4.3 LULUCF PROJECTS

4.3.1 Introduction

This section provides *good practice guidance* for defining project boundaries, measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gases, implementing plans to measure and monitor, and developing quality assurance and quality control plans. The material is intended for use with projects under Article 6 (Joint Implementation)[62] and Article 12 (Clean Development Mechanism) of the Kyoto Protocol. It does not address issues that are, at the time of writing, under the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC)[63], in the context of Article 12 of the Kyoto Protocol.

Guidance is provided for those elements for which standard methods exist and are applicable for project activities under Articles 6 and 12. In addition, guidance and/or recommendations are given on how to define project boundaries and on aspects to be considered within a project's baseline for activities under Article 6. However, other elements of Article 12 project activities, such as definitions for "project boundary" and "baseline", depend on decisions scheduled to be made at the ninth session of the Conference of the Parties (COP). These are not included in this *good practice guidance*. In general the application of this *good practice guidance* in respect of Article 6 and Article 12 projects depends on the requirements of the relevant COP decisions, including notably those relevant to Article 6 and the decisions which, at the time of writing, are under negotiation in respect of LULUCF projects under Article 12.

Section 4.1.1 provides an overview of the steps required by Annex I Parties to meet the requirements for reporting changes in carbon stocks and emissions and removals of greenhouse gases associated with Article 6 projects under the Kyoto Protocol. Emissions and/or removals resulting from Article 6 projects are also part of an Annex I host country's annual inventory, and Section 4.1.3 elaborates the relationship between the estimation and reporting of Article 3.3 and elected Article 3.4 activities on the one hand, and Article 6 project activities on the other.

Reporting for project activities under Article 12 (comprising the validation, monitoring and verification reports) involves the project participants, their contracted designated operational entity, the Parties involved and the CDM Executive Board. The reports are also made publicly available upon transmission to the CDM Executive Board. The modalities and procedures for reporting under Article 12 are also, at the time of writing, being considered by the SBSTA. Hence, reporting requirements for Article 12 project activities are not included as part of this *good practice guidance*.

Estimating and monitoring anthropogenic changes in carbon stocks and non-CO_2 greenhouse gas emissions and removals at the project level involve several challenges and specific circumstances, which may not be appropriately captured within *good practice guidance* developed for national inventories. It is therefore recommended to apply higher-tier methods, based on field measurements or field measurements in combination with models (e.g., allometric equations, simulation models). The recommended multiple methods, presented as a series of practical steps within a measuring, monitoring, and estimation plan, are detailed in Section 4.3.3 and its subsections. Options for standard sampling and field measurement techniques are described, along with the advantages and disadvantages of each. As clarified under Section 4.1.3, some areas with activities under Articles 3.3 and 3.4 can also be projects under Article 6. In such cases, it is *good practice* to use the same tier or a higher tier for estimating carbon stock changes and greenhouse gas emissions as was used for the same land in the UNFCCC inventory as specified in Chapter 3 of this report (refer to Section 4.2.3.4, Choice of method).

---

[62] Guidelines for the implementation of Article 6 of the Kyoto Protocol are found in the Annex to the Draft decision –/CMP.1 (Article 6), contained in document FCCC/CP/2001/13/Add.2, pp. 8-19.

[63] In Decision 17/CP.7, the SBSTA was requested to develop definitions and modalities for including afforestation and reforestation project activities under the CDM in the first commitment period, taking into account the issues of non-permanence, additionality, leakage, uncertainties, and socio-economic and environmental impacts, including impacts on biodiversity and natural ecosystems. A decision on these definitions and modalities will be adopted at the ninth session of the COP.

4.3.1.1 DEFINITION OF PROJECTS AND RELEVANCE TO ARTICLES 6 AND 12

A LULUCF project can be defined as a planned set of eligible activities within a specific geographic location that have the purpose of resulting in net greenhouse gas removals that are additional to those that would occur in the absence of the proposed project. A LULUCF project may be implemented by public or private entities, or a combination of the two, including private investors, private enterprises, local and national governments, other public institutions, and non-government organisations (NGOs).

For the first commitment period, eligible activities under Article 6 may include afforestation and reforestation, forest management, grazing land management, cropland management, and revegetation. Under Article 12, eligible activities for the first commitment period are limited to afforestation and reforestation. Under either article, projects can comprise multiple activities. For example, under Article 6, a project could consist of a combination of changes in both grazing and forest land management; under Article 12, a project could consist of afforestation with timber species and multipurpose tree species.

4.3.2 Project Boundaries

The Marrakesh Accords specify that the project boundary for Article 6 shall "encompass all anthropogenic emissions by sources and/or removals by sinks of greenhouse gases under the control of the project participants that are significant and reasonably attributable to the Article 6 project".[64] The definition for project boundary for LULUCF activities under Article 12 remains, at time of writing, under consideration by SBSTA. Therefore, it is *good practice* to identify all anthropogenic emissions by sources of greenhouse gases and removals by sinks arising from activities and practices associated with LULUCF projects. In a general sense, project boundaries can be thought of in terms of geographical area, temporal limits (project duration), and in terms of the project activities and practices responsible for greenhouse gas emissions and removals that are significant and reasonably attributable to the project activities.

4.3.2.1 GEOGRAPHIC AREA

Projects may vary in size and may be confined to a single or several geographic areas. Depending on the rules agreed for projects the area could be one contiguous block of land having a single owner or many small blocks of land spread more widely, perhaps having a large number of small land owners all being joined in some form of a cooperative or association. It is *good practice* to specify and clearly define spatial boundaries of the project lands so as to facilitate accurate measuring, monitoring, accounting, and verifying the project. These boundaries need to be identifiable by all stakeholders including project developers and Parties. It is *good practice*, when describing physical project boundaries, to include the following information:

- Name of the project area (e.g., compartment number, allotment number, local name, etc.)
- Map(s) of the area (paper format and/or digital format, if available)
- Geographic coordinates
- Total land area
- Details of ownership
- Land use and management history of the selected site(s).

The expectation is that boundaries remain unchanged during the duration of the project. In the event that boundary changes are inevitable, subject to the rules agreed for projects, then these would need to be reported and inclusions and/or exclusions of physical land area need to be surveyed using the above described methods (this would mean adjusting the net emissions or removals of greenhouse gases attributable to the project).

There are many different methods and tools that can be employed to identify and delineate physical project boundaries. These include, amongst others, the following:

- Permanent boundary markers (e.g., fences, hedgerows, walls, etc.);

---

[64] See Appendix B, paragraph 4(c) to draft decision -/CMP.1 (Article 6), contained in document FCCC/CP/2001/13/Add.2, p.19.

- Remote sensing data e.g., satellite imagery from optical and/or radar sensor systems, aerial photographs, airborne videos, etc.;
- Cadastral surveys (ground-based surveys to delineate property boundaries);
- Global Positioning Systems;
- Land records;
- National certified topographic maps with clearly defined topographic descriptions (e.g., rivers/creeks, mountain ridges); and
- Other nationally recognized systems.

Parties may opt to use any of these methods or tools, alone or in combination, provided accuracy is maintained.

4.3.2.2 TEMPORAL BOUNDARIES

Temporal boundaries (i.e., time boundaries), which are defined by the project starting and ending dates, should be set so that the boundaries encompass all changes in carbon stocks and non-CO_2 greenhouse gases emissions and removals that are reasonably attributable to project practices. Different project types have different patterns and rates of carbon accumulation as described in detail in the IPCC Special Report on LULUCF (Brown *et al.*, 2000b). For afforestation and reforestation projects activities under Article 12, the issue of project duration and its relation to permanence is not discussed here because it is being addressed by SBSTA (see Section 4.3.1).

4.3.2.3 ACTIVITIES AND PRACTICES

Different LULUCF projects have different direct human-induced changes in carbon stocks and non-CO_2 greenhouse gases. Examples of different project types and the likely changes in carbon stocks and non-CO_2 greenhouse gas emissions are provided in Box 4.3.1 (applicable to Articles 6 and 12, subject to the negotiations) and Boxes 4.3.2—4.3.4 (applicable to Article 6). Steps for identifying greenhouse gas emissions and removals caused by the project include the following:

- List and describe the greenhouse gas emissions and removals resulting from the primary project practices—e. g. tree planting, crop tillage, changed forest harvesting, etc.
- List and describe the greenhouse gas emissions and removals resulting from ancillary practices related to project operation and management—e. g. land preparation, nursery management, planting, thinning, logging—and describe these practices.
- Evaluate and report the emissions and removals of project-related greenhouse gases (CO_2, CH_4, and N_2O).

BOX 4.3.1
AFFORESTATION OR REFORESTATION PROJECTS

Tree planting on non-forested sites generally increases carbon stocks. These tree-planting projects could include planting with commercial timber species, planting with non-commercial native species, planting with multipurpose species (e.g., fruit trees, shade trees for coffee), or a combination of these species groups. Tree planting may also change emissions of greenhouse gases, in particular CO_2, CH_4 and N_2O.

The list below contains factors that may be relevant for measuring and monitoring in addition to changes in carbon stocks in pools defined by the Marrakesh Accords and decisions of the COP:

- Changes in emissions of greenhouse gases by burning of fossil fuels or biomass resulting from site preparation, monitoring activities, tree harvesting, and wood transportation.
- Changes in nitrous oxide emissions caused by nitrogen fertilization practices.
- Changes in nitrous oxide emissions from planting of leguminous trees.
- Changes in methane oxidation due to alteration of groundwater table level (particularly in high organic soil types), tree planting and soil management.

