CLEAN DEVELOPMENT MECHANISM
PROPOSED NEW BASELINE AND MONITORING METHODOLOGIES FOR A/R (CDM-AR-NM) Version 01

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Section I. Summary and applicability of the baseline and monitoring methodologies

1. Methodology title (for baseline and monitoring)

Methodology title:

>> Forest Restoration Carbon Analysis
Document version 1
March 8, 2006

If this methodology is a based on a previous submission, please state the previous reference number (ARNMXXXX/ARAMXXXX) here:

>> not applicable

2. Selected baseline approach for A/R CDM project activities

Choose One (delete others):

☒ Existing or historical, as applicable, changes in carbon stocks in the carbon pools within the project boundary;

☐ Changes in carbon stocks in the carbon pools within the project boundary from a land use that represents an economically attractive course of action, taking into account barriers to investment;

☐ Changes in carbon stocks in the pools within the project boundary from the most likely land use at the time the project starts.

Explanation/justification of choice:

>> The proposed baseline and monitoring method adopts the approach of quantification of historical changes in carbon stocks in the carbon pools within the project boundary. The approach provides the data necessary to determine baseline net greenhouse gas removal in an area where historical data show that reforestation occurs naturally and unassisted in the region of the project activity. The approach also provides the most effective framework in an area of subsistence or low-input agriculture and pastoralism where participants in the project activity do not conduct industrial-scale timber harvesting. In that case, local natural resource management practices influence land cover change more than macroeconomic conditions. For these reasons, the approach provides the most accurate data for projecting future land cover changes, the key to estimating baseline net greenhouse gas removal.

The approach of calculating economic values does not strongly apply to this situation because the low financial capital in a subsistence area makes land speculation rare. The remaining approach, quantification of changes in carbon stocks from a likely use, does not provide sufficient information to project future land cover.

3. Applicability conditions

Methodology procedure:

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1. The project activity is reforestation of non-forest land by natural regeneration or plantation.
2. Historical data show that reforestation can occur naturally and unassisted in the region of the project activity.
3. Project participants can gather enough data to quantify the aboveground and belowground carbon pools.

4. Dead wood stocks, the mass of litter per unit area, and the mass of soil organic matter per unit area in forest are greater than in non-forest, allowing project participants to omit these pools from calculations, as a conservative measure.
5. Site preparation and maintenance do not cause a loss of soil carbon.
6. Project participants engage in subsistence or low-input agriculture and pastoralism with no use of inorganic fertilizer.
7. Project participants do not burn biomass for the project activity.
8. Project participants can raise shade-tolerant agricultural crops under plantation trees in order to help maintain the same production of goods and services as the baseline scenario.
9. Project participants will improve the efficiency of agricultural production outside the project boundary to help maintain the same production of goods and services as the baseline scenario without increasing greenhouse gas emissions outside the project boundary.
10. Project participants define, before the starting date of the project activity, a limit of the total area under natural regeneration in the project activity and a fraction of the total trees planted in the project activity that will go to mortality and harvesting.
11. Project participants agree, before the starting date of the project activity, to a limit of the area of forest outside the project boundary that participants can cut.
12. Project participants include specialists in forest ecology, remote sensing, and geographic information systems (GIS).

Explanation/justification of choice:

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1. Reforestation is a CDM-eligible activity.
2. The possibility of natural or unassisted reforestation within the project boundary renders necessary a different choice of baseline scenario than offered in the only currently approved CDM baseline method (AR-AM0001).
3. The objective of the reforestation project activity is to increase carbon stocks in aboveground and belowground carbon pools.
4. See section 4 "Selected carbon pools."
5. Project participants will disrupt only a small amount of soil for digging holes to plant trees and will place the soil back into the holes.
6. Subsistence or low-input agriculture does not use significant amounts of inorganic fertilizer.
7. A lack of biomass burning reduces potential loss from actual net greenhouse gas removal by sinks.
8. Agroforestry can reduce the possibility of leakage.
9. Improved agricultural efficiency can reduce the possibility of leakage.
10. Project participants conserve some of this biomass for carbon stocks and part of the biomass for local needs. Harvesting of biomass produced by the project activity will result in a net zero removal from and emission to the atmosphere.
11. Project participants monitor deforestation outside the project boundary in order to calculate leakage from displaced deforestation.
12. These skills are necessary for the forest inventory and spatial analyses.

4. Selected carbon pools

Methodology procedure:

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Carbon pools	**Selected (yes or no)**	**Justification / Explanation**
Aboveground	yes	Objective of the reforestation project activity is to increase carbon stocks in this pool.
Belowground	yes	Objective of the reforestation project activity is to increase carbon stocks in this pool.
Dead wood	no	Dead wood stocks in forest are greater than in non-forest (IPCC 2003).

Carbon pools	Selected (yes or no)	Justification / Explanation
Litter	no	The mass of litter per unit area is greater in forest than in non-forest (IPCC 2003).
Soil organic carbon	no	The mass of soil organic matter per unit area is greater in forest than in non-forest (Palm et al. 2002, 2004; Birdsey and Lewis 2003).

Explanation/justification of choice:

>> The method quantifies carbon in aboveground and belowground vegetation because the objective of the reforestation project activity is to increase carbon stocks in those two pools.

The method does not quantify carbon in dead wood, litter, and soil because of the high cost of monitoring carbon in those pools. For a reforestation project, omitting these pools results in a lower, or conservative, estimate of net anthropogenic greenhouse gas removal by sinks.

Concerning the dead wood and litter pools, Section 3.2.2.2 "Change in carbon stocks in dead organic matter" of IPCC (2003) guides users to assume that carbon in these pools on non-forest land is zero, compared to a global range of 9-21 t C ha^{-1} in dead wood in forests (Table 3.2.2 of IPCC (2003)) and a global range of 2-55 t C ha^{-1} in litter in forests (Table 3.2.1 of IPCC (2003)). Furthermore, forests, by definition, contain higher densities of trees than non-forest land, so the amount of dead organic matter (dead wood and litter) will increase when non-forest land recovers to forest land if the ratio of dead organic matter to biomass remains constant. Indeed, field data confirm this fact: the 12-15 t ha^{-1} of carbon in dead wood in Amazon forest (Chambers et al. 2001, Fearnside and Laurance 2004) exceeds total aboveground carbon of 3 t ha^{-1} in Amazon agricultural land and pasture (Palm et al. 2004).

Concerning soil organic carbon pools, extensive research on permanent plots established by the International Centre for Research in Agroforestry (ICRAF) in a mosaic of agricultural land and forest in the Peruvian Amazon has demonstrated that soil organic carbon increases as land recovers from bare soil to agriculture to pasture to forest (Palm et al. 2002, 2004). Likewise, in temperate regions, soil organic carbon in forests is higher than soil organic carbon in non-forest (Birdsey and Lewis 2003).

5. Summary description of major baseline and monitoring methodological steps

Summary description:

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Baseline Method:

Method: Forest Restoration Carbon Analysis (FRCA) (Gonzalez et al. 2004, 2006) is an integrated spatial analysis of forest inventory and remote sensing data. The method assesses forest species patterns, quantifies deforestation and reforestation rates, and employs the default or carbon gain-loss method of the Intergovernmental Panel on Climate Change (IPCC 2003) to project baseline net greenhouse gas removal and net anthropogenic greenhouse gas emissions by sinks within the project boundary of a Clean Development Mechanism project activity.

Definition of the project boundary: The method analyzes remote sensing data and forest inventories to determine land eligible for a CDM reforestation project activity and the project boundary.

Stratification: The method analyzes remote sensing data and forest inventories to stratify land into classes of actual vegetation types in the field and that remote sensing can distinguish. Project participants stratify areas within the project boundary by type of project activity, by vegetation type for natural regeneration and species for plantation, and any other variable that produces strata of relatively homogenous biomass and biomass growth per unit area.

Choice of the baseline scenario: FRCA analyzes observed historical data on forest cover change in the ecological area of the project activity to project what future forest cover change would occur within the project boundary without a CDM project activity. The potential of unassisted reforestation within the project boundary renders necessary a different choice of baseline scenario than offered in approved CDM baseline method AR-AM0001. FRCA employs principal components analysis, a multivariate statistical test, to calculate the weight of factors in explaining observed deforestation and reforestation. FRCA combines weights with bivariate statistical fits of deforestation and reforestation observations to calculate future probabilities of deforestation and reforestation for each pixel in a raster geographic information system (GIS) data layer of land within the project boundary. The projected gross rate of future reforestation is the baseline scenario.

Ex ante calculation of baseline net greenhouse gas removal by sinks: FRCA employs the default or carbon gain-loss method (IPCC 2003) to calculate the changes in carbon stocks within the project boundary from projected reforestation that would occur in the absence of the CDM project activity.

Demonstration of additionality: This method uses the latest version of the UNFCCC CDM "Tool for the demonstration and assessment of additionality for afforestation and reforestation CDM project activities."

Ex ante calculation of actual net greenhouse gas removal by sinks: FRCA derives a biomass growth curve from forest inventories in the ecological area of the project activity. The method employs the default or carbon gain-loss method (IPCC 2003) to calculate the change in carbon stocks within the project boundary of new trees established by the CDM project activity.

Leakage: The method includes an *ex ante* calculation of greenhouse gas emissions outside the project boundary attributable to project activities inside the project boundary. To calculate leakage from fossil fuel use by vehicles for the project activity, FRCA uses IPCC (1996, 2000) methods to calculate greenhouse gas emissions from fossil fuel combustion. To limit leakage from displacement of deforestation, project participants agree, before the starting date of the project activity, to a limit of the area of forest outside the project boundary that participants can cut.

Monitoring method:

Method: Project participants monitor the surface area of reforestation stands, the number and species of trees planted or regenerated as part of the project activity, trees in permanent forest inventory plots outside the project boundary, and leakage.

Monitoring of the implementation of the project activity: Project participants record the surface area of all reforestation stands within the project boundary. They also record the number and species of any trees planted.

Stratification: Project participants stratify areas within the project boundary by type of project activity, natural regeneration or plantation, by vegetation type for natural regeneration and species for plantation, and any other ecological or edaphic characteristic that produces strata of relatively homogenous biomass and biomass growth per unit area.

Ex post calculation of baseline net greenhouse gas removal by sinks: Project participants use data from the permanent forest inventory plots and from natural regeneration to update the biomass growth curve. Project participants will conduct an *ex post* calculation of baseline net greenhouse gas removal by sinks by using the updated growth curve to update the *ex ante* calculation of baseline net greenhouse gas removal by sinks.

Ex post calculation of actual net greenhouse gas removal by sinks: Project participants directly measure a statistical sample of the trees planted or regenerated as part of the project activity. They use this data to calculate the actual net greenhouse gas removal by sinks.

