity verifying the monitoring data shall determine whether the documentation provided by the project proponent represents sufficient evidence to consider the increased *deforestation* as not attributable to the *project activity*.

Appendix 7 – Draft REDD Methodological Module

“Estimation of carbon stocks and changes in carbon stocks in the wood products pool”

Draft Version 21 November 2008

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module allows for estimating carbon stocks and changes in carbon stocks in the wood products pool.

Applicability

Where wood is harvested and converted to wood products in the process of degradation or deforestation, wood products is a required pool for REDD projects. Where it can be documented that no wood harvest occurs, this pool may be excluded.

Parameters

This module produces the following parameters:

Parameter	SI Unit	Description
C_{WP} and ΔC_{WP}	t CO ₂ -e	Total carbon stock and total carbon stock change in wood products pool (equivalent)
ΔC_{G_WP}	t C yr ⁻¹	Increase in (input to) carbon stock in wood products pool

II. PROCEDURES

Estimation of carbon stock change in the wood products pool

Total carbon stock change in wood products is estimated as:

$$\Delta C_{WP} = \sum_{t=1}^t \Delta C_{WPt} \quad (1)$$

where:

ΔC_{WP} Carbon stock changes in wood products; t CO₂-e

ΔC_{WPt} Annual carbon stock change in wood products at time t; t CO₂-e yr⁻¹

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

Note that because stock change is equivalent to inputs (below), total carbon *stock change* in the wood products pool is synonymous with total carbon *stock* in the wood products pool.

Change in carbon stocks in wood products

Carbon stock changes are estimated using the gain-loss method, in which only the proportion of extracted stocks estimated to remain sequestered after 100 years is included as gain. No losses (due to wood waste and eventual oxidation of retired wood products) are included as they are implicitly incorporated in the estimation of stocks remaining sequestered after 100 years (equation 4).

$$\Delta C_{WPt} = \Delta C_{G_WPt} * \frac{44}{12} \quad (2)$$

Where:

$\Delta C_{WP,t}$	Annual net carbon stock change in wood products at time t ; t CO ₂ -e yr ⁻¹
ΔC_{G_WPt}	Increase in carbon stock in wood products at time t ; t C yr ⁻¹
t	1, 2, 3 ... t years elapsed since the start of the project activity
44/12	Ratio of molecular weight of CO ₂ to carbon, t CO ₂ -e t C ⁻¹

This module estimates annual increase in (inputs to) carbon stock in wood products at time t (ΔC_{G_WPt}) following the conceptual framework detailed in Winjum et al 1998⁷⁹.

Step 1: Calculate the biomass carbon of the volume extracted by wood product type ty at time t from within the project boundary:

$$C_{XB,ty,t} = \sum_{j=1}^{S_{pg}} (V_{ex,ty,j,t} * D_j * CF_j) \quad (3)$$

where:

$C_{XB,ty,t}$	Total stock of extracted biomass carbon from within the project boundary by class of wood product ty at time t ; t C
$V_{ex,ty,j,t}$	Volume of timber extracted from within the project boundary (does not include slash left onsite) by species j and wood product class ty at time t ; m ³
D_j	Basic wood density of species j ; t d.m.m ⁻³
CF_j	Carbon fraction of biomass for tree species j ; t C t ⁻¹ d.m.
t	1, 2, 3 ... t years elapsed since the start of the project activity
j	1, 2, 3 ... S tree species
ty	Wood product class – defined here as sawnwood, wood-based panels, other industrial roundwood, paper and paper board, and other

Step 2: Calculate the proportion of biomass carbon extracted at time t that remains sequestered in longterm wood products after 100 years. This module applies the simplifying

⁷⁹ Winjum, J.K., Brown, S. and Schlamadinger, B. 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. *Forest Science* 44: 272-284

(and conservative) assumption that all extracted biomass not retained in longterm wood products after 100 years is emitted in the year harvested, instead of tracking annual emissions through retirement, burning and decomposition. All factors are derived from Winjum et al.1998.

$$\Delta C_{G_WP,t} = \sum_{s,w,of,p,o}^{ty} (((C_{XB,ty,t} - WW) - SLF) - OF) \quad (4)$$

where:

$\Delta C_{G_WP,t}$	Increase in carbon stock in wood products at time t ; t C yr ⁻¹
$C_{XB,ty,t}$	Total stock of extracted biomass carbon from within the project boundary by class of wood product ty at time t ; t C
WW	Wood waste. The fraction immediately emitted through mill inefficiency; t C
SLF	Fraction of wood products that will be emitted to the atmosphere within 5 years of timber harvest; t C
OF	Fraction of wood products that will be emitted to the atmosphere between 5 and 50 years of timber harvest; t C
ty	Wood product class – defined here as sawnwood, wood-based panels, other industrial roundwood, paper and paper board, and other
t	1, 2, 3 ... t years elapsed since the start of the project activity

Wood waste fraction (WW):

Winjum et al 1998 indicate that the proportion of extracted biomass that is oxidized (burning or decaying) from the production of commodities to be equal to 19% for developed countries, 24% for developing countries. WW is therefore equal to $C_{XB,ty}$ multiplied by 0.19 for developed countries and 0.24 for developing countries.