BOX 4.3.2
CROPLAND MANAGEMENT PROJECTS:
CONVERSION FROM CONVENTIONAL TO ZERO TILLAGE IN AGRICULTURE

Switching from conventional to reduced or zero tillage may cause modifications in soil physical, chemical and biological properties, as well as in water regimes, nutrient dynamics, fossil fuel use, and other factors related to the greenhouse gas balance of the system. The list below contains factors that may be taken into consideration for measuring and monitoring, in addition to changes in the soil organic carbon pool:

- Changes in nitrous oxide and methane emissions from soil.
- Changes in carbon dioxide emissions by transportation of agro-chemicals used in addition to those in the baseline case.
- Changes in carbon dioxide emissions by burning of fossil fuels in farm equipment.

BOX 4.3.3
FOREST MANAGEMENT PROJECTS: REDUCED IMPACT LOGGING

Some logging practices in forests can cause damage to both vegetation and soils that seriously impair regeneration. If adopted as part of sustainable forest management, reduced impact logging is a technique that aims at minimizing these negative impacts, thus reducing carbon dioxide emissions and improving the carbon removal capacity of regrowth. The list below contains factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant pools, particularly dead wood and soil organic carbon pools:

- Changes in carbon dioxide emissions from burning of fossil fuels due to improved harvesting and logging logistics.
- Changes in nitrous oxide and methane emissions from soil.

BOX 4.3.4
FOREST IMPROVEMENT PROJECTS:
ENRICHMENT PLANTING ON LOGGED-OVER FOREST OR SECONDARY GROWTH FOREST

Certain forest harvesting practices, such as selective logging, may cause poor residual tree growth. Enrichment planting with high-growth, commercially-valuable, or multipurpose species usually increases carbon stocks. The list below contains factors that may be taken into consideration for measuring and monitoring in addition to changes in carbon stocks in relevant carbon pools:

- Changes in nitrous oxide emissions from soils due to nitrogen inputs (fertilizers or use of leguminous trees).
- Changes in carbon dioxide emissions by burning of fossil fuels for site preparation, logging and wood transportation, in addition to those in the baseline case.
- Changes in methane oxidation caused by changes in vegetation and soil management.

4.3.3 Measuring, monitoring, and estimating changes in carbon stocks and non-CO_2 greenhouse gas emissions[65]

A key aspect of implementing LULUCF projects for mitigating greenhouse gas emissions is the accurate and precise estimation of greenhouse gas emissions and removals that are directly attributable to project activities. Techniques and methods for measuring, monitoring, and estimating terrestrial carbon pools that are based on commonly accepted principles of forest inventory, soil sampling, and ecological surveys are well established and applicable to LULUCF projects (Paivinen *et al.*, 1994; Pinard and Putz, 1997; MacDicken, 1997; Post *et al.*, 1999; Brown *et al.*, 2000a, 2000b; Schlegel *et al.*, 2001; Brown, 2002; Segura and Kanninen, 2002). These techniques and methods will be elaborated further in this section.

Methods for measuring and estimating non-CO_2 greenhouse gas emissions and removals are less well developed. However, projects could include practices that affect non-CO_2 greenhouse gases. Such practices include fertilizer application to enhance tree growth (possible N_2O emissions), wetland restoration (possible increase in CH_4 emissions), use of nitrogen-fixing plants (possible increase in N_2O emissions) and biomass burning during site preparation (possible change in N_2O and CH_4 emissions). Section 4.3.3.6 gives further advice on measuring, monitoring, and estimating emissions of non-CO_2 greenhouse gases for LULUCF projects.

Although the methods described here are appropriate for most situations at present, scientists are constantly developing new, and often more cost-effective, methods, and it is recommended to maintain awareness of the progress in this area. For example, remote sensing technology is a fast developing field and new sensors are being tested and launched (e.g., higher resolution sensors, radar systems) that could prove to be useful for planning, stratifying, and measuring and monitoring projects more cost-effectively. Furthermore, costs could be defrayed if measuring and monitoring carbon was combined with multipurpose resource inventories (Lund 1998).

Selective or partial accounting systems of the pools may be appropriate for projects as long as all pools for which emissions are likely to increase as a result of the project (loss of carbon or emission of non-CO_2 greenhouse gases) are included (Brown *et al.*, 2000b). However, for Article 12, the decision regarding the application of selective accounting of the pools is still under discussion by SBSTA. Possible criteria affecting the selection of carbon-accumulating pools to measure and monitor include the following: magnitude of the pool and its rate of change; availability of appropriate methods; cost to measure; attainable accuracy and precision (cf. Section 4.3.3.3).

There is a trade-off between the desired precision level of carbon-stock estimates and cost that is related to the spatial variability of the carbon-stock changes within the project boundary. The more spatially variable the carbon stocks in a project, the more sampling plots are needed to attain a given precision at the same confidence level. This may result, in principle, in cost implications to implement the measuring and monitoring plan. Stratification of the project lands into a reasonable number of relatively homogeneous units can reduce the number of plots needed for measuring, monitoring, and estimating. In general, the costs will increase with: the number of pools that need to be monitored; frequency of monitoring; precision level that is targeted; and the complexity of monitoring methods. The frequency of monitoring that is needed to detect change is related to the rate and magnitude of change: the smaller the expected change, the greater the potential that frequent monitoring will not detect a significant change. That is, frequency of monitoring should be determined by the magnitude of expected change—more frequent monitoring is applicable if the expected magnitude of change is large.

It is also necessary to monitor the overall performance of the project site to demonstrate that the project has accomplished what was originally proposed (e.g., that the project has achieved the targeted total planted area.) Measuring carbon at sampling plots only will not accomplish this, and additional steps are needed to monitor the overall performance of the project area.

Practical steps for designing and implementing a carbon measuring and monitoring plan are provided below, with multiple methods for various carbon pools. All methods provided are a combination of default data, field measurements, and models. In other words, the methods described here are multi-tier approaches.

---

[65] According to paragraph 53 in the Annex to the draft Decision -/CMP.1 (Article 12), project participants of Article 12 project activities are required to include the monitoring plan that provides for the collection and archiving of all relevant data necessary for estimating or measuring anthropogenic emissions by sources or removals by sinks of greenhouse gases occurring within the project boundary, cf. document FCCC/CP/2001/13/Add.2, p.38.

The recommended practical steps for designing and implementing a plan to measure, monitor, and estimate carbon-stock changes and non-CO_2 greenhouse gas emissions are[66]:

- Develop the baseline.
- Stratify the project area.
- Identify the relevant carbon pools and non-CO_2 greenhouse gases (this applies presently for Article 6 only; pools to be included in Article 12 are presently being discussed by the SBSTA).
- Design the sampling framework.
- Identify the methods (field and models) for monitoring carbon pools and non-CO_2 greenhouse gases.
- Develop the monitoring plan, including the quality assurance/quality control plan.

The details on each one of these steps are described next.

4.3.3.1 BASELINE

The baseline for an Article 6 project is the scenario that reasonably represents the anthropogenic emissions by sources and anthropogenic removals by sinks of greenhouse gases that would occur in the absence of the proposed project. This implies the need to assess potential greenhouse gas emissions and removals in a manner consistent with those associated with the project. For Article 12, issues related to the definition, which pools, gases, and activities the baseline shall include, how the baseline will be established, and choices of a baseline methodology are presently under consideration by SBSTA.

Changes in the carbon stocks in the relevant carbon pools and the non-CO_2 greenhouse gas emissions associated with the project need to be measured and monitored and then compared to those of the project's baseline. There are two aspects that have to be considered:

- The relevant carbon pools and non-CO_2 greenhouse gas emissions prior to the start of project activity need to be estimated. This estimation should preferably be based on measurements made on the same site where the project will be established. It is possible to use alternative ways for estimating carbon stocks and non-CO_2 greenhouse gas emissions, including for example, measurements on sites that are considered to reproduce, as far as possible, the initial condition of the project site (i.e., sites with similar soil type, vegetation cover and land-use history). Another possibility consists of using simulation models that have been calibrated for local conditions.
- A projection[67] of the carbon stocks in the relevant carbon pools and non-CO_2 greenhouse gas emissions in the project area has to be elaborated to estimate their trajectory without the project activity. The projection of the carbon stocks and non-CO_2 greenhouse gas emissions in the project area can be developed through the use of either, or both, of the following:
  - Peer-reviewed simulation models (e.g., CO2fix —Masera *et al.*, 2003; CENTURY—Parton *et al.*, 1987; or a locally developed model). Such models project the changes in carbon stocks of those components to be measured in the project case in each land-use category over time, and in some cases, project non-CO_2 greenhouse gas emissions too. It is recommended that these models be used to simulate changes in the selected carbon stocks and non-CO_2 greenhouse gas emissions without the project activity at the start of the project.
  - Control areas where the selected carbon pools and non-CO_2 greenhouse gases are measured and monitored over time. Data from the control areas can also be used in combination with the models in the previous step to improve the simulation results.

---

[66] For Article 12, it is recognized that leakage is an additional element in the monitoring plan; however, it has not been addressed here due to the ongoing work by SBSTA. For Article 6, leakage outside the project boundary is less of an issue because it should be accounted for in national greenhouse gas inventories (Brown *et al.*, 2000b).