Leakage: Project participants record fossil fuel use by vehicles for the project activity. Project participants also monitor and measure forest areas that participating farmers and herders cut outside the project boundary.

a. Baseline methodology steps:

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1. Definition of ecological area for baseline analyses
2. Establishment of permanent forest inventory plots
3. Change detection using forest inventories and remote sensing
4. Definition of project boundary
5. Compilation of spatial data of major deforestation and reforestation factors
6. Principal components analysis to calculate weight of factors in explaining observed deforestation and reforestation
7. Derivation of deforestation and reforestation probability functions

8. Calculation of deforestation and reforestation probability for each pixel
9. Projection of future deforestation and reforestation
10. Determination of baseline scenario
11. Calculation of biomass using local tree allometric equations and species-specific wood densities
12. Derivation of biomass growth function
13. Projection of baseline net greenhouse gas removal by sinks
14. Projection of actual net greenhouse gas removal by sinks
15. Calculation of leakage from fossil fuel use and displacement of deforestation
16. Calculation of net anthropogenic greenhouse gas removal by sinks

b. Monitoring methodology steps:

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17. Measurement of surface area of all reforestation stands within the project boundary and the number and species of any trees planted
18. Establishment of a statistical sample of trees planted or regenerated by the project activity
19. Re-measurement, at least every five years, of trees in the permanent forest inventory plots
20. Update of the original biomass growth function
21. Re-calculation of baseline net greenhouse gas removal with an updated biomass growth function
22. Measurement, at least every five years, of the diameter of each tree in the sample and any other dimensions of the tree required by the allometric equation for that species
23. Re-calculation of actual net greenhouse gas removal by sinks
24. Monitoring of deforestation by project participants
25. Re-calculation of leakage from fossil fuel use and displacement of deforestation
26. Re-calculation of net anthropogenic greenhouse gas removal by sinks

Section II. Baseline methodology description

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1. Project boundary

Methodology procedure:

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Step 1. Definition of ecological area for baseline analyses

The UNFCCC "Clean Development Mechanism Guidelines for Completing the Project Design Document for A/R (CDM-AR-PDD), the Proposed New Methodology for A/R: Baseline And Monitoring (CDM-AR-NM)," Version 3, page 10, states that, in order to demonstrate eligibility of land, "project participants shall provide one of the following verifiable information:

(a) Aerial photographs or satellite imagery complemented by ground reference data; or

(b) Ground-based surveys…

(c) …Participatory Rural Appraisal…"

FRCA chooses option (a) by using satellite imagery with permanent forest inventory plots as ground reference sites to determine eligibility of land and to define the project boundary.

FRCA is a baseline and monitoring method for discrete, discontinuous parcels of non-forest land. Definition of the project boundary first requires definition of an ecological area that will constitute the spatial limit of any part of the project boundary and will serve as the area for calculation of historical deforestation and reforestation rates, variables used in the calculation of baseline net greenhouse gas removal by sinks and leakage.

Therefore, FRCA defines "ecological area" as "an region of land with relatively homogeneous biological characteristics and broadly similar land management regimes that constitutes the spatial limit of any part of the project boundary and serves as the region for calculation of historical deforestation and reforestation rates, variables used in the calculation of baseline net greenhouse gas removal by sinks and leakage."

Biologically significant geographic features that delineate ecological areas include ecosystems, ecoregions, vegetation types, climate zones, indigenous peoples' areas, mountains or other distinct topography, watersheds, rivers, declared protected areas, declared natural resource management areas, and any other significant ecological features. Again, these features will generally define areas with similar ecological characteristics or with broadly similar land management regimes. On the other hand, administrative boundaries or other arbitrary geometric shapes, like rectangles or circles, will generally cut across natural features and generate areas of conflicting ecological characteristics.

Step 2. Establishment of permanent forest inventory plots

Permanent forest inventory plots serve as the ground reference sites for analyses of remote sensing data. The plots also provide the biomass data necessary for determining the biomass density of local vegetation types and for developing local biomass growth equations. Project participants use biomass density and biomass growth equations to calculate baseline net greenhouse gas removal by sinks and actual net greenhouse gas removal by sinks.

Project participants define the same land cover classes (strata) for both the permanent forest inventory plots and the remote sensing analyses (Step 3). A land cover class should include vegetation of similar physiognomy, canopy, structure and carbon density. The permanent forest inventory plots will provide the field data to assess physiognomy, canopy structure, and carbon density. Remote sensing data will confirm whether differences in physiognomy and canopy structure manifest themselves in distinct spectral signatures for each land cover class. Importantly, the satellite used (Step 3) must be able to distinguish each individual class.

Project participants use systematic or stratified random sampling to establish the locations of plots and detailed procedures (Snowdon et al. 2002) to determine the numbers, shapes, and sizes of plots. In large areas, where limited finances or lack of access to private property prevent completely systematic or random sampling, forest ecologists will establish standardized networks of plots in sites that represent the physiognomy and structure of forest classes in the ecological area (Malhi et al. 2002, Phillips et al. 2003, Baker et al. 2004a).

Project participants set up permanent markers at the permanent plots and use global positioning system (GPS) receivers to record the geographic coordinates of the plot center, vertices, and any other significant point locations. Project participants record or estimate the age of the stand, a datum needed to derive biomass growth functions (Step 12). In areas of high tree density, forest ecologists will define a diameter threshold below which they will not measure trees in every plot in order to optimize sampling effort. For tropical forests, the threshold is often a diameter of 10 cm at a height of 1.3 m (Baker et al. 2004a), while in temperate forests the threshold is often 19.5 cm at a height of 1.37 m (USDA FS 2004). In that case, detailed sampling of the understory in a smaller sample of plots will provide data to calculate understory biomass.

Project participants identify the species of each measured tree to the lowest taxonomic level possible, measure the trunk diameter at a height of 1.3 m, measure the height, if required by the allometric equation for that species (Step 11), tag the tree at a height of 1.4 m, and record the data in an electronic database. Project participants also estimate the accuracy of their measurements by repeating measurements on individual trees and re-measuring until error falls below 1%.

Step 3. Change detection using forest inventories and remote sensing

Change detection is the analysis of spatial differences from two images acquired over the same location at different times (Howarth and Wickware 1981, Lu et al. 2004). Users can conduct change detection on aerial photographs, satellite scenes, on any other spatial images. Landsat, a satellite series launched by the National Aeronautics and Space Administration (NASA) and operated by the U.S. Geological Survey (USGS), is the only satellite system at a 30 m spatial resolution (USGS 2003) with a continuous archive of global data since the baseline date of the CDM, December 31, 1989. In addition, geographic information system (GIS) software greatly facilitates the analyses of spatial data.

Project participants conduct change detection on two spatial images. The first image comes from a date as close as possible to December 31, 1989. The second image from a date as close as possible to the starting date of the project activity. Project participants mosaic each image, geographically register one image to the other so that the two images are aligned, project each image into an equal-area geographic projection, and crop the images. After processing, each image is aligned to each other and covers the exact same spatial extent. Geographic registration is extremely important because the pixel covering one location in one image must align with the pixel covering that same location in the second image.

Using the forest inventory plots as reference sites for the land cover classes (strata) defined in Step 2 and reference sites for non-land features such as clouds, shadows, and water, project participants conduct a GIS supervised classification of each image. The supervised classification assigns each pixel to a land cover class base on the similarity of the pixel's spectral signature to the spectral signatures of the reference sites. The resulting land cover data layer will divide the image into land cover classes and into classes for non-land features.

Project participants combine the different non-land classes into one non-land class. Project participants exclude non-land pixels from all subsequent analyses. This measure will exclude eligible land from the project boundary if that land was under clouds in either image.

Project participants create a data layer of forest cover by combining all land classes that meet the definition of forest that the Party has reported to the CDM. Project participants combine all other land classes into a non-forest class. A forest cover layer has three classes:

0. clouds, shadow, water, or other non-land cover in either image
1. non-forest
2. forest.

Comparison of the two forest data layers produces a data layer of forest change between the two analysis years. The forest change layer has five classes:

0. non-land
1. non-forest
2. deforestation
3. reforestation
4. forest.

The "non-forest" class in the forest change layer includes all CDM-eligible land.

Step 4. Definition of project boundary

The "non-forest" class in the forest change layer (Step 3) includes all CDM-eligible land. Based on organizational capabilities and practical considerations, project participants set a total number of hectares less than or equal to the total surface area of eligible land (Step 3) within the ecological area (Step 1) to include in the project activity.

Therefore, the spatial extent of the project boundary is the perimeter of the "non-forest" land identified as eligible by remote sensing and selected by project participants for reforestation. Project participants define the project boundary in a GIS data file. Eventually, project participants verify in the field that land identified by remote sensing is eligible and that the landowner agrees to participate in the project activity. Project participants subsequently substitute land that field observations show is no longer eligible or whose owner does not want to participate with other land within the ecological area that field observations confirm is eligible and where the landowner wishes to participate. Eventually, project participants record geographic coordinates of each vertex of all individual parcels within the project boundary using global positioning system (GPS) receivers.

The following table indicates the greenhouse gases included in the project boundary:

Sources	Gas	Included/ excluded	Justification / Explanation
fossil fuel use by project activity vehicles	CO_2	yes	IPCC (1996, 2000) methods
	CH_4	yes	IPCC (1996, 2000) methods
	N_2O	yes	IPCC (1996, 2000) methods
biomass burning	CO_2	no	project participants do not burn biomass for the project activity
	CH_4	no	project participants do not burn biomass for the project activity
	N_2O	no	project participants do not burn biomass for the project activity
fertilizer	CO_2	no	project participants do not use fertilizer in the project activity
	CH_4	no	project participants do not use fertilizer in the project activity
	N_2O	no	project participants do not use fertilizer in the project activity

Explanation/justification of choice:

>> FRCA uses forest inventory and remote sensing data to define a project boundary that only includes CDM-eligible land, land under the control of project participants, and all significant anthropogenic emissions of greenhouse gases attributable to the project activity.

2. Stratification

Methodology procedure:

>> As explained in Section II.1 "Project boundary," project participants analyze data from permanent forest inventory plots (Step 2) and remote sensing data (Step 3) to stratify land into classes of actual vegetation types in the field that remote sensing can distinguish. A land cover class includes vegetation of similar physiognomy, canopy structure, and carbon density. The permanent forest inventory plots will provide the field data to assess physiognomy, canopy structure, and carbon density. Remote sensing data will confirm whether differences in physiognomy and canopy structure manifest themselves in distinct spectral signatures for each land cover class.

Project participants stratify areas within the project boundary by type of project activity: natural regeneration or plantation. The next level of stratification is vegetation type for natural regeneration and species for plantation. Project participants further stratify by other edaphic or ecological variables. Each class (stratum) circumscribes areas of relatively homogenous biomass and biomass growth per unit area.

Explanation/justification of choice:

>> FRCA employs forest inventories and remote sensing to define land cover classes (strata) of similar physiognomy, canopy structure, and carbon density. Within the project boundary, project participants define classes (strata) of homogenous biomass and biomass growth per unit area.

3. Procedure for selection of most plausible baseline scenario

Methodology procedure:

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Step 5. Compilation of spatial data of major deforestation and reforestation factors

FRCA determines the most plausible baseline scenario by analyzing observed historical data on forest cover change in the ecological area of the project activity and then projecting what future forest cover change would occur within the project boundary if historical trends continued without a CDM project activity. This analysis requires data on the factors that could explain observed patterns of deforestation and reforestation, as determined in Step 3. These factors include, but are not limited to, distance to non-forest in the year of the first image (for analyzing deforestation), distance to forest in the year of the first image (for analyzing deforestation), elevation, distance to rivers, distance to roads, slope, and distance to towns. A factor can be used only if it is measured in continuous values. For example, distance to roads might vary from 0 meters to 500 kilometres. Distance to roads has continuous physical values. As a contrary example, soil degradation expressed as "low," "medium," and "high" or as "class 1," "class 2," and "class 3) is not measured in continuous physical values. On the other hand, soil degradation expressed as cation exchange capacity measured in mmol g^{-1} is measured in continuous physical values.