Short-lived fraction (SLF)

Winjum et al 1998 give the following proportions for wood products with short-term (<5 yr) uses (applicable internationally):

Sawnwood	0.2
Woodbase panels	0.1
Other industrial roundwood	0.3
Paper and Paperboard	0.4

The methodology makes the assumption that all other classes of wood products are 100% oxidized within 5 years.

Therefore SLF will be equal to:

$$SLF = (C_{XB,ty} - WW) * slp \quad (5)$$

where:

SLF	Fraction of wood products that will be emitted to the atmosphere within 5 years of timber harvest; t C
$C_{XB,ty}$	Total stock of extracted biomass carbon from within the project boundary by class of wood product ty ; t C
WW	Wood waste. The fraction immediately emitted through mill inefficiency; t C
slp	Short-lived proportion - 0.2 for sawnwood, 0.1 for woodbase panels, 0.3 for other industrial roundwood, 0.4 for paper and paperboard and 1 for other; t C t C ⁻¹
ty	Wood product class – defined here as sawnwood, wood-based panels, other industrial roundwood, paper and paper board, and other
t	1, 2, 3 ... t years elapsed since the start of the project activity

Additional oxidized fraction (OF)

Winjum et al 1998 gives annual oxidation fractions for each class of wood products split by forest region (boreal, temperate and tropical). This methodology projects these fractions over 95 years to give the additional proportion that is oxidized between the 5th and 100th years after initial harvest (Table 1):

Table 1: Proportion of remaining wood products oxidized between 5 and 100 years after initial harvest by wood product class and forest region

Wood Product Class	Boreal	Temperate	Tropical
Sawnwood	0.36	0.60	0.84
Woodbase panels	0.60	0.84	0.97
Other industrial roundwood	0.84	0.97	0.99
Paper and paperboard	0.36	0.60	0.99

OF is therefore equal to:

$$OF = ((C_{XB,ty} - WW) - SLF) * f_c \quad (6)$$

where:

OF	Fraction of wood products that will be emitted to the atmosphere between 5 and 100 years of timber harvest; t C
$C_{XB,ty}$	Total stock of extracted biomass carbon from within the project boundary by class of wood product ty ; t C
WW	Wood waste. The fraction immediately emitted through mill inefficiency; t C

<i>SLF</i>	Fraction of wood products that will be emitted to the atmosphere within 5 years of timber harvest; t C
<i>f_o</i>	Fraction oxidized – see Table 1 for defaults; t C t C ⁻¹
<i>ty</i>	Wood product class – defined here as sawnwood, wood-based panels, other industrial roundwood, paper and paper board, and other
<i>t</i>	1, 2, 3 ... <i>t</i> years elapsed since the start of the project activity

III. DATA AND PARAMETERS NOT MONITORED (DEFAULT OR POSSIBLY MEASURED ONE TIME)

Data / parameter:	<i>OF, SLF, WW</i>
Data unit:	kg kg ⁻¹ .
Used in equations:	4, 5, 6
Description:	<p>OF = Fraction of wood products that will be emitted to the atmosphere between 5 and 50 years after production;</p> <p>SLF = Fraction of wood products that will be emitted to the atmosphere within 5 years of production</p> <p>WW = Fraction of extracted biomass effectively emitted to the atmosphere during production</p>
Source of data:	The source of data is the published paper of Winjum et al. 1998 ⁸⁰
Measurement procedures (if any):	
Any comment:	

Data / parameter:	<i>CF</i>
Data unit:	t C t ⁻¹ d.m.
Used in equations:	3
Description:	Carbon fraction of dry matter
Source of data:	Default value 0.47 t C t ⁻¹ d.m. can be used, or species specific values from the literature (e.g. IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.3)
Measurement procedures (if any):	
Any comment:	

⁸⁰ Winjum, J.K., Brown, S. and Schlamadinger, B. 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. *Forest Science* 44: 272-284

Data / parameter:	D
Data unit:	t d.m. m ⁻³
Used in equations:	3
Description:	Basic wood density
Source of data:	The source of data shall be chosen with priority from higher to lower preference as follows: (a) National and species-specific or group of species-specific (e.g. from National GHG inventory); (b) Species-specific or group of species-specific from neighboring countries with similar conditions. Sometimes (b) may be preferable to (a); (c) Globally species-specific or group of species-specific (e.g. IPCC 2006 INV GLs AFOLU Chapter 4 Tables 4.13 and 4.14).
Measurement procedures (if any):	N/A
Any comment:	

IV. DATA AND PARAMETERS MONITORED

Data / parameter:	V_{ex}
Data unit:	m ³
Used in equations:	3
Description:	The volume of timber extracted from within the project boundary (does not include slash left onsite), preferably reported by species and wood product class.
Source of data:	Timber harvest records and/or estimates derived from field measurements or remote assessments with aerial photography or satellite imagery.
Measurement procedures (if any):	
Any comment:	Note that this volume does not include logging slash left onsite (tracked as part of the dead wood pool). Data compilers should also make sure

	that extracted volumes reported are gross volumes removed (i.e. reported volume does not already discount for estimated wood waste, as is often the practice in harvest records)
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