[67] The projection may require consideration of socio-economic and other factors that go well beyond the scope of inventory guidance as set out in Appendix B to the draft decision -/CMP.1 (Article 6) (cf. document FCCC/CP/2001/13/Add.2, p.18), and (for non-LULUCF projects) in section G of the draft decision -/CMP.1 (Article 12) dealing with the CDM (cf. document FCCC/CP/2001/13/Add.2, pp.36-37). Provisions for LULUCF baseline projections are expected to be agreed upon at COP10.

4.3.3.2 STRATIFICATION OF THE PROJECT AREA[68]

At the start of a project, it is *good practice* to collect basic background information and data about the important bio-physical, and socio-economic characteristics of the project area. The information and data include, e.g.,: land-use history; maps of soil, vegetation, and topography; and land ownership. It is *good practice* that the land proposed for the project be geo-referenced. A geographic information system (GIS) would be useful for integrating the data from different sources, which can then be used to identify and stratify the project area into more or less homogeneous units.

It is *good practice* to stratify the project area (population of interest) into sub-populations or strata that form relatively homogenous units, if the project is not homogenous. Stratification can be done prior to implementing the measuring and monitoring plan (pre-stratification) or after (post-stratification) (see also Section 5.3.3). Post-stratification defines the strata using auxiliary data after the field measurements have been made.

Stratification of the project area can increase the accuracy and precision of the measuring and monitoring in a cost-effective manner. The size and spatial distribution of a project does not influence this step – one large contiguous block of land or many small parcels are considered the population of interest and are stratified in the same manner. In general, stratification decreases the costs of measuring and monitoring because it is expected to diminish the sampling effort necessary to achieve a given level of confidence caused by smaller variance in each stratum than in the project area itself. The stratification should be carried out using criteria that are directly related to the variables to be measured and monitored, e.g., the change in carbon stocks in trees for afforestation, or soil for cropland management.

For pre-stratification of an afforestation/reforestation project, the strata may be defined on the basis of one or more variables such as the tree species to be planted (if several), age class (as generated by delay in practical planting schedules), initial vegetation (e.g., completely cleared versus cleared with patches or scattered trees), and/or site factors (soil type, elevation, and slope etc.). For some afforestation/reforestation projects, the project site may appear to be homogeneous in all these and any other characteristics. However, it is possible that after the first monitoring event, the change in carbon stocks is highly variable and that on further analysis it is found that the measurements can be grouped into similar classes—in other words can be post-stratified.

There is a trade-off between the number of strata and sampling intensity. The goal is to balance the number of strata identified against the total number of plots needed to adequately sample each stratum. There is no hard and fast rule, and project developers need to use their expert judgement in deciding on the number of strata to include.

4.3.3.3 SELECTION OF CARBON POOLS AND NON-CO_2 GREENHOUSE GASES[69]

The major carbon pools in LULUCF projects are: aboveground biomass, belowground biomass, litter, dead wood, and soil organic carbon, which in turn, can be further subdivided (Table 4.3.1; see also Chapter 3 and Glossary). The major non-CO_2 greenhouse gases in LULUCF projects are N_2O and CH_4. For different types of LULUCF projects, a decision matrix that illustrates the possible choices of carbon pools for measuring and monitoring is shown in Table 4.3.1.

The selection of which pools to measure and monitor under agreed rules[70] is likely to depend on several factors, including expected rate of change, magnitude and direction of the change, availability and accuracy of methods to quantify change, and cost to measure. Provisions could include that all pools that are expected to decrease as a result of project activities must be measured and monitored, or that all pools that are expected to increase need not be measured and monitored. In practical terms, the latter provision could be the case if monitoring costs are high relative to the expected increase in carbon stocks—which might be the case, for example, with understorey herbaceous vegetation in an afforestation/reforestation project.

---

[68] See Chapter 5, Section 5.3.3.1 for further discussion on stratification.

[69] In paragraph 21 of the Annex to the draft decision -/CMP.1 (Land use, land-use change and forestry) it is stated: "A Party may choose not to account for a given pool in a commitment period, if transparent and verifiable information is provided that the pool is not a source." (cf. document FCCC/CP/2001/13/Add.1, p. 62). The discussion in this section refers to Article 6, and may also be applicable to Article 12, depending upon the decisions to be made by SBSTA.

[70] For Article 6 projects, see paragraph 21 of the Annex in the draft decision -/CMP.1 (Land use, land-use change and forestry), cf. document FCCC/CP/2001/13/Add.1, p. 62; rules for Article 12 projects are scheduled for adoption at COP9.

TABLE 4.3.1
A DECISION MATRIX TO ILLUSTRATE POSSIBLE SELECTION CRITERIA OF POOLS TO MEASURE AND MONITOR IN LULUCF PROJECTS (FOR EXPLANATION OF LETTERS AND NUMBERS IN THIS TABLE, SEE IMMEDIATELY BELOW THE TABLE)

Project type	**Carbon pools**					
	Living biomass			**Dead Organic Matter**		**Soil Organic Carbon**
	Aboveground: trees	**Aboveground: non-tree**	**Below-ground**	**Litter**	**Dead wood**	
Afforestation/reforestation	Y1	M2	Y3	M4	M4	M5
Forest management	Y1	M2	Y3	M4	Y4	M5
Cropland management	M1	M2	M3	M4	N	Y5
Grazing land management	M1	Y2	M3	M4	N	Y5
Revegetation	M1	Y2	M3	M4	M4	M5

Letters in the above table refer to the need for measuring and monitoring the carbon pools:

Y= Yes – the change in this pool is likely to be large and should be measured.

N = No – the change is likely to be small to none and thus it is not necessary to measure this pool.

M = Maybe – the change in this pool may need to be measured depending upon the forest type and/or management intensity of the project.

Numbers in the above table refer to different methods for measuring and monitoring the carbon pools:

1= Use the method for aboveground biomass of trees in Section 4.3.3.5.1.

2 = Use the method for aboveground biomass of non-trees vegetation in Section 4.3.3.5.1.

3 = Use the method for belowground biomass in Section 4.3.3.5.2.

4 = Use the method for litter and dead wood in Section 4.3.3.5.3.

5 = Use the method for soils in Section 4.3.3.5.4.

Source: modified from Brown *et al.*, 2000b.

Changes in emissions of non-CO_2 greenhouse gases may result from all project activities under Article 6; the sources of the non-CO_2 greenhouse gases are biomass burning, fossil fuel combustion, and soil (see Boxes 4.3.1–4.3.4). Furthermore, changes in grazing land management to enhance soil carbon, for example, can also change emissions of non-CO_2 greenhouse gases due to effects on livestock production (Sampson and Scholes, 2000). Under Article 12, afforestation/reforestation activities may also change emissions of non-CO_2 greenhouse gases through practices such as those given in Box 4.3.1 (see also Section 4.3.3.6).

4.3.3.4 SAMPLING DESIGN

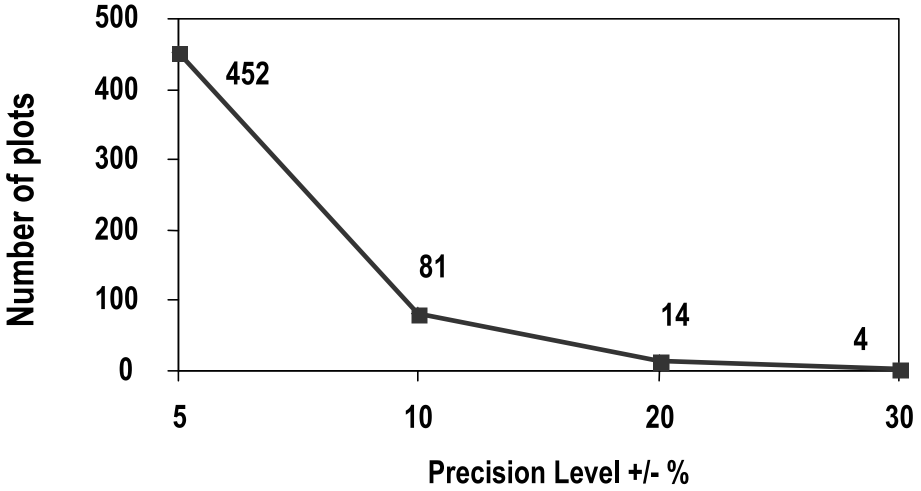
A discussion of general issues related to sampling design is given in detail in Section 5.3. For LULUCF projects, permanent or temporary sampling plots could be used for sampling over time to estimate changes in the relevant carbon pools and non-CO_2 greenhouse gases. Both methods have advantages and disadvantages. Permanent sample plots are generally regarded as statistically more efficient in estimating changes in forest carbon stocks than temporary plots because typically there is high covariance between observations at successive sampling events (Avery and Burkhart, 1983). Disadvantages of permanent plots are that their location could be known and they could be treated differently (such as by fertilizer, irrigation, etc. to enhance the carbon stocks), or that they could be destroyed or lost by disturbances over the project interval. The advantages of temporary plots is that they may be established more cost-effectively to estimate the carbon stocks of the relevant pools, their location changes after each sampling interval, and they would not be lost by disturbances. The main disadvantage of temporary plots is related to the precision in estimating the change in forest carbon stocks. Because individual trees are not tracked (see Clark *et al.*, 2001, for further discussion), the covariance term is non-existent and it will be more difficult to attain the targeted precision level without measuring more plots. Thus any cost advantage gained by using temporary over permanent forest plots may be lost by the need to install more temporary plots to achieve the targeted precision. For non-forestry based projects, where changes in carbon stocks of only soil or herbaceous vegetation are measured and monitored, temporary plots could be used because the statistical advantage of permanent plots (high covariance) is lost (see next Section 4.3.3.4.1).