Project participants compile available spatial data on deforestation and reforestation factors. As much as possible, project participants compile data for each factor at the time of the first remote sensing image and at the time of the second remote sensing image. The extent of the raw factor data should be larger than extent of the ecological area (Step 1) because features outside the ecological area will influence deforestation inside the ecological area and, therefore, inside the project boundary. Project participants geographically register and crop the data to the reference spatial image (Step 3) so that each image is aligned to each other and covers the exact same spatial extent. Geographic registration is extremely important because the pixel covering one location in one image must align with the pixel covering that same location in the second image.

<u>Step 6. Principal components analysis to calculate weight of factors in explaining observed deforestation and reforestation</u>

A complex interaction of numerous environmental and socio-economic factors determines the amount and spatial pattern of deforestation. Principal components analysis (Pearson 1901, Hotelling 1933) offers the exact multivariate statistical test required to determine the weight of different quantitative factors in explaining observed patterns of deforestation and reforestation. Principal components analysis determines the factors that account for most of the variability in a set of multivariate data and reveals any clustering of samples.

Project participants conduct two separate principal components analyses, one for deforestation and another for reforestation. The procedure is the same for each; the input data is different.

To create the input data layers for the deforestation principal components analysis, project participants extract one data layer from each of the deforestation factors at the time of the first remote sensing image (Step 5) such that each data layer contains the values of that factor for each of the cells that experienced deforestation (Step 3). The value of the non-deforestation cells is zero.

Likewise, to create the input data layers for the reforestation principal components analysis, project participants extract one data layer from each of the reforestation factors at the time of the first remote sensing image (Step 5) such that each data layer contains the values of that factor for each of the cells that experienced reforestation (Step 3). The value of the non-reforestation cells is zero.

Project participants use the principal components analysis function of their GIS or statistics software on the set of data layers that contain the values of each factor for each of the cells that experienced deforestation. Separately, project participants run principal components analysis on the set of data layers that contain the values of each factor for each of the cells that experienced reforestation. ENVI/IDL, ERDAS Imagine, and other software applications conduct principal components analyses. Project participants use the correlation matrix for principal components analyses (Orlóci 1978).

Principal components analysis yields the following:

1. A number of principal components equal to the number of input factor. Each principal component is a spatial data layer equal to a combination of the six original factors.
2. Fraction of the variance in the data that each principal component explains.
3. The eigenvalue loadings of each factor for each principal component.
4. A matrix of the correlation of each combination of two factors with the number of columns and the number of rows each equal to the number of factors.

Project participants use the scree test (Cattell 1966) to determine the number of explanatory principal components, which equals the number of principal components before an abrupt change in the graph of fraction of the variance in the data that each principal component explains versus the number of the principal component.

The weight of each factor in explaining observed deforestation and, separately, observed reforestation (Equation 1) is (Gonzalez et al. 2004, 2006):

♦ Equation 1:

$$W_n^{process} = \frac{V_m}{\sum_{m=1}^{i} V_m} \times \frac{L_{mn}}{\sum^{q} \sum_{n=1}^{j} \left| L_{mn} \right|}$$

i	= total number of principal components
j	= total number of factors explaining observed deforestation or, separately, observed reforestation
L_{mn}	= eigenvalue loading of principal component m for factor n
m	= index number for each principal component (1, 2,…, i)
n	= index number for each factor explaining observed deforestation or, separately, observed reforestation (1, 2,…, j)
process	= either <u>deforestation</u> or <u>reforestation</u>
q	= number of explanatory principal components given by the scree test (Cattell 1966)
V_m	= fraction of variance explained by principal component m
$W_n^{process}$	= weight of factor n in explaining a process, range of values 0–1.

Step 6 produces a weight for each factor for deforestation ($W_1^{deforesation}$, $W_2^{deforestation}$,…, $W_j^{deforestation}$) and, separately, for reforestation ($W_1^{reforesation}$, $W_2^{reforestation}$,…, $W_j^{reforestation}$). The value for each weight ranges from 0 to 1. The sum of all weights for deforestation equals 1. The sum of all weights for reforestation equals 1.

Step 7. Derivation of deforestation and reforestation probability functions

For each factor, project participants derive equations of the probability of deforestation and, separately, the probability of reforestation, as a function of the value of the factor. First, classify the deforestation pixels (Step 3) for each factor at the time of the first remote sensing image (Step 5) into factor value classes of logical size, such as 100 m for distance with the value of the factor value class equal to the middle value of the class. For example, for factor value classes of 0 m–100 m, 100 m–200 m,…, 1900 m–2000 m, the values of the factor value classes will be 50 m, 150 m,…, 1950 m. Repeat this reclassification for the pixels that were forest in the first remote sensing image (Step 3), for the reforestation pixels (Step 3), and for the pixels that were non-forest in the first remote sensing image. This generates 4 x j files.

The probability of deforestation for each factor value class equals the fraction of forest in the first remote sensing image that became non-forest land by the time of the second remote sensing image (Equation 2), where the probabilities range from 0 (not probable) to 1 (probable):

♦ Equation 2: $$p_{\text{factor value class}}^{\text{deforestation}} = f_{\text{factor value class}}^{\text{deforestation}} = \frac{A_{\text{factor value class}}^{\text{deforestation}}}{A_{\text{factor value class}}^{\text{forest } t_1}}$$

$A_{\text{factor value class}}^{\text{forest } t_1}$ = area in a factor value class that was forest at t_1 (ha)
$A_{\text{factor value class}}^{\text{deforestation}}$ = area in a factor value class deforested between t_1 and t_2 (ha)
$f_{\text{factor value class}}^{\text{deforestation}}$ = fraction of t_1 forest land in a factor value class that became non-forest land by t_2, range 0–1
factor value class = a range of possible values of a factor explaining observed deforestation with a value equal to the middle value of the class; for example, factor value classes of 0 m–100 m, 100 m–200 m,…, 1900 m–2000 m will have values of 50 m, 150 m,…, 1950 m
$p_{\text{factor value class}}^{\text{deforestation}}$ = probability of deforestation in a specific factor value class in a period of years equal to the time between t_1 and t_2, range of values 0–1
t_1 = year of first remote sensing image (past) (Step 3)
t_2 = year of second remote sensing image (present) (Step 3).

Separately, the probability of reforestation for each factor value class equals the fraction of non-forest land in the first remote sensing image that became forest by the time of the second remote sensing image (Equation 3), where the probabilities range from 0 (not probable) to 1 (probable):

♦ Equation 3: $$p_{\text{factor value class}}^{\text{reforestation}} = f_{\text{factor value class}}^{\text{reforestation}} = \frac{A_{\text{factor value class}}^{\text{reforestation}}}{A_{\text{factor value class}}^{\text{non-forest } t_1}}$$

$A_{\text{factor value class}}^{\text{non-forest } t_1}$ = area in a factor value class that was non-forest land at t_1 (ha)
$A_{\text{factor value class}}^{\text{reforestation}}$ = area in a factor value class reforested between t_1 and t_2 (ha)
$f_{\text{factor value class}}^{\text{reforestation}}$ = fraction of t_1 non-forest land in a factor value class that became forest by year 2, range 0–1
factor value class = a range of possible values of a factor explaining observed reforestation with a value equal to the middle value of the class; for example, factor value classes of 0 m–100 m, 100 m–200 m,…, 1900 m–2000 m will have values of 50 m, 150 m,…, 1950 m
$p_{\text{factor value class}}^{\text{reforestation}}$ = probability of reforestation in a specific factor value class in a period of years equal to the time between year 1 and year 2, range of values 0–1

t_1 = year of first remote sensing image (past) (Step 3)
t_2 = year of second remote sensing image (present) (Step 3).

The relationship of probability versus factor value defines an empirical probability function for each factor for deforestation and, separately, for reforestation. Statistics software applications can fit the data to a continuous polynomial function (Equations 4, 5) and give the polynomial functions for the upper and lower confidence intervals at p = 0.05:

♦ Equation 4: $p_{factor}^{deforestation} = f(\text{factor value})$

$p_{factor}^{deforestation}$ = probability of deforestation for a specific factor, range of values 0–1
factor = factor explaining observed deforestation
factor value = value of the factor explaining observed deforestation

♦ Equation 5: $p_{factor}^{reforestation} = f(\text{factor value})$

$p_{factor}^{reforestation}$ = probability of reforestation for a specific factor, range of values 0–1
factor = factor explaining observed reforestation
factor value = value of the factor explaining observed reforestation.

Step 8. Calculation of deforestation and reforestation probability for each pixel

The number of years of historical observations of deforestation and reforestation is the limit on the number of years into the future that we can project the spatial distribution of future deforestation and reforestation. Therefore, project participants project deforestation and reforestation probabilities for a time period equivalent to the number of years between the two remote sensing images (Equation 6):

♦ Equation 6: $t_3 = t_2 + (t_2 - t_1)$

t_1 = year of first remote sensing image (past) (Step 3)
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future).

The probability of future deforestation for each forest pixel at the time of the second remote sensing image (Equation 7) equals the sum of the individual factor probabilities for the continuous factor values at the time of the second remote sensing image (Step 5), weighted by individual factor weights derived by principal components analysis. Likewise, the probability of future reforestation for each non-forest pixel at the time of the second remote sensing image (Equation 7) equals the sum of the individual factor probabilities for the continuous factor values at the time of the second remote sensing image (Step 5), weighted by individual factor weights derived by principal components analysis:

♦ Equation 7: $p_{pixel}^{process} = \sum_{n=1}^{j} W_n^{process} \cdot p_n^{process}$

j = total number of factors explaining observed deforestation or, separately, observed reforestation
n = index number for each factor explaining observed deforestation or, separately, observed reforestation (1, 2,…, j)
$p_n^{process}$ = probability of a process from a specific factor from t_2 to t_3, range of values 0–1 (Equations 4, 5)
$p_{pixel}^{process}$ = total probability for an individual pixel of a process from t_2 to t_3, range of values 0–1
process = either deforestation or reforestation
$W_n^{process}$ = weight of each factor in explaining a process, range 0–1 (Equation 1)
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future) (Equation 6).

In Equation 7, use of the probabilities functions for the upper and lower confidence intervals at p = 0.05 (Step 7) in will give the upper and lower confidence probabilities of future deforestation and reforestation.

Step 9. Projection of future deforestation and reforestation

The fraction of forest at t_2 (year of the second remote sensing image) that would be cut by t_3 (Equation 6) equals the sum of the deforestation probabilities of all forest pixels (Equation 8). Likewise, the fraction of non-forest land at t_2 (year of the second remote sensing image) that would reforest by t_3 (Equation 6) equals the sum of the reforestation probabilities of all the year 2 non-forest pixels (Equation 8):

♦ Equation 8: $f^{process} = \sum^{\text{all pixels}} p_{pixel}^{process}$

$f^{process}$ = fraction of a land class at t_2 undergoing a process by t_3, range of values 0–1
$p_{pixel}^{process}$ = total probability for an individual pixel of a future process from t_2 to t_3, range of values 0–1 (Equation 7)
process = either deforestation or reforestation
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future) (Equation 6).

The projected gross area of deforestation from t_2 to t_3 (Equation 9) equals the fraction of forest at t_2 projected to undergo deforestation multiplied by the area of forest at t_2:

♦ Equation 9: $\Delta_{\text{gross forest}}(t_3 - t_2) = A_{forest}(t_2) \times f^{deforestation}$

$A_{forest}(t_2)$ = area of forest at t_2 (ha) (Step 3)
$\Delta_{\text{gross forest}}(t_3 - t_2)$ = gross area of deforestation from t_2 to t_3 (ha)
$f^{deforestation}$ = fraction of forest at t_2 lost by t_3, range of values 0–1 (Equation 2)
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future) (Equation 6).

The projected gross area of deforestation from t_2 to t_3 (Equation 10) equals the fraction of non-forest land at t_2 projected to reforest multiplied by the area of non-forest land at t_2:

♦ Equation 10: $\Delta_{\text{gross non-forest}}(t_3 - t_2) = A_{\text{non-forest}}(t_2) \times f^{reforestation}$

$A_{\text{non-forest}}(t_2)$ = area of forest at t_2 (ha) (Step 3)
$\Delta_{\text{gross non-forest}}(t_3 - t_2)$ = gross area of reforestation from t_2 to t_3 (ha)
$f^{reforestation}$ = fraction of non-forest land at t_2 reforested by t_3, range of values 0–1 (Equation 3)
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future) (Equation 6).

The projected gross deforestation rate (Equation 11) equals the fraction of forest lost divided by the years elapsed.

♦ Equation 11: $r_{deforestation} = \frac{f^{deforestation}}{t_3 - t_2}$

$f^{deforestation}$ = fraction of forest at t_2 lost by t_3, range of values 0–1 (Equation 8)
$r_{deforestation}$ = projected gross deforestation rate (y^{-1})
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future) (Equation 6).

Likewise, the projected gross reforestation rate (Equation 12) equals the fraction of non-forest reforested divided by the years elapsed:

♦ Equation 12: $r_{reforestation} = \dfrac{f^{reforestation}}{t_3 - t_2}$

$f^{reforestation}$ = fraction of non-forest land at t_2 reforested by t_3, range of values 0–1 (Equation 8)
$r_{reforestation}$ = projected gross reforestation rate (y^{-1})
t_2 = year of second remote sensing image (present) (Step 3)
t_3 = year of deforestation and reforestation projection (future) (Equation 6).

Step 10. Determination of baseline scenario

The baseline scenario for the proposed project activity is the gross reforestation rate projected in Steps 1-9. If FRCA projects any reforestation in the future ($r_{reforesation} > 0$), then the baseline scenario is continued reforestation at the rate $r_{reforesation}$. Under that scenario, project participants continue to FRCA Step 11 to calculate baseline net greenhouse gas removal. If FRCA projects no reforestation in the future ($r_{reforesation} \leq 0$), then the baseline scenario is no reforestation and project participants continue to FRCA Step 13 to calculate baseline net greenhouse gas removal.

As a conservative measure, project participants do not consider potential future loss of carbon from non-forest land. This will result in a higher estimate of baseline net greenhouse gas removal and a lower estimate of net anthropogenic greenhouse gas removal.

Explanation/justification of choice:

>> FRCA determines the most plausible baseline scenario by analyzing observed historical data on forest cover change and projecting what future forest cover change would occur within the project boundary if historical trends continued without a CDM project activity. The use of actual field data from permanent forest inventory plots, remote sensing data of actual forest cover change since 1989, and multivariate and bivariate statistical analyses create an objective and fact-based scientific method for determining the baseline scenario. In this way, the method confronts the complexities of projecting future reforestation in an area that experiences natural or unassisted reforestation.

A certain amount of uncertainty rests with the deforestation and reforestation probabilities, but FRCA addresses this uncertainty by deriving probability functions (Equation 7) for the upper and lower statistical confidence intervals at $p = 0.05$.

FRCA addresses national policies by using the national definition of forest determine the stratification of land (Step 2). FRCA takes account of local circumstances by the use of local field data (Step 2), local remote sensing data (Step 3), and local factors that could explain observed deforestation and reforestation (Step 5).

4. Estimation of baseline net GHG removals by sinks

Methodology procedure:

>>

Step 11. Calculation of biomass using local tree allometric equations and species-specific wood densities

The permanent forest inventory plots provide the data to calculate biomass per unit area in each forest class, measures required to estimate of baseline net greenhouse gas removal. Allometric equations are empirical functions that give the biomass of a tree as a function of tree diameter and/or tree height (Equation 13). Foresters derive allometric equations by cutting down trees, measuring their physical dimensions, and weighing their components. Differences in the architecture, form, and physiognomy among tree species renders necessary the development of allometric equations specific to a taxon or to a functional group (King 1996, Ter-Mikaelian and Korzukhin 1997, Ketterings et al. 2001, Jenkins et al. 2004). Research has produced numerous allometric equations for forest species and forest types around the word (*e.g.* Baker et al. 2004a for Amazon rainforest, Jenkins et al. 2004 for North American temperate forest, Poupon et al. 1980 for Africa semi-arid woodland, and Zianis et al. 2005 for European temperate forest).

♦ Equation 13: b_{tree} = f(tree diameter and/or height)

b_{tree} = aboveground biomass of an individual tree (kg)

Wood density strongly influences spatial patterns of forest biomass (Baker et al. 2004b, IPCC 2003). Therefore, project participants use wood density measurements for local tree species (*e.g.* CTFT 1989, Reyes et al. 1992, Fearnside 1997, Baker et al. 2004b, Barbosa and Fearnside 2004) to accurately calculate biomass from allometric equations that were developed with a sample of trees of different basic wood density.

The ratio of belowground (root) biomass to aboveground (shoot) biomass displays global patterns of uniformity within vegetation types (Enquist and Niklas 2002, Mokany et al. 2006). This uniformity permits the use of root:shoot ratios developed in the same vegetation type, but in a location outside of the project boundary (Mokany et al 2006).

Field measurements of the biomass of understory trees, lianas, and other vegetation less than the threshold diameter of the tree inventory (*e.g.* Araújo et al. 1999) provide data for calculating understory biomass.

Biomass density of a forest equals the sum of the biomass in individual trees divided by the area sampled and understory and belowground biomass:

♦ Equation 14:
$$B_{forest} = (1+R) \times \left[1 + \frac{f_{understory}}{1 - f_{understory}}\right] \times \frac{\sum^{\text{all trees}} \left(\frac{\rho_{tree}}{\rho_{sample}}\right) \times b_{tree}}{A_{forest}} \times \left(\frac{1\ \text{t}}{10^3\ \text{kg}}\right)$$

A_{forest} = area of a forest (ha)

B_{forest} = biomass density of a forest (t ha^{-1})

b_{tree} = aboveground biomass of an individual tree (kg) (Equation 13)

$f_{understory}$ = fraction of total biomass in understory vegetation less than the threshold diameter of the tree inventory (t understory biomass (t total aboveground biomass)$^{-1}$)

R = root:shoot ratio (t belowground biomass (t aboveground biomass)$^{-1}$)

ρ_{sample} = specific wood density of allometric sample (kg oven-dry biomass (kg field-dry biomass)$^{-1}$)

ρ_{tree} = specific wood density of a tree (kg oven-dry biomass (kg field-dry biomass)$^{-1}$).

<u>Step 12. Derivation of biomass growth function</u>

An equation of biomass vs. stand age (Equation 15) provides data to calculate biomass density of a regenerating forest, data needed to accurately estimate of baseline net greenhouse gas removal. Project participants derive the biomass growth function by applying Equation 14 to each permanent forest inventory plot.

♦ Equation 15: B(age) = f(age)

age = age of a forest stand (y)

B(age) = biomass density at a specified age (t ha^{-1}).

Biomass growth is rapid in young stands and slower in older stands (Hughes et al. 1999, Feldpausch et al. 2004, Neeff and dos Santos 2005, Zarin et al. 2005). Biomass growth is not linear.

<u>Step 13. Projection of baseline net greenhouse gas removal by sinks</u>

Project participants employ the default or carbon gain-loss method (Equations 3.2.2 and 3.2.22 of IPCC (2003)) to calculate the changes in carbon stocks within the project boundary of reforestation that would have occurred in the absence of a CDM project activity at the rate projected in Step 9.

The projected rate of reforestation without a project activity (Equation 12) indicates that a certain amount of land starts to regenerate each year. For example, if FRCA shows that the projected rate of reforestation for a 1000 ha area is 0.01 y^{-1}, then 10 ha would begin to reforest in the first year. In the second year, the first 10 ha would continue to accumulate biomass at a growth rate for a stand 1 year old. In addition, another 9.9 ha would begin to reforest. In the third year, the first 10 ha would continue to accumulate biomass at a growth rate for a stand 2 years old, the 9.9 ha would continue to accumulate biomass at a growth rate for a stand 1 year old, and an additional 9.8 ha would begin to reforest.

Therefore, the biomass accumulation in a specified year (Equation 16) equals the sum of that year's biomass accumulation in that year's new area of reforestation and any areas from previous years of reforestation:

♦ Equation 16: $$B_{baseline}(t) = \sum_{age=1}^{t-t_{start}+1} r_{reforestation} \times A_{project} \times [B(age) - B(age-1)] \div 1\ y$$

age = age of a reforestation area (y)
$A_{project}$ = area of proposed reforestation project activity (ha)
B(age) = biomass density of regenerating forest at a specified age (t ha^{-1}) (Equation 15)
$B_{baseline}(t)$ = biomass accumulation in baseline reforestation during year t (t)
$r_{reforestation}$ = projected rate of baseline scenario reforestation (y^{-1}) (Equation 12)
t = calendar year, range of values t_{start} to t_{end} (y)
t_{end} = year of the end of the operational lifetime of a project activity (y)
t_{start} = year of the starting date of the project activity (y).

Equation 16 provides a detailed procedure to calculate the biomass increment of Equation 3.2.5 of IPCC (2003).

For ease of calculation, Equation 16 uses the total area of the proposed reforestation project activity for each year, instead of decreasing the total area by an amount proportional to the rate. This is a conservative measure because it will result in a higher estimate of baseline net greenhouse gas removal and a lower estimate of net anthropogenic greenhouse gas removal.

Carbon fraction of biomass is the key variable for converting units of biomass to units of carbon. The carbon fraction of biomass varies displays patterns of uniformity within vegetation types (Hughes et al. 2000, Andreae and Merlet 2001, Chambers et al. 2001, Gayoso et al. 2002, Lamlom and Savidge 2003, Lasco and Pulhin 2003, Feldpausch et al. 2004). This uniformity permits the use of a carbon fraction developed in the same vegetation type, but outside of a project boundary. For areas without local carbon fraction measurement, project participants use the results of an analysis of field data from 106 plots in boreal, temperate, and tropical forests around the world (McGroddy et al. 2004) that document a carbon fraction of tree biomass of 0.47.

Therefore, the *ex ante* calculation of baseline net greenhouse gas removal by sinks (Equation 17) takes the sum of the carbon in projected baseline biomass accumulation for each year from the starting date to the end of the operation lifetime of the project activity:

♦ Equation 17: $$C_{baseline} = f_C \times \left(\frac{44\ t\ CO_2}{12\ t\ C}\right) \times \sum_{t_{start}}^{t_{end}} B_{baseline}(t)$$

$B_{baseline}(t)$ = biomass accumulation in baseline reforestation during year t (t) (Equation 16)
$C_{baseline}$ = baseline net greenhouse gas removal by sinks (t CO_2 equivalent)
f_C = carbon fraction of biomass (kg C (kg biomass)$^{-1}$)

Equation 17 is a temporal sum of Equation 3.2.4 of IPCC (2003).

FRCA does not quantify biomass losses in baseline scenario reforestation. This is a conservative measure because it will result in a higher estimate of baseline net greenhouse gas removal and a lower estimate of net anthropogenic greenhouse gas removal.

Explanation/justification of choice:

>> The method uses local tree allometric equations, local wood densities, a local carbon fraction of biomass, and the IPCC (2003) default or carbon gain-loss method to produce a robust *ex ante* calculation of baseline net greenhouse gas removal by sinks.