4.3.3.4.1 THE NUMBER AND TYPE OF SAMPLE PLOTS

It is *good practice* to define the sample size for measuring and monitoring in each stratum on the basis of the estimated variance of the carbon stock in each stratum and the ratio of the area of the stratum to the total project area. Typically, to estimate the number of plots needed for measuring and monitoring, at a given confidence level, it is necessary to first obtain an estimate of the variance of the variable (for example, carbon stock of the main pools – trees in an afforestation/reforestation project or soil in a cropland management project) in each stratum. This can be accomplished either from existing data of the type of project to be implemented (e.g., a forest or soil inventory in an area representative of the proposed project) or by making measurements on an existing area representing the proposed project. For example, if the project is to afforest/reforest agricultural lands and the project will last for 20 years, then a measure of the carbon stocks in the trees of about 10-15 plots (for plot dimensions see Section 4.3.3.4.2) of an existing 20 year forest would possibly suffice. If the project area comprises more than one stratum, then this procedure needs to be repeated for each of them. Such measurements will provide estimates of the variance in each stratum.

The sample size (number of sample plots) needed can be calculated when the estimated variance in each stratum, area of each stratum, targeted precision level (based on sampling error only), and estimation error are known (see Section 5.3.6.2; Freese, 1962; MacDicken, 1997; Schlegel *et al.*, 2001; Segura and Kanninen, 2002). These sources provide methods and equations to compute the number of sample plots within each stratum, taking into account the variance and area of each stratum and the targeted precision at a given confidence level. Figure 4.3.1 illustrates the relationship between targeted precision level and number of sample plots (taking into consideration the variance and area of each of the six strata present in this forest) and shows that to attain increasing levels of precision (expressed as plus/minus a given percentage of the mean with 95% confidence), an increasingly high number of plots is needed. It is also recommended that an additional 10% of the calculated number of plots be installed to account for unexpected events that may make it impossible to re-locate all plots in the future.

Figure 4.3.1 An example of the relationship between the number of plots and the precision level (+/- % of total carbon stock in living and dead biomass, with 95% confidence) for all strata combined, for a complex tropical forest in Bolivia (the Noel Kempff Pilot Project); the project encompassed six strata and 625 plots were actually installed (from data in Boscolo *et al.*, 2000, and Brown *et al.*, 2000a).



Experience has shown that in the LULUCF sector, carbon stocks and the change in carbon stocks in complex forests can be estimated to precision levels of within ±10% of the mean, with 95% confidence, at a modest cost (Brown, 2002; http://www.winrock.org/REEP/NoelKmpff_rpt.html). National and regional forest inventories that are used to assess growing stock of timber typically target precision levels of less than 10% of the mean (see IPCC, 2000b).

The procedure described in the previous paragraph provides an estimate of the number of plots for various levels of precision based only on sampling error. There are other sources of error when estimating carbon stocks, for example, the errors from the use of allometric equations (model error) and from field and laboratory measurements (measurement error). In general, the sampling error is the largest source of error and can account for up to 80% of the total error (Phillips *et al.*, 2000). See Section 5.3.6.3 for more details on how to account for other sources of error.

When permanent sample plots are used to monitor changes in carbon stocks over time, it is *good practice* to locate them systematically (e.g., a uniform gid) with a random start, especially if stratified sampling is being used. The goal is to avoid subjective choice of plot locations (plot centres, plot reference points, movement of plot centres to more "convenient" positions). In the field, this is usually accomplished with the help of a GPS. Permanent sample plots may also be located in control areas (i.e., in areas adjacent to the project area that are biophysically similar to the project area) if it is expected that the reference case is likely to change over time (e.g., abandoned agriculture land).

In the case of projects where planting of trees may occur over several years, it is *good practice* to measure and monitor carbon stocks and non-CO_2 greenhouse gases in age-class cohorts (a group of trees of similar age), treating each cohort class as a population. It is recommended to combine no more than two to three age classes into a one-cohort class.

The carbon stocks and non-CO_2 greenhouse gases can be measured in reference plots if needed. If this is done, a number of plots similar to the number used in the project case will be required to maintain the targeted level of precision when comparing the with-project case to the baseline.

Estimating changes in carbon stocks over time from plot data

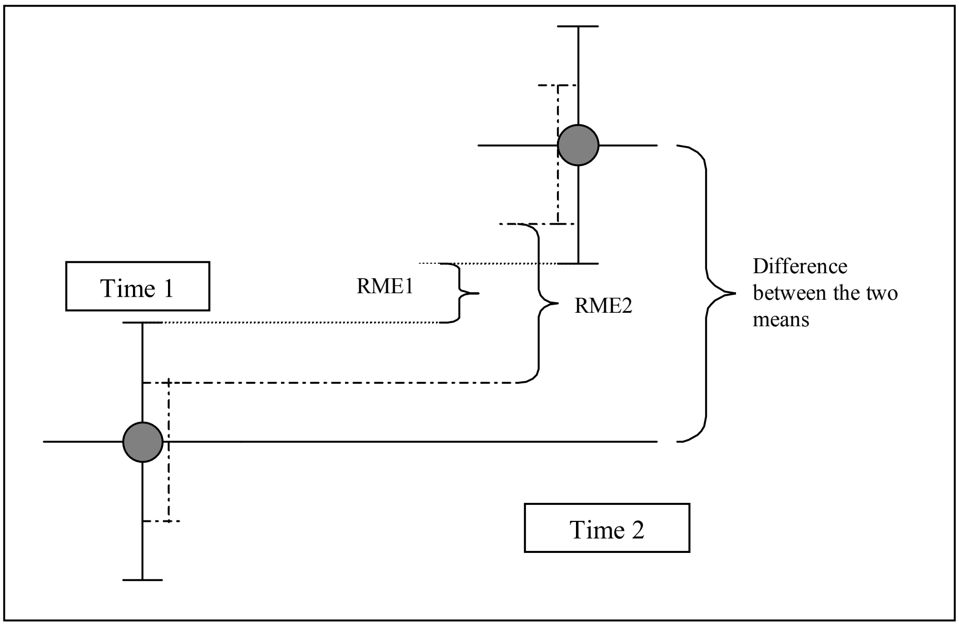
A key component of a project is to measure, monitor, and estimate the quantity of carbon accruing on the project area over the length of the project and over separate time periods. This is accomplished by estimating the changes in carbon stocks over time. Projections of the amount of carbon accumulating can be made by combining field measurements and models. However, if models are used, it is recommended to validate them with field measurements and to recalibrate as necessary.

For monitoring forests using permanent plots, it is *good practice* to measure the growth of individual trees at each time interval, keeping track of growth of survivors, mortality, and growth of new trees (ingrowth). Changes in carbon stocks for each tree are then estimated and summed per plot. Changes in carbon stocks in dead organic matter are also measured per plot and added to those for trees. Statistical analyses are then performed on net carbon accumulation in biomass per plot. As discussed above, because these plots undergo repeated measurements on basically the same components, there will be a high covariance term in the statistical analysis and the uncertainty around the estimates of change should be within the level targeted by the sampling design.

For soil or non-forest vegetation (e.g., croplands or grazing lands), in contrast to the procedure indicated for forests, the same soil or plant sample cannot be monitored over time. Instead, on each sample collection, the unit sampled (soil or plant sample) is destroyed for the analysis of its relevant components. Also, as variability among samples can be high even at small spatial scales, the statistical concept of paired samples, even if collected only centimetres apart, cannot be reliably employed. Thus the changes in the mean carbon content between two temporally-separated sample pools are best quantified by comparing means, via, for instance, the Reliable Minimum Estimate (RME) approach (Dawkins, 1957), or by directly calculating the difference between the means and associated confidence limits (Sokal and Rohlf, 1995). (The following discussion uses soil as an example, but it could easily apply for vegetation on cropland and grazing land management projects).

The objective is to estimate the number of plots needed to establish the *minimum* change in the mean carbon stocks, with 95% confidence, that has taken place from one monitoring event to the next, rather than to estimate the number of plots needed to establish that the two means are significantly different from each other. For the RME approach (Figure 4.3.2), the monitoring results from plots are pooled to derive a mean for the sample population at Time 1 and Time 2. Change in soil carbon is estimated by subtracting the maximum estimate of the population mean at Time 1 (mean at Time 1 plus half the 95% confidence interval at Time 1) from the minimum mean estimate at Time 2 (mean at Time 2 minus half the 95% confidence interval at Time 2). The resulting difference represents, with 95% confidence, the minimum reliable change in mean soil carbon from Time 1 to Time 2 (Figure 4.3.2).