5. Additionality

Methodology procedure:

>> Project participants should use the latest version of the UNFCCC CDM "Tool for the demonstration and assessment of additionality for afforestation and reforestation CDM project activities" to demonstrate and assess additionality.

Explanation/justification of choice:

>> The CDM Executive Board has approved the "Tool for the demonstration and assessment of additionality for afforestation and reforestation CDM project activities" (UNFCCC CDM EB 21 Report, Annex 16).

6. Ex ante actual net GHG removals by sinks

Methodology procedure:

>>

Step 14. Projection of actual net greenhouse gas removal by sinks

Project participants employ the default or carbon gain-loss method (Equations 3.2.2 and 3.2.22 of IPCC (2003)) to calculate the changes in carbon stocks in new trees growing within the project boundary due to a reforestation project activity. Carbon gains accrue with biomass accumulating in new trees. Carbon losses go to harvesting and mortality.

Calculation of biomass accumulation in project activity reforestation broadly follows the same procedure as calculation of biomass accumulation in baseline scenario reforestation (Step 13). In general, however, a project activity will start with a few annual stages of reforestation and a long period of growth and maintenance. So, project participants first define the reforestation stages as the areas and types of reforestation planted in which years of the operational lifetime of a project activity, *e.g.* 500 ha of natural regeneration and 100 ha of plantations in year 1, 1000 ha of natural regeneration and 200 ha of plantations in year 2, 1000 ha of natural regeneration and 500 ha of plantations in year 3, no additional reforestation in year 4 to year 30.

The age of a reforestation area (Equation 18) is a function of stage and time:

♦ Equation 18: $age = t - t_{start} + G(stage)$

age = age of a reforestation area (y)
G(stage) = calculation coefficient (y); G(stage) = 1, 0, -1, -2, -3 …. for stage = 1, 2, 3, 4, 5…
stage = serial number of annual reforestation stages; 1, 2, 3…
t = calendar year, range of values t_{start} to t_{end} (y)
t_{start} = year of the starting date of the project activity (y).

The biomass accumulation in a natural regeneration stand (Equation 19) is a function of age, stage, and biomass growth:

♦ Equation 19: $B_{nat.reg.}(age) = A_{nat.reg.}(stage) \times [B(age) - B(age - 1)]$

$A_{nat.reg.}(stage)$ = area of natural regeneration for a specified stage (ha)
age = age of a reforestation area (y) (Equation 18)
B(age) = biomass density of regenerating forest at a specified age (t ha^{-1}) (Equation 15)
$B_{nat.\ reg.}(age)$ = biomass accumulation in a natural regeneration of a specified age in one year (t)
stage = serial number of annual reforestation stages; 1, 2, 3…

The biomass accumulation in a plantation of a mix of native species similar to the natural species composition (Equation 20) is a function of age, stage, biomass growth, and tree density:

♦ Equation 20: $B_{plant}(age) = A_{plant}(stage) \times \frac{D_{plant}}{D_{secondary\ forest}} \times [B(age) - B(age - 1)]$

A_{plant}(stage) = area of plantation for a specified stage (ha)
age = age of a reforestation area (y) (Equation 18)
B(age) = biomass density of regenerating forest at a specified age (t ha^{-1}) (Equation 15)
B_{plant}(age) = biomass accumulation in a plantation of a specified age in one year (t)
D_{plant} = tree density of a plantation (trees ha^{-1})
$D_{secondary\ forest}$ = tree density of natural secondary forest (trees ha^{-1})
stage = serial number of annual reforestation stages; 1, 2, 3…

Therefore, the biomass accumulation in a specified year (Equation 21) equals the sum of that year's biomass accumulation in that year's new areas of natural regeneration and plantation and any areas from previous years:

♦ Equation 21: $$B_{project}(t) = \sum^{\text{all stages of age}>0} B_{nat.reg.}(age) + B_{plant}(age)$$

age = age of a reforestation area (y) (Equation 18)
$B_{nat.\ reg.}$(age) = biomass accumulation in a natural regeneration of a specified age in one year (t) (Equation 19)
B_{plant}(age) = biomass accumulation in a plantation of a specified age in one year (t) (Equation 20)
$B_{project}(t)$ = biomass accumulation in project activity reforestation during calendar year t (t)
t = calendar year, range of values t_{start} to t_{end} (y).

Equations 19-21 provide a detailed procedure to calculate the biomass increment of Equation 3.2.5 of IPCC (2003).

The actual gross greenhouse gas removal by sinks (Equation 22) equals the sum of the carbon in project activity reforestation biomass accumulation for each year from the starting date to the end of the operation lifetime of the project activity:

♦ Equation 22: $$C_{actual\ gross} = f_C \left(\frac{44\ t\ CO_2}{12\ t\ C} \right) \sum_{t_{start}}^{t_{end}} B_{project}(t)$$

$B_{project}(t)$ = biomass accumulation in project activity reforestation during calendar year t (t) (Equation 21)
$C_{actual\ gross}$ = actual gross greenhouse gas removal by sinks (t CO_2 equivalent)
f_C = carbon fraction of biomass (kg C (kg biomass)$^{-1}$)
t = calendar year; range of values t_{start} to t_{end} (y)
t_{end} = year of the end of the operational lifetime of a project activity (y)
t_{start} = year of the starting date of the project activity (y).

Equation 22 is a temporal sum of Equation 3.2.4 of IPCC (2003).

Carbon losses go to harvesting and mortality. Project participants define a fraction of the total area under natural regeneration in the project activity and a fraction of the total trees planted in the project activity that sets the combined limit for each of these losses. For example, project participants can agree that harvesting and mortality can claim a maximum of 0.02 of the area under natural regeneration and 0.02 of the trees planted in the project activity. In this case, actual gross greenhouse gas emissions (losses) by sinks (Equation 23) equal a fraction of actual gross greenhouse gas removal by sinks:

♦ Equation 23: $L_{mortality\ harvest} = f_{mortality\ harvest} \times C_{actual\ gross}$

$C_{actual\ gross}$ = actual gross greenhouse gas removal by sinks (t CO_2 equivalent) (Equation 22)
$f_{mortality\ harvest}$ = agreed fraction of allowed combined mortality and harvest (t mortality and harvest (t actual gross removal by project activity)$^{-1}$)
$L_{mortality\ harvest}$ = greenhouse gas emissions (losses) from mortality and harvesting (t CO_2 equivalent)

Equation 23 provides a simplified procedure to calculate the carbon losses of Equations 3.2.6, 3.2.7, 3.2.8, 3.2.9, and 3.2.24 of IPCC (2003).

Actual net greenhouse gas removal by sinks (Equation 24) equals the difference between actual gross greenhouse gas removal by sinks and actual gross greenhouse gas emissions by sinks:

♦ Equation 24: $$C_{actual\ net} = (1 - f_{mortality\ harvest}) \cdot f_C \cdot \left(\frac{44\ t\ CO_2}{12\ t\ C}\right) \cdot \sum_{t_{start}}^{t_{end}} B_{project}(t)$$

$B_{project}(t)$ = biomass accumulation in project activity reforestation during calendar year t (t) (Equation 21)
$C_{actual\ net}$ = actual net greenhouse gas removal by sinks (t CO_2 equivalent)
f_C = carbon fraction of biomass (kg C (kg biomass)$^{-1}$)
$f_{mortality\ harvest}$ = agreed fraction of allowed combined mortality and harvest (t mortality and harvest (t actual gross removal by project activity)$^{-1}$)
t = calendar year, range of values t_{start} to t_{end} (y)
t_{end} = year of the end of the operational lifetime of a project activity (y)
t_{start} = year of the starting date of the project activity (y).

Equation 24 is a detailed version of Equation 3.2.2 of IPCC (2003).

Explanation/justification of choice:

>> FRCA uses the methods and equations of IPCC (2003), the reference for standard procedures for afforestation and reforestation activities.

7. Leakage

Methodology procedure:

>>

Step 15. Calculation of leakage from fossil fuel use and displacement of deforestation

Greenhouse gas emissions from fossil fuel combustion (Equation 25) are the sum of the product of greenhouse gas emission factor, greenhouse gas global warming potential, fuel density, and amount of fuel used by project activity vehicles:

♦ Equation 25: $$L_{fossil\ fuels} = \sum^{all\ gases} GWP_{gas} \cdot E_{gas} \cdot \rho_{fuel} \cdot U_{fuel} \cdot \frac{1\ t}{10^6\ g}$$

E_{gas} = emissions factor for a specified gas (g gas (kg fuel)$^{-1}$), values from national sources or from Tables I-27 to I-32 and I-36 to I-42 of IPCC (1996) and from Table 2.7 of IPCC (2000)
gas = CO_2, CH_4, and N_2O
GWP = Global Warming Potential (t CO_2 equivalent (t gas)$^{-1}$), values from IPCC (2001)
$L_{fossil\ fuels}$ = leakage from fossil fuel combustion by project activity vehicles (t CO_2 equivalent)
ρ_{fuel} = fuel density (kg l^{-1}), values from national sources or from IPCC (2000)
U_{fuel} = fuel use by project activity vehicles (l).

Equation 25 is a streamlined version of Equation 2.4 of IPCC (2000). Project participants assume that combustion of fossil fuels is complete and that carbon stored in vehicles is zero, two simplifications of Equation 2.4 of IPCC (2000) that comprise conservative assumptions because they result in a higher estimate of leakage and a lower estimate of net anthropogenic greenhouse gas removal.

In order to control leakage from displaced deforestation, project participants will agree, before the starting date of the project activity, to a limit of the area of forest outside the project boundary that participants can cut. Project participants will sign an agreement binding them to this limit. Project participants will agree to an inventory of their land before the starting date of the project activity and every five years during the operational lifetime of the project. Project participants will select a single date before the public announcement of the project activity that will serve as a date after which all deforestation will count as leakage.

Leakage from displaced deforestation (Equation 26) equals the product of the deforestation limit, the proposed area of the project activity, and the carbon density of the local forest class with the highest biomass:

♦ Equation 26: $L_{displacement} = f_{displacement} \cdot A_{project} \cdot f_C \cdot \left(\frac{44 \text{ t } CO_2}{12 \text{ t C}}\right) \cdot B_{forest}$

$A_{project}$ = area of proposed project activity (ha)
B_{forest} = biomass density of the local forest class with the highest biomass density (t ha^{-1}) (Equation 14)
f_C = carbon fraction of biomass (kg C (kg biomass)$^{-1}$)
$f_{displacement}$ = agreed and monitored limit of the area of forest that participants can cut outside of the project boundary as a fraction of the area of the proposed project activity, range of values 0–1
$L_{displacement}$ = leakage from displacement of deforestation (t CO_2 equivalent)

Because some deforestation of lower biomass forest will occur, calculation of leakage using the highest local forest biomass is a conservative measure that will result in a lower estimate of net anthropogenic greenhouse gas removal.

Project activities that promote reforestation by non-project participants in adjacent parcels outside the project boundary will cause a 'beneficial' type of leakage, namely, greenhouse gas removal outside the project boundary attributable to project activities. FRCA does not quantify this greenhouse gas removal, a conservative measure because it will result in a lower estimate of net anthropogenic greenhouse gas removal.

Total leakage (Equation 27) is the sum of leakage from fossil fuel combustion by project activity vehicles and leakage from deforestation displacement:

♦ Equation 27: $L_{leakage} = L_{fossil\ fuel} + L_{displacement}$

$L_{displacement}$ = leakage from displacement of deforestation (t CO_2 equivalent) (Equation 26)
$L_{fossil\ fuels}$ = leakage from fossil fuel combustion by project activity vehicles (t CO_2 equivalent) (Equation 25)
$L_{leakage}$ = total leakage (t CO_2 equivalent)

Equation 27 is an *ex ante* calculation of greenhouse gas emissions outside the project boundary attributable to project activities inside the project boundary.

Explanation/justification of choice:

>> FRCA uses local data to calculate leakage due to fossil fuel combustion by project activity vehicles and to displacement of deforestation to areas outside the project boundary. These two phenomena are the only major sources of leakage under the conditions listed in Section I.3.

8. Ex ante net anthropogenic GHG removal by sinks

Methodology procedure:

>>

Step 16. Calculation of net anthropogenic greenhouse gas removal by sinks

Net anthropogenic greenhouse gas removal by sinks (Equation 31) equals the difference of actual net greenhouse gas removal by sinks and baseline net greenhouse gas removal by sinks and leakage:

♦ Equation 28: $C_{anthropogenic} = C_{actual\ net} - C_{baseline} - L_{leakage}$

$C_{actual\ net}$ = actual net greenhouse gas removal by sinks (t CO_2 equivalent) (Equation 24)
$C_{anthropogenic}$ = net anthropogenic greenhouse gas removal by sinks (t CO_2 equivalent)

$C_{baseline}$ = baseline net greenhouse gas removal by sinks (t CO_2 equivalent) (Equation 17)
$L_{leakage}$ = leakage (t CO_2 equivalent) (Equation 27)

Explanation/justification of choice:

>> FRCA provides procedures for calculating all three variables necessary to calculate net anthropogenic greenhouse gas removal by sinks: actual net greenhouse gas removal by sinks (Equation 24), baseline net greenhouse gas removal by sinks (Equation 17), and leakage (Equation 27).

9. Uncertainties and conservative approach

Methodology procedure:

>> The principal uncertainties of a baseline method include carbon density of forest classes, future reforestation trends, and future displacement of deforestation. FRCA reduces the uncertainty of carbon density of forest classes by using original forest inventory data from the ecological area of the project activity and by utilizing locally-derived tree allometric equations (Step 11), species-specific wood densities (Step 11), carbon fraction of biomass (Step 13), and biomass growth rates (Step 12). Moreover, project participants track errors in measurements of diameter and height and re-measure trees until error falls below 1% (Step 2). FRCA reduces the uncertainty of projecting future reforestation trends by basing all estimates on real observations of past reforestation detected by remote sensing (Step 3) and verified by ground-truth sites in the field (Step 2). In addition, project participants track the statistical variability of the bivariate deforestation and reforestation probability curves by deriving probability functions for the upper and lower statistical confidence intervals at p = 0.05. (Step 7). FRCA reduces the uncertainty of an *ex ante* calculation of leakage through a quantitative method based on field data (Step 15).

FRCA follows a conservative approach by ensuring that any simplifying measure results in a lower estimate of net anthropogenic greenhouse gas removal by sinks. These measures include:

1. Measuring carbon in aboveground and belowground pools, but not in dead wood, litter, and soil–field data show that the latter three pools increase with reforestation (Section I.4).
2. Non-quantification of potential future loss of carbon from non-forest land–this will result in a higher estimate of baseline net greenhouse gas removal and a lower estimate of net anthropogenic greenhouse gas removal (Step 10).
3. In calculating actual net greenhouse gas removal, use of the total area of the proposed reforestation project activity for each year, instead of decreasing the total area by an amount proportional to the rate–this results in a higher estimate of baseline net greenhouse gas removal and a lower estimate of net anthropogenic greenhouse gas removal (Equation 16, Step 13).
4. Calculation of leakage from displacement of deforestation using the highest local forest biomass–because some deforestation of lower biomass forest will occur, this measure will result in a lower estimate of net anthropogenic greenhouse gas removal (Step 15).
5. Non-quantification of a 'beneficial' type of leakage, greenhouse gas removal outside the project boundary attributable to project activities–this results in a higher estimate of leakage and a lower estimate of net anthropogenic greenhouse gas removal (Step 15).

In quantifying uncertainty, project participants can use IPCC (2000, 2003) procedures (Equations 29, 30, 31):

♦ Equation 29 (Equation 6.3 of IPCC (2000):

$$\text{uncertainty} = \frac{t_{student} \times \sigma}{\mu}$$

μ = mean of variable of interest (Step 2)
σ = standard deviation of the variable of interest (Step 2)
$t_{student}$ = Student's t, $t_{student}$ = 1.96 for probability = 0.05
uncertainty = dispersion of values that could be reasonably attributed to the measured quantity (IPCC 2003), expressed as a percentage of the mean, range 0-100%

♦ Equation 30 (Equation 5.2.1 of IPCC (2003):

$$U_{product} = \sqrt{\sum^{\text{all factors}} (U_{factor})^2}$$

U_{factor} = uncertainty of an individual factor (Equation 29)
$U_{product}$ = uncertainty of a product of factors, range 0-100%

♦ Equation 31 (Equation 5.2.2 of IPCC (2003):

$$U_{sum} = \frac{\sqrt{\sum^{\text{all factors}} (U_{factor} \times Q_{factor})^2}}{\left|\sum^{\text{all factors}} (Q_{factor})^2\right|}$$

Q_{factor} = quantity of an individual factor
U_{factor} = uncertainty of a single factor (Equation 29)
U_{sum} = uncertainty of a sum of factors, range 0-100%.

Explanation/justification of choice:

>> The identified measures address uncertainty and produce a conservative, or lower, estimate of net anthropogenic greenhouse gas removal. Project participants can use IPCC (2000, 2003) to quantify uncertainty.

10. Data needed for ex ante estimations

Methodology procedure:

>>

Data / parameter	Description	Vintage	Data sources and geographical scale
aboveground biomass density	aboveground biomass per unit area of principal forest types	as close as possible to the present	permanent forest inventory plots in the ecological area of the project activity (Step 2)
biomass growth	increase in biomass per unit area per unit time	as close as possible to the present	permanent forest inventory plots in the ecological area of the project activity (Step 2) for the forest types of the ecological area of project activity
carbon fraction of biomass	carbon mass per unit of biomass	as close as possible to the present	McGroddy et al. (2004) or local data
coordinates of project boundary	geographic location of the vertices of land parcels included in the project activity	as close as possible to the present	global positioning system (GPS) receivers in the project boundary (Step 4)
deforestation and reforestation factors	factors that could explain observed patterns of deforestation and reforestation, *e.g.* distance to non-forest areas, distance to forest areas, elevation, distance to rivers, distance to roads, slope, and distance to towns	as close as possible to December 31, 1989 and to the present	remote sensing, aerial photographs, any other sources of spatial data for the ecological area of project activity (Step 5)
fossil fuel density	mass per unit volume of fossil fuel	as close as possible to the present	IPCC (2000) or other scientific reference (Step 15)

Data / parameter	Description	Vintage	Data sources and geographical scale
fossil fuel use	volume of fossil fuel used by project activity vehicles	operational lifetime of the project activity	decision of project participants (Step 15)
fraction of allowed mortality and harvest	combined limit of mortality and harvest as a fraction of the total area under natural regeneration in the project activity and a fraction of the total trees planted in the project activity	operational lifetime of the project activity	decision of project participants (Step 14)
Global Warming Potential	relative impact of a greenhouse gas as a multiple of the impact of CO_2	as close as possible to the present	IPCC (2001) or other scientific reference (Step 15)
greenhouse gas emissions factor	mass of greenhouse gas released per unit mass of a fossil fuel	as close as possible to the present	IPCC (1996, 2000) or other scientific reference (Step 15)
land cover	type of vegetation	as close as possible to December 31, 1989 and to the present	remote sensing data, aerial photographs of ecological area of project activity (Step 3)
limit on deforestation by project participants	agreed and monitored limit of the area of forest that participants can cut outside of the project boundary as a fraction of the area of the proposed project activity,	operational lifetime of the project activity	decision of project participants (Step 15)
local tree allometric equations	empirical functions that give the biomass of a tree as a function of tree diameter and/or tree height	as close as possible to the present	scientific literature (*e.g.* Baker et al. 2004a for Amazon rainforest, Jenkins et al. 2004 for North American temperate forest, Poupon et al. 1980 for Africa semi-arid woodland, and Zianis et al. 2005 for European temperate forest) for the forest types of the ecological area of project activity (Step 11)
project activity plantation and natural regeneration areas and years	areas and years of proposed project activity reforestation	operational lifetime of the project activity	decision of project participants (Step 14)
root:shoot ratio	ratio of belowground biomass to aboveground biomass	as close as possible to the present	Mokany et al. (2006) or local data (Step 11)
species-specific wood densities	dry mass of wood per unit volume of moist wood	as close as possible to the present	scientific literature (*e.g.* CTFT 1989, Reyes et al. 1992, Fearnside 1997, Baker et al. 2004b, Barbosa and Fearnside 2004) for the forest species of the ecological area of project activity or local data (Step 11)
tree density of a project activity plantation	trees per unit area in a project activity plantation	operational lifetime of the project activity	decision of project participants (Step 14)
tree density of natural secondary forest	trees per unit area in regenerating forest	as close as possible to the present	permanent forest inventory plots in the ecological area of the project activity (Step 2)

Explanation/justification of choice:

>> The procedures of the baseline and monitoring method require the specified data.

11. Other information

Explanation/justification of choice:

>> The use of actual field data from permanent forest inventory plots, remote sensing data of actual forest cover change since 1989, and multivariate and bivariate statistical analyses create an objective and fact-based scientific method for determining the baseline scenario. In this way, the method confronts the complexities of projecting future reforestation in an area that experiences natural or unassisted reforestation.

FRCA reduces the uncertainty of carbon density of forest classes by using original forest inventory data from the ecological area of the project activity and by utilizing locally-derived tree allometric equations (Step 11), species-specific wood densities (Step 11), carbon fraction of biomass (Step 13), and biomass growth rates (Step 12). FRCA reduces the uncertainty of projecting future reforestation trends by basing all estimates on real observations of past reforestation detected by remote sensing (Step 3) and verified by ground-truth sites in the field (Step 2). FRCA reduces the uncertainty of an *ex ante* calculation of leakage through a quantitative method based on field data (Step 15).

FRCA allows for the development of baselines in a transparent manner by making all calculations explicit and verifiable and by using publicly available data and scientific references.

Section III: Monitoring methodology description

>>

1. Monitoring project implementation

Methodology procedure:

>>

<u>Step 17. Measurement of surface area of all reforestation stands within the project boundary and the number and species of any trees planted</u>

Project participants locate and record geographic coordinates of each vertex of all individual parcels within the project boundary using global positioning system (GPS) receivers, calculate the areas using geographic information system (GIS) software, and record the information in a database of the attributes of all individual parcels. At the time of reforestation, project participants record the number and species of any trees planted and the surface area of natural regeneration parcels.

Explanation/justification of choice:

>> The specified procedure monitors project implementation.

2. Sampling design and stratification

Methodology procedure:

>>

<u>Step 18. Establishment of a statistical sample of trees planted or regenerated by the project activity</u>

Project participants establish a systematic network of sampling plots in project activity natural regeneration areas and select a systematic sample of trees in project activity plantation areas. Snowdon et al. (2002) detail procedures for fixed area plots. Project participants place the plots in a grid pattern in natural regeneration areas and select trees in a grid pattern in plantation areas.

Project participants stratify areas within the project boundary by type of project activity, natural regeneration or plantation, by vegetation type for natural regeneration and species for plantation, and any other ecological or edaphic characteristic that produces strata of relatively homogenous biomass and biomass growth per unit area.