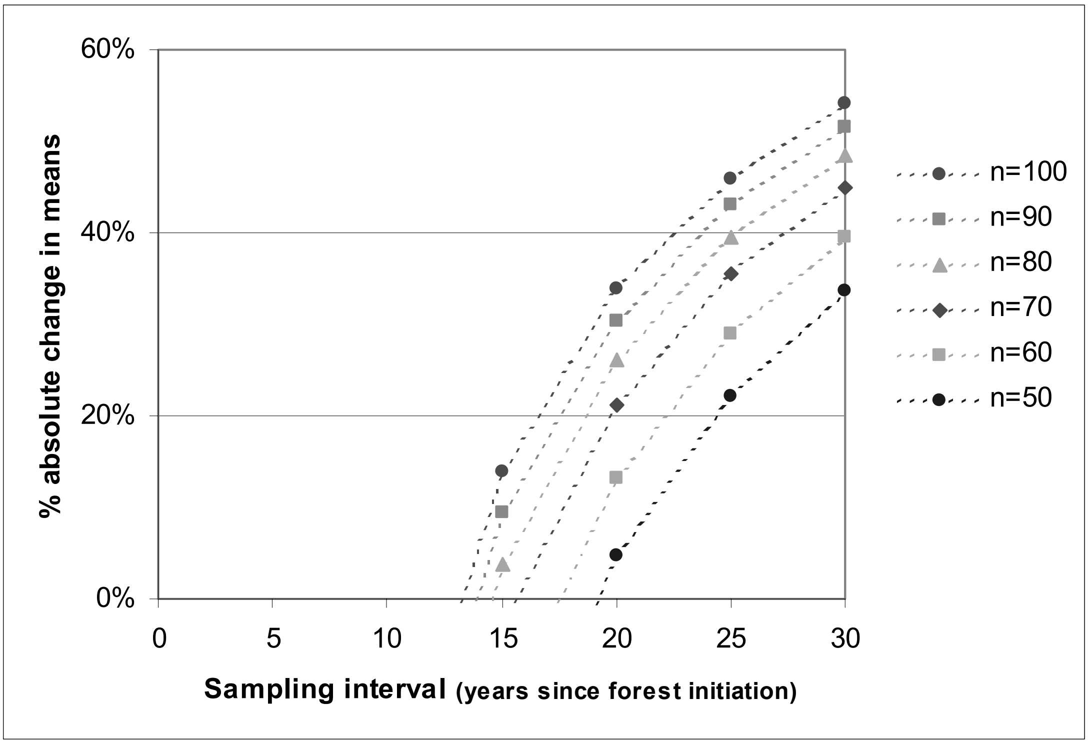
Figure 4.3.2 Illustration of the relationship between the magnitude of the Reliable Minimum Estimate (RME) between Time 1 and Time 2 sampling periods and the 95% confidence interval (the solid and dashed bars) around the mean soil carbon content (shaded circle). The confidence interval is a function of the standard error, defined as the ratio between the standard deviation and the square root of the sample size. The larger the sample size the smaller the standard error and thus the smaller the 95% confidence interval. Hence, RME1 is smaller than RME2 as a result of fewer samples.



Both sampling intensity (i.e., number of soil samples) and frequency of sampling must be taken into consideration when attempting to estimate changes in soil carbon over time. The minimum estimated change in soil carbon stocks between two means at a given level of confidence can be expressed as a percentage of the absolute difference between the means. A targeted estimate (e.g., 80% of the absolute difference between the means), or alternatively, a targeted magnitude of change in soil carbon (not to exceed the absolute difference between the means), can be achieved by adjusting sampling intensity, sampling frequency, or a combination of both (Figure 4.3.3).

In general, increasing the number of soil samples reduces the standard error around means separated in time, and better distinguishes the change that takes place (Figure 4.3.3). As high levels of variability in carbon among sample units are typical of soils (coefficient of variation of ~ 30%), high sampling intensity is generally needed to discern change. The resolution of change detection also depends on the magnitude of the change itself, and as this is time-dependent, it is appropriate to consider frequency of sampling. Increasing the time interval between sampling events is expected to increase the magnitude of the change that takes place, assuming the variance around the means stays the same. Thus, the percentage and magnitude of the absolute change estimated also increases (Figure 4.3.3). This is an important consideration, in that small changes expected with short sampling intervals may be undetectable, even with high sampling intensity. By assuming a rate of soil carbon accumulation, sampling intervals can be designed to achieve a targeted estimate of the minimum change in soil carbon. It is *good practice* to estimate the number of plots and sampling interval needed based on the variability in carbon stocks and an assumed rate of carbon accumulation. For the details on how to estimate sample size for soil sampling, refer to the RME method as described in MacDicken (1997), or by adapting the Minimum Detectable Difference calculation (Zar, 1996) to solve for sample size for a targeted difference in means.

Figure 4.3.3 An example of how the percent absolute change in mean soil carbon (with 95% confidence) for an afforestation project varies in relation to the sampling interval and sample size (n), assuming constant coefficient of variation (30%), constant annual rate of soil carbon accumulation of 0.5 tonnes C per hectare and year, and initial soil carbon of 50 tonnes C per hectare (generated from unpublished data).



4.3.3.4.2 PLOT SHAPE AND SIZE

The type of plots used in vegetation and forest inventories include: fixed area plots that can be nested or clustered, variable radius or point sampling plots (e.g., prism or relascope plots), or transects. It is recommended to use permanent nested sample plots containing smaller sub-units of various shapes and sizes, depending on the variables to be measured. For instance, in an afforestation/reforestation project, saplings could be measured in a small circular plot; trees between 2.5 to 50 cm diameter at breast height (dbh) could be measured in a medium circular plot; trees above 50 cm dbh could be measured in a larger circular plot; and understorey and fine litter could be measured in four small square or circular plots located in each quadrant of the sample plot. The radius and diameter limits for each circular plot would be a function of local conditions and expected size of the trees through time.

The size of the sample plot is a trade-off between accuracy, precision, and time (cost) of measurement. The size of the plot is also related to the number of trees, their diameter, and variance of the carbon stock among plots. The plot should be large enough to contain an adequate number of trees per plot to be measured. In general, it is recommended to use a single plot varying between 100 m^2 (for densely planted stand of 1,000 trees/ha or more) and 600 m^2 (for sparsely planted stand of multi-purpose trees) in area for even-sized stands. For projects where it is expected that the forest will be uneven-sized (e.g., through a combination of planting and natural regeneration), it is recommended to use nested plots or even clusters of nested plots depending upon the forest characteristics. Whether one uses circular or rectangular plots depends on local conditions. There are cases (e.g., rows of trees to serve as windbreaks or sand dune stabilisation) where a number of transects may be the most appropriate sampling method to use; and, the number of transects needed should be based on the variance, as described above.

4.3.3.5 FIELD MEASUREMENTS AND DATA ANALYSIS FOR ESTIMATING CARBON STOCKS

It is *good practice* to use standard techniques for field measurements of vegetation and soil. Details of such techniques are described in detail in MacDicken (1997) and Schlegel *et al.* (2001), among others. Any *good practice* method that requires ground-based field measurements should have a formal quality control plan (see

Section 4.3.4). This section focuses on what constitutes *good practices* in conducting these measurements and analysing them for carbon stock estimation.

For field measurements of carbon pools, the recommended sample unit is a permanent sample plot of nested fixed radius subplots (see above). The project area should be stratified as described in Section 4.3.3.2, and the number of sample plots to be established for each stratum should be calculated.

All the biomass data obtained in field measurements must be expressed on an oven-dry basis, and converted to carbon by multiplying the oven-dry matter values by the carbon fraction of dry biomass. This value varies slightly depending on species and biomass component in question (trunk, branches, roots, understorey vegetation etc.) (see Chapter 3, Section 3.2). However, the value of 0.50 for the conversion is the approximation indicated in the *IPCC Guidelines*, and should be applied if no local values are available.

4.3.3.5.1 ABOVEGROUND BIOMASS

Trees

There are two approaches for estimating aboveground biomass in trees: a direct approach using allometric equations, and an indirect approach using biomass expansion factors. For LULUCF projects, it is *good practice* when using permanent sample plots to estimate the carbon stock of trees through the direct approach. The indirect approach is often used with temporary plots, a common practice in forest inventories. The details of both approaches are presented next.

Direct approach

Step 1: The diameter at breast height (dbh; typically measured at 1.3 m above ground) of all the trees in the permanent sample plots above a minimum diameter is measured. The minimum dbh is often 5 cm, but can vary depending on the expected size of trees —for arid environments where trees grow slowly, the minimum dbh may be as small as 2.5 cm, whereas for humid environments where trees grow rapidly it could be up to 10 cm.

For afforestation/reforestation projects, small trees (e.g., saplings with dbh less than the minimum, but yet taller than breast height) will likely dominate during the early stages of establishment. These can be readily included in this approach by counting their number in a subplot.

Step 2: Biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements in Step 1. There are many multi-species allometric equations for native temperate and tropical forest species (e.g., Araújo *et al.*, 1999; Brown, 1997; Schroeder *et al.*, 1997; Pérez and Kanninen, 2002 and 2003; Tables 4.A.1 to 4.A.3 of Annex 4A.2). These equations are developed using variables, singly or in combination, such as dbh, wood density, and total height as independent variables and aboveground biomass of trees as the dependent variable. Further discussion regarding the development of these equations and their use can be found in Brown (1997) and Parresol (1999).

The minimum diameter tree included in most of the allometric equations (Tables 4.A.1–4.A.3 in Annex 4A.2) is smaller than the recommended minimum dbh given in Step 1 above, thus the biomass of these small trees can be estimated from the same allometric regressions. A typical approach is to estimate the common dbh of the saplings, usually the mid-point between the smallest size observed and the minimum diameter, estimate the biomass for this diameter sapling, and multiply this estimated biomass by the number of saplings counted. If the allometric equation does not include trees of the small size classes, an alternative approach to estimating the aboveground biomass is to grow and harvest about 10-15 such saplings planted in a site nearby the project area.

Step 3: When allometric equations developed from a biome-wide database, such as those in Annex 4A.2, Tables 4.A.1 and 4.A.2, are used, it is *good practice* to verify the equation by destructively harvesting, within the project area but outside the sample plots, a few trees of different sizes and estimate their biomass and then compare against a selected equation. If the biomass estimated from the harvested trees is within about +/- 10% of that predicted by the equation, then it can be assumed that the selected equation is suitable for the project. If this is not the case, it is recommended to develop local allometric equations for the project use. For this, a sample of trees, representing different size classes, is destructively harvested, and its total aboveground biomass is determined. The number of trees to be destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more trees are required. If resources permit, the wood density (specific gravity) and the carbon content can be determined in the laboratory. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the dbh and total height. Further discussion of the development of local allometric equations is presented in Brown (1997), MacDicken (1997), Schlegel *et al.* (2001) and Segura and Kanninen (2002).

Table 4.A.1 of Annex 4A.2 presents general allometric equations for estimating the aboveground biomass (kg dm/tree) for different forest types using the diameter at breast height as the independent variable. These equations are based on a multi-species database that contains biomass data for more than 450 individuals.

In many tropical regions, palm trees of various species are common, both in restored forests and in abandoned pastures. Table 4.A.2 (Annex 4A.2) presents some allometric equations for estimating the aboveground biomass of several common palm species in tropical America. Biomass of palms does not relate well to their dbh; instead height is used alone as the independent variable.

Table 4.A.3 (Annex 4A.2) presents examples of allometric equations for individual species commonly used in the tropics. However, as discussed above, any project would need to assess the applicability of particular allometric equations for local conditions. This will be particularly important if species are grown in mixtures. If not, it is *good practice* either to validate existing equations with data collected at the project site or to develop local allometric equations based on field measurements.

Indirect approach

An alternative approach for estimating aboveground biomass of forests, particularly commercial plantations, is to base it on the volume of the commercial component[71] of the tree for which there are often many equations or methods available for estimating this component. The indirect method is based on factors developed at the stand level, for closed canopy forests, and cannot be used for estimating biomass of individual trees. There are two ways of obtaining estimates of the commercial volume in this approach:

Method 1:

Step 1: As with the direct approach, the diameter of all trees above some minimum diameter is measured.

Step 2: The volume of the commercial component of each tree is then estimated based on locally derived methods or equations. The volume is then summed for all trees and expressed as volume per unit area (e.g., m^3/ha).

Method 2:

Steps 1 and 2 combined: There are field instruments (e.g., relascope) that measure volume directly. Using this instrument or other appropriate means, the volume of each tree in the plots is measured. The sum for all trees is then expressed as volume per unit area.

Once the volume of the commercial component is estimated, it then needs to be converted to biomass and then estimates of the other tree components, such as branches, twigs, and leaves need to be added. This method is expressed in Equation 4.3.1 (Brown, 1997) (see also Section 3.2.1.1 on use of BEF and Annex 3A.1, Table 3A.1.10):

EQUATION 4.3.1
ESTIMATION OF ABOVEGROUND BIOMASS OF FORESTS

$$\text{Aboveground biomass} = \text{Commercial tree volume} \bullet D \bullet BEF$$

Where:

Aboveground biomass, tonnes of dry matter ha^{-1}

Commercial tree volume, m^3 ha^{-1}

D = volume-weighted average wood density, tonnes of oven-dry matter per m^3 of green volume

BEF = biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of commercial volume), dimensionless.

Wood density values of most commercially important species are generally available (see, for example, Brown, 1997; Fearnside, 1997; and Annex 3A.1 Table 3A.1.9) or relatively straightforward to measure. Most published density values are for mature individuals; if wood densities are not available for young individuals, it is recommended that measurements be made. The BEF is significantly related to the commercial biomass for most forest types (in these examples, volume is over-bark for all trees with a dbh of 10 cm and above), generally starting high (>4.0) at low volumes, then declining at an exponential rate to a constant low value (about 1.3-1.8) at high volumes. Thus, using one value for the BEF for all values of standing volume is incorrect. It is recommended to either develop a local regression equation for this relationship or use those in Annex 3A.1 Table 3A.1.10 or from published sources (e.g., Brown, 1997; Brown and Schroeder, 1999; Fang et al., 2001). Additional discussion on the topic of converting commercial volume to biomass is provided in Section 3.2.1.1 of this report.

---

[71] It is important to state whether the volume is estimated as over or under bark; in case of under-bark volume, the expansion factor needs to take bark into account.

If a significant amount of effort is required to develop local BEFs, involving, for instance, harvest of trees, then it is recommended not to use this approach but rather to use the resources to develop local allometric equations as described under the direct approach above. The direct approach generally results in more precise biomass estimates than the indirect approach because the calculations of the former involve only one step (e.g., dbh to biomass), whereas the indirect approach involves several steps (diameter and height to volume, volume to volume-based biomass, estimation of BEF based on volume, product of three variables to biomass).

Non-tree vegetation

Non-tree vegetation such as herbaceous plants, grasses, and shrubs can occur as components of a forestry project or of cropland and grazing land management projects. Herbaceous plants in forest understorey can be measured by simple harvesting techniques of up to four small subplots per permanent or temporary plot. A small frame (either circular or square), usually encompassing about 0.5 m^2 or less, is used to aid this task. The material inside the frame is cut to ground level, pooled by plot, and weighed. Well-mixed sub-samples from each plot are then oven dried to determine dry-to-wet matter ratios. These ratios are then used to convert the entire sample to oven-dry matter. For cropland and grazing land management projects, the same approach can be used in temporary plots because, as mentioned above, there is no statistical advantage over using permanent plots (Section 4.3.3.4.1).

For shrubs and other large non-tree vegetation it is *good practice* to measure the biomass by destructive harvesting techniques. A small sub-plot depending on the size of the vegetation is established and all the shrub vegetation is harvested and weighed. An alternative approach, if the shrubs are large, is to develop local shrub allometric equations based on variables such as crown area and height or diameter at base of plant or some other relevant variable (e.g., number of stems in multi-stemmed shrubs). The equations would then be based on regressions of biomass of the shrub versus some logical combination of the independent variables. The independent variable or variables would then be measured in the sampling plots.

4.3.3.5.2 BELOWGROUND BIOMASS

Trees

Methods for measuring and estimating aboveground biomass are relatively well established. However, the belowground biomass (roots) is difficult and time-consuming to measure and estimate in most ecosystems, and methods are generally not standardized (Körner, 1994; Kurz *et al.*, 1996; Cairns *et al.*, 1997; Li *et al.*, 2003). A review of the literature shows that typical methods include spatially distributed soil cores or pits for fine and medium roots, and partial ones to complete excavation and/or allometry for coarse roots. Live and dead roots are generally not distinguished and hence root biomass is generally reported as the total of live and dead.

A comprehensive literature review by Cairns *et al.* (1997) included more than 160 studies covering native tropical, temperate, and boreal forests that reported both belowground biomass and aboveground biomass. The average belowground to aboveground dry biomass ratios based on these studies was 0.26, with a range of 0.18 (lower 25% quartile) to 0.30 (upper 75% quartile). The belowground to aboveground dry biomass ratios did not vary significantly with latitudinal zone (tropical, temperate, boreal), soil texture (fine, medium, coarse), or tree type (angiosperm, gymnosperm). Further analyses of the data produced a significant regression equation of belowground biomass density versus aboveground biomass density when all data were pooled. Inclusion of age or latitudinal belt significantly improved the model (Cairns *et al.*, 1997). Given the lack of standard methods and the time-consuming nature of monitoring belowground biomass in forests, it is *good practice* to estimate belowground biomass from either estimated aboveground biomass based on the equations in Table 4.A.4, Annex 4A.2, or from locally derived data or models.

The data used to develop the belowground biomass equations in Table 4.A.4 were based on native forests, and may not apply to plantations. Ritson and Sochacki (2003) reported that belowground to aboveground biomass ratios of plantations of *Pinus pinaster* varied between 1.5 and 0.25, decreasing with increasing tree size and/or age. For commercial plantation species, it is likely that research on belowground biomass exists that could be used. Failing that, it is *good practice* to use an estimate for belowground biomass by using the average belowground to aboveground biomass ratios, such as those in Annex 3A.1, Table 3A.1.8.

Non-tree vegetation

In non-forest project types (e.g., cropland and grazing land management), where large changes in the belowground biomass from non-tree vegetation are expected to occur, the carbon stock in the belowground biomass pool needs to be estimated (Table 4.3.1). For non-tree vegetation, it is not possible to estimate belowground biomass from aboveground biomass data and therefore, on-site measurements may be required.

Direct measurement of belowground biomass requires collecting soil samples, usually in the form of cores of known diameter and depth, separating the roots from soil, and oven-drying and weighing the roots. It is recommended to perform the following steps for direct measurement of belowground biomass in the field:

- The sampling design should follow the procedures detailed earlier in Section 4.3.3.4.
- Because a large proportion of non-tree root biomass is usually present in the upper soil layers, in most situations sampling to a depth of 0.3-0.4 m should suffice. In cases where samples are collected at deeper depths, it is recommended to split the sample into two or more layers, clearly recording the depth of each layer.
- Separation of roots from soil can be performed by using root washing devices (Cahoon and Morton, 1961; Smucker *et al.*, 1982) for maximum recovery. If these devices are not available, simpler procedures (e.g., placing soil samples on a sieve and washing roots with high pressure water) may yield recovery of a relatively large proportion of root biomass.
- Non-root belowground biomass (e.g., stolons, rhizomes and tubers) should be considered as part of the belowground biomass pool.
- Roots should be oven-dried at 70 ^{o}C until dry and then weighed. The resulting weight should be divided by the cross sectional area of the sample core to determine belowground biomass on a per-area basis.