Project participants use Neyman (1934) allocation to determine the number of plots and trees (Equation 32) (Snowdon et al. 2002):

♦ Equation 32: $n_{sample} = \left(\frac{t_{student} \cdot \sigma}{\mu \cdot accuracy} \right)^2$

accuracy	= target accuracy, range of values 0–1
μ	= mean of variable of interest (Step 2)
n_{sample}	= sample size required to achieve a specified accuracy (plots or trees)
σ	= standard deviation of the variable of interest (Step 2)
$t_{student}$	= Student's t, $t_{student}$ = 1.96 for probability = 0.05

Explanation/justification of choice:

>> Neyman (1934) allocation is the appropriate procedure (Snowdon et al 2002).

3. Calculation of *ex post* baseline net GHG removals by sinks, if required

Methodology procedure:

>>

Step 19. Re-measurement, at least every five years, of trees in the permanent forest inventory plots

Project participants will re-measure the trees in the permanent forest inventory plots using the same forest inventory procedures established in Step 2 and enter the information in a database with every tree comprising an individual data record.

Step 20. Update of the biomass growth function

Project participants will use the data from Step 19 to update the biomass growth function (Equation 15) using the same procedures established in Step 12.

Step 21. Re-calculation of baseline net greenhouse gas removal with an updated biomass growth function

Project participants will use the updated biomass growth function from Step 20 to re-calculate baseline net greenhouse gas removal (Equation 17) every five years. This will be an *ex post* calculation of baseline net greenhouse gas removal by sinks.

The potential 'beneficial' leakage due to the project activity, namely, greenhouse gas removal outside the project boundary attributable to the promotion by the project activity of reforestation by non-project participants in adjacent parcels outside the project boundary, prevents the *ex post* changing of variables in Equation 17 except biomass growth.

Explanation/justification of choice:

>> The specified procedure produces an *ex post* calculation of baseline net greenhouse gas removal by sinks.

4. Data to be collected and archived for the estimation of baseline net GHG removals by sinks

Methodology procedure:

>>

ID number	Data Variable	Source of data	Data Unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Proportion of data monitored	How will data be archived? (electronic/ paper)	Comment
FRCA-01	aboveground biomass density	permanent forest inventory plots (Steps 2, 19)	$t\ ha^{-1}$	c	5 years	1	elec. and paper	
FRCA-02	biomass growth	permanent forest inventory plots (Steps 2, 19)	$t\ ha^{-1}\ y^{-1}$	c	5 years	1	elec. and paper	

ID number	Data Variable	Source of data	Data Unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Proportion of data monitored	How will data be archived? (electronic/ paper)	Comment
FRCA-03	carbon fraction of biomass	McGroddy et al. (2004) or local data	t C (t biomass)$^{-1}$	m or scientific literature	latest data	1	elec. and paper	
FRCA-04	deforesation and reforestation factors	remote sensing, aerial photographs, other sources of spatial data (Step 5)	specific to each factor	specific to each factor	December 31, 1989 and present	1	elec. and paper	
FRCA-05	desired accuracy	scientific literature or local data	fraction	e or scientific literature	starting date	< 1	elec. and paper	
FRCA-06	land cover	remote sensing data, aerial photographs (Step 3)	ha	m	5 years	1	elec. and paper	
FRCA-07	local tree allometric equations	scientific literature (Step 11)	kg	m or scientific literature	latest data	≤ 1	elec. and paper	
FRCA-08	natural regeneration monitoring sample	calculated (Equation 31)	ha	c	starting date	< 1	elec. and paper	
FRCA-09	plantation monitoring sample	calculated (Equation 31)	trees	c	starting date	< 1	elec. and paper	
FRCA-10	root:shoot ratio	Mokany et al. (2006) or local data (Step 11)	t root biomass (t shoot biomass)$^{-1}$	m or scientific literature	latest data	1	elec. and paper	
FRCA-11	species-specific wood densities	scientific literature or local data (Step 11)	t m^{-3}	m or scientific literature	latest data	≤ 1	elec. and paper	
FRCA-12	tree diameter at height of 1.3 m	permanent forest inventory plots (Steps 2, 19)	cm	m	5 years	1	elec. and paper	
FRCA-13	tree height, if necessary for allometric equation	permanent forest inventory plots (Steps 2, 19)	m	m	5 years	< 1	elec. and paper	
FRCA-14	permanent forest inventory plot locations	permanent forest inventory plots (Steps 2, 19)	geographic coordinates	m	establishment	1	elec. and paper	
FRCA-15	permanent forest inventory tree species	permanent forest inventory plots (Steps 2, 19)	species	m	5 years	1	elec. and paper	
FRCA-16	understory vegetation less than the threshold diameter of the tree inventory	local data or scientific literature	t understory biomass (t total aboveground biomass)$^{-1}$	m or scientific literature	latest data	<1	elec. and paper	

5. Calculation of ex post actual net GHG removal by sinks

Methodology procedure:

>>

Step 22. Measurement, at least every five years, of the diameter of each tree in the sample and any other dimensions of the tree required by the allometric equation for that species

Project participants will measure the diameter at a height of 1.3 m and any other dimensions required for allometric equations and record the species of each tree in the statistical samples of plantation trees and natural regeneration areas, using the same forest inventory procedures established in Step 2. They will inventory the sample natural regeneration areas before the start of project activities in order to identify non-project activity biomass of the existing non-forest land. They will enter the information in computers databases with every plantation tree and every natural regeneration area comprising an individual data record.

Step 23. Re-calculation of actual net greenhouse gas removal by sinks

Project participants will record the number, species, and dimensions of dead trees or trees selected for harvest, according to the forest inventory procedures in Step 2.

Project participants will use the data from Step 22 and the mortality and harvest data to re-calculate actual net greenhouse gas removal by sinks (Equation 24) every five years. The calculation will exclude the non-project activity biomass of the pre-existing non-forest land and deduct any decrease. The calculation will be an *ex post* calculation of actual net greenhouse gas removal by sinks.

6. Data to be collected and archived for actual net GHG removals by sinks

Methodology procedure:

>>

ID number	Data Variable	Source of data	Data Unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Proportion of data monitored	How will data be archived? (electronic/ paper)	Comment
FRCA-17	coordinates of project boundary	field surveys (Steps 4, 17)	geographic coordinates	m	starting date and when changed	1	elec. and paper	
FRCA-18	natural regeneration mortality and harvest	field surveys (Step 22)	ha	m	annual	< 1	elec. and paper	
FRCA-19	non-project activity tree species	field surveys (Step 22)	species	m	establishment and annual	< 1	elec. and paper	
FRCA-20	non-project activity trees	field surveys (Step 22)	trees	m	establishment and annual	< 1	elec. and paper	
FRCA-21	non-project activity tree diameter at height of 1.3 m	field surveys (Step 22)	cm	m	establishment and annual	< 1	elec. and paper	
FRCA-22	non-project activity tree height	field surveys (Step 22)	m	m	establishment and annual	< 1	elec. and paper	
FRCA-23	plantation mortality and harvest	field surveys (Step 22)	trees	m	annual	< 1	elec. and paper	
FRCA-24	project activity natural	field surveys (Step 17)	ha	m	establishment and annual	< 1	elec. and paper	

ID number	Data Variable	Source of data	Data Unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Proportion of data monitored	How will data be archived? (electronic/ paper)	Comment
	regeneration area							
FRCA-25	project activity plantation area	field surveys (Step 17)	ha	m	establishment and annual	< 1	elec. and paper	
FRCA-26	project activity plantation species	field surveys (Step 17)	species	m	establishment and annual	< 1	elec. and paper	
FRCA-27	project activity plantation trees	field surveys (Step 17)	trees	m	establishment and annual	< 1	elec. and paper	
FRCA-28	project activity tree diameter at height of 1.3 m	field surveys (Step 22)	cm	m	establishment and annual	< 1	elec. and paper	
FRCA-29	project activity tree height	field surveys (Step 22)	m	m	establishment and annual	< 1	elec. and paper	

7. Leakage

Methodology procedure:

>>

Step 24. Monitoring of deforestation by project participants.

At the starting date of the project activity, every year for the first five years, and every five years afterwards, project participants will record the location, land cover, and surface area of all land that participating farmers and herders hold. Project participants will select a single date before the public announcement of the project activity that will serve as a date after which all deforestation on the land held by participating farmers and herders will count as leakage (Step 15).

Step 25. Re-calculation of leakage from fossil fuel use and displacement of deforestation

Project participants will record fossil fuel used by project activity vehicles and re-calculate fossil fuel leakage (Equation 25).

Project participants will use the actual area of deforestation to re-calculate leakage from displaced deforestation (Equation 33):

♦ Equation 33: $$L_{displacement} = A_{displacement} \cdot f_C \cdot \left(\frac{44 \text{ t } CO_2}{12 \text{ t C}}\right) \cdot B_{forest}$$

$A_{displacement}$ = measured area of deforestation on land held by participating farmers and herders outside the project boundary (ha)

B_{forest} = biomass density of the local forest class with the highest biomass density (t ha^{-1}) (Equation 14)

f_C = carbon fraction of biomass (kg C (kg biomass)$^{-1}$)

$L_{displacement}$ = leakage from displacement of deforestation (t CO_2 equivalent)

Because some deforestation of lower biomass forest will occur, calculation of leakage using the highest local forest biomass is a conservative measure that will result in a lower estimate of net anthropogenic greenhouse gas removal.

Project activities that promote reforestation by non-project participants in adjacent parcels outside the project boundary will cause a 'beneficial' type of leakage, namely, greenhouse gas removal outside the project boundary attributable to project activities. FRCA does not quantify this greenhouse gas removal, a conservative measure because it will result in a lower estimate of net anthropogenic greenhouse gas removal.

Project participants will re-calculate leakage (Equation 27).

Explanation/justification of choice:

>> The specified procedure re-calculates leakage based on new data.

8. Data to be collected and archived for leakage

Methodology procedure:

>>

ID number	Data Variable	Source of data	Data Unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Proportion of data monitored	How will data be archived? (electronic/ paper)	Comment
FRCA-30	fossil fuel density	IPCC (2000) or other scientific reference (Step 15)	$t\ m^{-3}$	scientific literature	latest data	1	elec. and paper	
FRCA-31	fossil fuel use	project participants (Step 25)	l	m	annual	1	elec. and paper	
FRCA-32	Global Warming Potential	IPCC (2001) or other scientific reference (Step 15)	$t\ CO_2$ equivalent $(t\ gas)^{-1}$	scientific literature	latest data	1	elec. and paper	
FRCA-33	greenhouse gas emissions factor	IPCC (1996, 2000) or other scientific reference (Step 15)	g gas (kg fossil fuel)$^{-1}$	scientific literature	latest data	1	elec. and paper	
FRCA-34	land (location) held by participating farmers and herders	project participants (Step 25)	geographic coordinates	m	establishment, annual years 1-5, then every 5 years	1	elec. and paper	
FRCA-35	land (surface area) held by participating farmers and herders	project participants (Step 25)	ha	m	establishment, annual years 1-5, then every 5 years	1	elec. and paper	
FRCA-36	land (cover class) held by participating farmers and herders	project participants (Step 25)	land cover class	m	establishment, annual years 1-5, then every 5 years	1	elec. and paper	

9. Ex post net anthropogenic GHG removal by sinks

Methodology procedure:

>>

Step 26. Re-calculation of net anthropogenic greenhouse gas removal by sinks

Project participants will use the re-calculated baseline net greenhouse gas removals (Step 21), the re-calculated actual net greenhouse gas removals (Step 23), and the re-calculated leakage (Step 25) to re-calculate the net anthropogenic greenhouse gas removal by sinks (Equation 28). This will be an *ex post* calculation of net anthropogenic greenhouse gas removal by sinks. To calculate the number of long-term certified emission reductions, project participants use Equation 28 to calculate net anthropogenic greenhouse gas removal by sinks for the crediting period of the project activity.