The core-break method has been found to be a rapid method for evaluating root distributions in the field (Böhm, 1979; Bennie *et al.*, 1987). With this technique, cores are removed from different soil depths, broken in half, and the visible root axes on each cross-sectional surface area are counted and averaged. To convert root counts to estimates of root length density or biomass requires calibration equations for each crop species, soil type, and management practice. Calibration equations should be developed locally and may change with crop development or soil depth (Drew and Saker, 1980; Bennie *et al.*, 1987; Bland, 1989).

4.3.3.5.3 DEAD ORGANIC MATTER

Litter

Litter can be directly sampled using a small frame (either circular or square), usually encompassing an area of about 0.5 m^2, as described above for herbaceous vegetation (four subplots within the sample plot). The frame is placed in the sample plot and all litter within the frame is collected and weighed. A well-mixed sub-sample is collected to determine oven dry-to-wet weight ratios to convert the total wet mass to oven-dry mass.

An alternative approach for systems where the litter layer is well-defined and deep (more than 5 cm), is to develop a local regression equation that relates depth of the litter to the mass per unit area. This can be done by sampling the litter in the frames as mentioned above and at the same time measuring the depth of the litter. At least 10-15 such data points should be collected, ensuring that the full range of the expected litter depth is sampled.

Dead wood

Dead wood, both standing and lying, does not generally correlate well with any index of stand structure (Harmon *et al.*, 1993). Methods have been developed for measuring biomass of dead wood and have been tested in many forest types and generally require no more effort than measuring live trees (Brown, 1974; Harmon and Sexton, 1996; Delaney *et al.*, 1998). For dead wood lying on the ground, the general approach is to estimate the volume of logs by density class (often related to its decomposition state, but not always) and then convert to mass as a product of volume and density, for each density class. There are two approaches that can be used to estimate the volume of dead wood present, depending upon the expected quantity present.

Method 1 – when the quantity is expected to be a relatively small proportion of the aboveground biomass (i.e., about 10-15%, based on expert judgement): A time-efficient method is the line-intersect method, and it is *good practice* to use at least 100 m length of line, generally divided into two 50 m sections placed at right angles across the plot centre. The diameters of all pieces of wood that intersect the line are measured and each piece of dead wood is also classified into one of several density classes. If the intersected log is elliptical in shape the minimum and maximum diameters need to be measured. The volume per hectare is estimated for each density class as follows (for more details on the derivation of this equation see Brown (1974)):

EQUATION 4.3.2
VOLUME OF LYING DEAD WOOD

$$\text{Volume (m}^3\text{/ha)} = \pi^2 \bullet (D_1^2 + D_2^2 + \ldots + D_n^2) / (8 \bullet L)$$

Where:

$D_1, D_2, \ldots, D_n$ = diameter of each of n pieces intersecting the line, in centimetres (cm). The round equivalent of an elliptically shaped log is computed as the square root of ($D_{minimum} \bullet D_{maximum}$) for that log.

L = the length of the line, in metres (m).

An additional multiplier is often introduced to Equation 4.3.2 to correct the bias introduced by the non-horizontal orientation of the pieces (Brown and Roussopolos, 1974). However, this correction is not required for coarse dead wood, as this bias decreases with piece diameter. For more details see Harmon and Sexton (1996).

Method 2 – when the quantity is expected to be a relatively large proportion of the aboveground biomass (i.e., more than about 15%, based on expert judgement): When the quantity of dead wood lying on the forest floor is expected to be high and variably distributed, as in slash left behind after logging, it is *good practice* to do a complete inventory of the wood in the sampling plots. It is recommended to measure all the dead wood in a subplot of the sampling plots (see also Harmon and Sexton, 1996, for details on the methods). For a complete census, the volume of each piece of dead wood lying within the circle is calculated based on the diameter measurements taken at 1 m intervals along each piece of dead wood in the plot. The volume of each piece is then estimated as the volume of a truncated cylinder based on the average of the two diameter measurements and the distance between them (usually 1 m). As with Method 1, each piece of dead wood is also classified into a density class. The volume is summed for each density class and, using the appropriate factor (based on the area of the plot), expressed on a m^3/ha basis for each density class.

Density measurements: Experience shows that three density classes are sufficient—sound, intermediate and rotten. An objective and consistent way to distinguish between them is needed. A common practice in the field is to strike the wood with a “machete”—if the blade bounces off it is sound, if it enters slightly is it intermediate, and if it causes the wood to fall apart it is rotten (“machete test”). Samples of dead wood in each density class are then collected to determine their wood density. Mass of dead wood is then the product of volume per density class (from above equation) and the wood density for that class. Thus a key step in this method is to classify the dead wood into its correct density class and then to adequately sample a sufficient number of logs in each class to represent the wood densities present. It is *good practice* to sample at least 10 logs of each different density class. In forests with palms or early colonizers or hollow logs, it is also *good practice* to treat these as separate groups and sample them the same way.

For projects based on few species and where the rate of decomposition of wood is well known for given species or forest types, models could be locally developed for estimating the density of the dead wood at different stages of decomposition (Beets *et al.*, 1999). Volume of wood would still need to be estimated based on either Method 1 or 2 above, but the density could be estimated based on the model of decomposition.

Standing dead wood is measured as part of the tree inventory. Standing dead trees should be measured according to the same criteria as live trees. However, the measurements that are taken and the data that are recorded vary slightly from live trees. For example, if the standing dead tree contains branches and twigs and resembles a live tree (except for leaves) this would be noted in the field data. From the measurement of its dbh, its biomass can be estimated using the appropriate allometric equation as for live trees, subtracting out the biomass of leaves (about 2-3% of aboveground biomass). However, a dead tree can contain only small and large branches, or only large branches, or no branches – these conditions need to be recorded in the field measurements and the total biomass can be reduced accordingly; in particular if only large branches remain, the biomass estimated from the appropriate allometric equation is reduced by about 20% to account for the absence of smaller branches and twigs. When a tree has no branches and is just the bole, then its volume can be estimated from measurements of its basal diameter, height, and an estimate of its top diameter; and its biomass can be calculated with its density class.

4.3.3.5.4 SOIL ORGANIC CARBON

The soil organic carbon pool is estimated from soil samples taken in the sample plots. Soil samples are usually taken with a metallic cylinder at different depths or by the excavation method. It is *good practice* to collect a composite sample (recommended to collect about two to four such samples per composite) in each plot and depth. These are then mixed and homogenized to make one composite sample for each depth and plot. To estimate the soil carbon stock, an additional composite sample needs to be collected for bulk density measurements at each depth and plot (see also Section 3.2.1.3.1.1 and Section 3.2.1.3.1.2 for further discussion on soil organic carbon).

In coarse textured, stony soils, sampling bulk density by soil cores is inadequate and will probably overestimate the bulk density of the fine soil in the horizon (Blake and Hartage, 1986; Page-Dumroese *et al.*, 1999). Instead, the excavation method is recommended, supplemented with an estimate of the percent volume occupied by stones. If significant non-soil areas (e.g., large rocky outcrops) exist in the project site, these should be eliminated at the start of the project during stratification; estimates of soil carbon should only be scaled to the area where soil exists.

The depth to which the soil carbon pool should be measured and monitored may vary according to project type, site conditions, species, and expected depth at which change will take place (see Chapter 3 and other sections in Chapter 4 for additional details). In most cases, soil organic carbon concentrations are highest in the uppermost layer of soil and decrease exponentially with depth. However, the relationship of soil organic carbon concentrations with soil depth can vary as a result of such factors as the depth distribution of roots, transport of soil organic carbon within the soil profile, and erosion/deposition. It is *good practice* to measure the soil carbon pool to a depth of at least 30 cm. This is the depth where the changes in the soil carbon pool are likely to be fast enough to be detected during the project period. In cases where a project is using deep-rooted plants, it may be useful to measure and monitor the soil carbon pool to depths greater than 40 cm. However, this increases the costs of measuring and monitoring.

If soils are shallower than 30 cm then it is important that the depth of each soil sample collected be measured and recorded. Calculations to estimate the soil carbon stocks need to account for varying soil depth over the project area and soil depth should therefore be taken into account in the stratification.

The two most commonly used methods for soil carbon analysis are: the dry combustion method and the Walkley Black method (wet oxidation method). MacDicken (1997) discusses advantages and disadvantages of these methods for soil analysis. The Walkley Black method is commonly used in laboratories that have few resources, as it does not require sophisticated equipment. However, in many countries, professional labs exist that use the dry combustion method, and the cost can often be modest. It is *good practice*, especially where soil carbon is a significant aspect of the project, to use the dry combustion method. Because the dry combustion method includes carbonates, it is important that the soils that could contain carbonates be pre-tested and the inorganic carbon be removed by acidification.

There are two ways to express soil carbon – on an equal mass or equal volume basis. There are advantages and disadvantages to both methods. To express changes in soil carbon on an equal mass basis requires that the change in the soil bulk density be known ahead of the sampling so that adjustments can be made to collect an equal mass of soil. Alternatively, the adjustments can be made as part of the calculations. It is likely that projects designed to enhance soil organic carbon will also cause the soil bulk density to decrease. If it is expected that the soil bulk density will change significantly during the course of the project, it is recommended to assess the impact of expressing the changes in soil carbon on an equal mass or equal volume basis on the total projected change in soil carbon stocks. Otherwise, it is recommended that the changes in soil carbon stocks be reported on an equal volume basis, as it is commonly done.