To calculate the number of temporary certified emission reductions, project participants use Equation 28 to calculate net anthropogenic greenhouse gas removal by sinks for period from the starting date of the of the project activity to the year of the end of the commitment period following the commitment period during which the temporary certified emission reduction was issued.

10. Uncertainties and conservative approach

Explanation/justification of choice:

>>

The principal uncertainties of a baseline method include carbon density of forest classes, future reforestation trends, and displacement of deforestation. FRCA reduces the uncertainty of carbon density of forest classes by using original forest inventory data from the ecological area of the project activity and by utilizing locally-derived tree allometric equations (Step 11), species-specific wood densities (Step 11), carbon fraction of biomass (Step 13), and biomass growth rates (Steps 12, 20). Moreover, project participants track errors in measurements of diameter and height and re-measure trees until error falls below 1% (Steps 2, 19, 22). FRCA reduces the uncertainty of projecting future reforestation trends by basing all estimates on real observations of past reforestation detected by remote sensing (Step 3) and verified by ground-truth sites in the field (Step 2). In addition, project participants track the statistical variability of the bivariate deforestation and reforestation probability curves by deriving probability functions for the upper and lower statistical confidence intervals at $p = 0.05$ (Step 7). FRCA reduces the uncertainty of an *ex post* calculation of leakage through a quantitative method based on field data (Step 25).

FRCA follows a conservative approach by ensuring that any simplifying measure results in a lower estimate of net anthropogenic greenhouse gas removal by sinks. These measures include:

1. Measuring carbon in aboveground and belowground pools, but not in dead wood, litter, and soil–field data show that the latter three pools increase with reforestation (Section I.4).
2. Non-quantification of loss of carbon from non-forest land–this will result in a higher estimate of baseline net greenhouse gas removal and a lower estimate of net anthropogenic greenhouse gas removal (Step 21).
3. Calculation of leakage from displacement of deforestation using the highest local forest biomass–because some deforestation of lower biomass forest will occur, this measure will result in a lower estimate of net anthropogenic greenhouse gas removal (Step 25).
4. Non-quantification of a ‘beneficial’ type of leakage, greenhouse gas removal outside the project boundary attributable to project activities–this results in a higher estimate of leakage and a lower estimate of net anthropogenic greenhouse gas removal (Step 25).

In quantifying uncertainty, project participants can use IPCC (2000, 2003) procedures (Equations 29, 30, 31).

11. Other information

Explanation/justification of choice:

>> The use of actual field data from permanent forest inventory plots, from project activity natural regeneration stands and plantations, remote sensing data of actual forest cover change since 1989, and multivariate and bivariate statistical analyses create an objective and fact-based scientific method for determining the reforestation baseline and leakage.

FRCA allows for the development of baselines in a transparent manner by making all calculations explicit and verifiable and by using publicly available data and scientific references.

Section IV: Lists of variables, acronyms and references

1. List of variables used in equations:

Variable	SI Unit	Description
accuracy	fraction	target accuracy (Equation 32)
$A^{deforestation}$	ha	area of deforestation (Equation 2)
A^{forest}	ha	area of forest (Equation 2)
$A_{displacement}$	ha	measured area of deforestation on land held by participating farmers and herders outside the project boundary (Equation 33)
A_{forest}	ha	area of forest (Equation 14)
A_{forest} (t)	ha	area of forest in year t (Equation 9)
age	y	age of a forest stand (Equation 15)
$A_{nat\ reg.}$(stage)	ha	area of natural regeneration for a specified stage (Equation 19)
$A^{non\text{-}forest}$	ha	area of non-forest (Equation 3)
$A_{non\text{-}forest}$ (t)	ha	area of non-forest in year t (Equation 10)
A_{plant}(stage)	ha	area of plantation for a specified stage (Equation 20)
$A_{project}$	ha	area of proposed reforestation project activity (Equation 16)
$A^{reforestation}$	ha	area of reforestation (Equation 3)
B(age)	$t\ ha^{-1}$	biomass density at a specified age (Equation 15)
$B_{baseline}$(t)	t	biomass accumulation in baseline reforestation during year t (Equation 16)
B_{forest}	$t\ ha^{-1}$	biomass density of a forest (Equation 14)
$B_{nat.\ reg.}$(age)	t	biomass accumulation in a natural regeneration of a specified age in one year (Equation 19)
B_{plant}(age)	t	biomass accumulation in a plantation of a specified age in one year (Equation 20)
$B_{project}$(t)	t	biomass accumulation in project activity reforestation during calendar year t (Equation 21)
b_{tree}	kg	aboveground biomass of an individual tree (Equation 13)
$C_{actual\ gross}$	t CO_2 equivalent	actual gross greenhouse gas removal by sinks (Equation 22)
$C_{actual\ net}$	t CO_2 equivalent	actual net greenhouse gas removal by sinks (Equation 24)
$C_{anthropogenic}$	t CO_2 equivalent	net anthropogenic greenhouse gas removal by sinks (Equation 31)
$C_{baseline}$	t CO_2 equivalent	baseline net greenhouse gas removal by sinks (Equation 17)
□$_{gross\ forest}$ (t_3 - t_2)	ha	gross area of deforestation from t_2 to t_3 (Equation 9)
D_{plant}	trees ha^{-1}	tree density of a plantation (Equation 20)
$D_{secondary\ forest}$	trees ha^{-1}	tree density of natural secondary forest (Equation 20)
□$_{gross\ non\text{-}forest}$ (t_3 - t_2)	ha	gross area of reforestation from t_2 to t_3 (Equation 10)
E_{gas}	t gas $(t\ fuel)^{-1}$	emissions factor for a specified gas (Equation 25)
factor	specific to each factor	factor explaining observed deforestation or reforestation (Equation 4)
factor value	specific to each factor	value of the factor explaining observed deforestation or reforestation (Equation 4)
factor value class	specific to each factor	a range of possible values of a factor explaining observed deforestation with a value equal to the middle value of the class;

Variable	SI Unit	Description
		for example, factor value classes of 0 m–100 m, 100 m–200 m,…, 1900 m–2000 m will have values of 50 m, 150 m,…, 1950 m (Equation 2)
f_C	kg C (kg biomass)$^{-1}$	carbon fraction of biomass (Equation 17)
$f^{deforestation}$	fraction	fraction of forest land that later became non-forest land (Equation 2)
$f_{displacement}$	fraction	agreed and monitored limit of the area of forest that participants can cut outside of the project boundary as a fraction of the area of the proposed project activity (Equation 26)
$f_{mortality\ harvest}$	t mortality and harvest (t actual gross removal by project activity)$^{-1}$	agreed fraction of allowed combined mortality and harvest (Equation 23)
$f^{reforestation}$	fraction	fraction of non-forest land that later became forest land (Equation 3)
$f_{understory}$	t understory biomass (t total aboveground biomass)$^{-1}$	fraction of total biomass in understory vegetation less than the threshold diameter of the tree inventory ((Equation 14)
G(stage)	y	calculation coefficient; G(stage) = 1, 0, -1, -2, -3 …. for stage = 1, 2, 3, 4, 5… (Equation 18)
GWP	g CO_2 equivalent (kg gas)$^{-1}$	Global Warming Potential (Equation 25)
i	principal component	total number of principal components (Equation 1)
j	factor	total number of factors explaining observed deforestation or, separately, observed reforestation (Equation 1)
$L_{displacement}$	t CO_2 equivalent	leakage from displacement of deforestation (Equation 26)
$L_{fossil\ fuels}$	t CO_2 equivalent	leakage from fossil fuel combustion by project activity vehicles (Equation 25)
$L_{leakage}$	t CO_2 equivalent	total leakage (Equation 27)
L_{mn}	no dimensions	eigenvalue loading of principal component m for factor n (Equation 1)
$L_{mortality\ harvest}$	t CO_2 equivalent	greenhouse gas emissions (losses) from mortality and harvesting (Equation 23)
m	no dimensions	index number for each principal component (1, 2,…, i) (Equation 1)
	specific to each variable	mean (Equation 29)
n	no dimensions	index number for each factor explaining observed deforestation or, separately, observed reforestation (1, 2,…, j) (Equation 1)
n_{sample}	specific to each variable	sample size required to achieve a specified accuracy (Equation 32)
$p^{deforestation}$	fraction	probability of deforestation (Equation 2)

Variable	SI Unit	Description
$p^{reforestation}$	fraction	probability of reforestation (Equation 3)
q	principal component	number of explanatory principal components (Equation 1)
Q_{factor}	specific to each factor	quantity of an individual factor
R	kg belowground biomass (kg aboveground biomass)$^{-1}$	root:shoot ratio (Equation 14)
$r_{deforestation}$	y^{-1}	deforestation rate (Equation 11)
$□_{fuel}$	kg l^{-1}	fuel density (Equation 25)
$r_{reforestation}$	y^{-1}	reforestation rate (Equation 12)
$□_{sample}$	kg oven-dry biomass (kg field-dry biomass)$^{-1}$	specific wood density of allometric sample (Equation 14)
$□_{tree}$	kg oven-dry biomass (kg field-dry biomass)$^{-1}$	specific wood density of a tree (Equation 14)
stage	no dimensions	serial number of annual reforestation stages; 1, 2, 3… (Equation 18)
□	specific to each vatiable	standard deviation (Equation 29)
t	y	calendar year (Equation 16)
t_1	y	year of first remote sensing image (Equation 2)
t_2	y	year of second remote sensing image (Equation 2)
t_3	y	year of deforestation and reforestation projection (Equation 6)
t_{end}	y	year of the end of the operational lifetime of a project activity (Equation 16)
t_{start}	y	year of the starting date of the project activity (Equation 16)
$t_{student}$	no dimensions	Student's t statistical probability distribution (Equation 29)
U_{fuel}	l	fuel use by project activity vehicles (Equation 25)
U_{factor}	%	uncertainty of a single factor (Equation 30)
$U_{product}$	%	uncertainty of a product of factors (Equation 30)
U_{sum}	%	uncertainty of a sum of factors (Equation 31)
uncertainty	%	dispersion of values that could be reasonably attributed to the measured quantity (IPCC 2003) (Equation 29)
V_m	fraction	fraction of variance explained by principal component m (Equation 1)
$W_n^{deforestation}$	fraction	weight of factor n in explaining deforestation, range of values 0–1 (Equation 1)
$W_n^{reforestation}$	fraction	weight of factor n in explaining reforestation, range of values 0–1 (Equation 1)

2. List of acronyms used in the methodologies:

Acronym	Description
AR-AM0001	UNFCCC CDM Afforestation/Reforestation approved methodology 1
CDM	Clean Development Mechanism

Acronym	**Description**
FRCA	Forest Restoration Carbon Analysis
CTFT	Centre Technique Forestier Tropical
ENVI	Environment for Visualizing Images
ERDAS	Earth Resources Data Analysis System
GIS	geographic information system
GPS	global positioning system
IDL	Interactive Data Language
IPCC	Intergovernmental Panel on Climate Change
NASA	National Aeronautics and Space Administration
UNFCCC	United Nations Framework Convention on Climate Change
USDA FS	United States Department of Agriculture, Forest Service
USGS	United States Geological Survey

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