The soil carbon stock per unit area on an equal volume basis is then calculated as:

EQUATION 4.3.3
SOIL ORGANIC CARBON CONTENT

$$SOC = [SOC] \bullet \text{Bulk Density} \bullet \text{Depth} \bullet \text{CoarseFragments} \bullet 10$$

Where:

SOC = the soil organic carbon stock for soil of interest, Mg C ha^{-1}

[SOC] = the concentration of soil organic carbon in a given soil mass, g C $(kg\,soil)^{-1}$ (from lab analyses)

Bulk Density = the soil mass per sample volume, Mg m^{-3}

Depth = sampling depth or thickness or soil layer, m

CoarseFragments = 1 – (% volume of coarse fragments / 100) [72]

The final multiplier of 10 is introduced to convert units to Mg C ha^{-1}.

4.3.3.6 ESTIMATING CHANGES IN NON-CO_2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Although the primary purpose of LULUCF projects is to increase carbon stocks relative to a baseline, practices included as part of LULUCF projects may also result in changes in non-CO_2 greenhouse gas emissions and

---

[72] In soils with coarse fragments (e.g., soils developed on till or coarse alluvium, or with high concentration of roots), SOC is adjusted for the proportion of the volumetric sample occupied by the coarse fraction (>2 mm fraction).

removals. Such practices, associated with the LULUCF sector, include, for instance, biomass burning (e.g., during site preparation); change in livestock production (caused, for example, by changes in forage species in grazing land management); application of synthetic and organic fertilizers to soils; cultivation of nitrogen fixing trees, crops, and forages; flooding and drainage of soils. In addition, land-use practices that disturb soils, e.g., tillage for crop cultivation or for afforestation/reforestation site preparation, may affect non-CO_2 emissions and removals from soils. Table 4.3.2 lists possible LULUCF project practices that can affect non-CO_2 emissions and removals. However, the definitions and modalities for Article 12, which are under negotiation at the time of this writing, may determine which of these practices are to be included in measurement, monitoring, and reporting of Article 12 project activities.

TABLE 4.3.2
POSSIBLE LULUCF PROJECT PRACTICES THAT MAY RESULT IN EMISSIONS OR REMOVALS OF NON-CO_2 GREENHOUSE GASES

Practice	Effect on non-CO_2 gases	Emission or removal process
Biomass Burning	Source of CH_4 and N_2O[a]	Combustion[b]
Synthetic and Organic Fertilizer Application	Source of N_2O	Nitrification/denitrification of fertilizers and organic amendments applied to soils
	Reduced CH_4 removal	Suppression of soil microbial oxidation of CH_4
Cultivation of N-Fixing Trees, Crops, and Forages	Source of N_2O	Nitrification/denitrification of soil N from enhanced biological N fixation
Soil Re-Flooding	Source of CH_4	Anaerobic decomposition of organic material in soils
	Reduced/Eliminated source of N_2O	Reduces mineralization of soil organic matter
Soil Drainage	Reduced/Eliminated source of CH_4	Reduction of anaerobic decomposition of organic material
	Source of N_2O	Mineralization of soil organic matter and subsequent nitrification/denitrification of mineralised nitrogen
Soil Disturbance	Source of N_2O	Mineralization of soil organic matter and subsequent nitrification/denitrification of mineralised nitrogen
	Reduced CH_4 removal	Suppression of soil microbial oxidation of CH_4
Changes in Grazing Land Management[c]	Increased or decreased source of CH_4 and N_2O from effects on livestock	Animal digestion (CH_4)
		Anaerobic decomposition of manure stored in manure management systems and applied/deposited on soils (CH_4)
		Nitrification/denitrification of N in manure stored in manure management systems and applied/deposited on soils (N_2O)

[a] Biomass burning is also a source of carbon monoxide, oxides of nitrogen, and non-methane volatile organic compounds. These emissions are not addressed here because these gases are not considered under the Kyoto Protocol.

[b] Some experiments have indicated that open biomass burning (i.e., field burning of vegetation) results in elevated emissions of N_2O from soils for up to six months after burning (cf. Chapter 5 of Volume 3 of the *IPCC Guidelines*). However, other experiments have found no long-term effect on soil N_2O emissions, so this process is not addressed further here.

[c] Changes in the species mix of grazing land plants for enhancing soil carbon, for example, could affect livestock production and thus the non-CO_2 greenhouse gases they produce.

In general, it is recommended to estimate the net greenhouse gas emissions and removals from these practices with project-specific activity data and site-specific emission factors. It is also recommended to derive the emission factors from either well-designed and well-implemented field measurements at either the project site(s) or at sites that are considered to reproduce the conditions of the project site(s); or from validated, calibrated, and well-documented simulation models implemented with project site-specific input data. The *IPCC Guidelines*, as amended by *GPG2000*, and Chapter 3 of this report provide default Tier 1 methods and emission factors for estimating emissions from many of these practices at the national level (see Table 4.3.3). However, these documents provide limited *good practice guidance* for either measurement of, or simulation modelling of, emissions and removals from many of these practices. Because these practices fall within IPCC national inventory sectors other than Land-Use Change and Forestry (e.g., the Energy or Agriculture sectors), it is beyond the scope of this report to provide detailed *good practice guidance* for measuring, monitoring, and estimating emissions and removals from these practices.

Changes in non-CO_2 greenhouse gas emissions or removals caused by these practices may be small relative to net changes in carbon stocks over the lifetime of the LULUCF project. Therefore, when any of these practices are part of a LULUCF project, it is recommended first to estimate the likely annual net changes in non-CO_2 emissions or removals over the lifetime of the project based upon project activity data and the default IPCC methods and emission factors provided in the *IPCC Guidelines*, as amended by *GPG2000* and Chapter 3 of this report. If the expected average annual net change in non-CO_2 emissions or removals is relatively small, e.g., less than about 10% of expected average total annual net carbon stock changes on a CO_2-equivalent basis, use of the default IPCC emission factors may be adequate. However, if the expected average annual net change in non-CO_2 emissions or removals from an activity is relatively large, e.g., greater than about 10% of expected average annual net carbon stock changes on a CO_2-equivalent basis, it is recommended to develop project-specific emission factors, either through measurement or simulation models.

TABLE 4.3.3
LOCATION OF IPCC DEFAULT METHODS AND DATA FOR ESTIMATION OF NON-CO_2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Practice	Location of IPCC Default Methods and Data
Biomass Burning	• Emission ratio methodologies and emission ratios for confined burning for energy production in the Energy chapter of the *IPCC Guidelines* and the *GPG2000.* • Emission ratio methodologies and emission ratios for open field burning in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. • Emission ratio and emission factor methodology, and combustion efficiencies, emission ratios, and emission factors for open field burning in forest, grassland, and savanna ecosystem types in Chapter 3 of this Report (see Section 3.2.1.4, Section 3.4.1.3, and Annex 3A.1).
Synthetic and Organic Fertilizer [a] Application	• Emission factor method, fertilizer nitrogen contents, volatilisation and leaching/runoff rates, and default emission factors for N_2O emissions in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. Note: Both direct and indirect N_2O emissions should be estimated, even though some of the indirect emissions may occur outside of a project's geographic boundaries. • N_2O emissions from fertilized soils may be affected by liming (see Section 3.2.1.4 of this Report). However, because liming has been found to both enhance and reduce N_2O emissions from fertilization, default emission factors for fertilizer application to limed soils are not provided
Cultivation of N-Fixing Trees, Crops, and Forages	• Emission factor method, biomass nitrogen content, and emission factor for crops and forages in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. The method is based on the amount of nitrogen in the aboveground biomass produced annually, which is used as a proxy for the additional amount of nitrogen available for nitrification and denitrification. Default methods have not been developed for leguminous trees (see Section 3.2.1.4 of Chapter 3 of this Report).
Soil Re-Flooding and Drainage	• Methods and area-based N_2O emission factors for drainage of forest soils and drainage of wetlands in Appendix 3a.2 and Appenddix 3a.3, respectively, of this Report. • Methods and emission factors for CH_4 are not provided.
Soil Disturbance	• Method and N_2O emission factors for cultivation of organic soils (i.e., histosols) in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. • For disturbance of mineral soils, methods and emission factors for estimating increases in N_2O emissions in lands converted to croplands in Section 3.3.2.3 of this Report. • Methods and emission factors for CH_4 are not provided.
Changes in Grazing Land Management	• Emission factor methodologies for animal digestion and manure application/deposition in the Agriculture chapter of the *IPCC Guidelines* and the *GPG2000*. Emission factors and data for deriving emission factors, as well as emission estimation models for some animal types are also provided. Project-specific emission factors for some animal types can be developed by applying project-specific data (e.g., animal weight and feed digestibility) to the IPCC emission estimation models.

a The term fertilizer is used here to encompass both synthetic and organic fertilizers, e.g., urea and compost, as well as organic soil amendments such as uncomposted crop residues.

4.3.3.7 MONITORING CHANGES IN GREENHOUSE GAS EMISSIONS AND REMOVALS FROM PROJECT OPERATION PRACTICES

Greenhouse gas emissions from the direct use of energy in project operations can be significant. Such direct energy use includes both fuels and electricity consumed in both mobile and stationary equipment. Examples of mobile sources include tractors used for site preparation, fertilizer application, tillage, or planting; road transport to and from sites for monitoring; light-rail transport such as for the transport of logs out of the forest; air transport such as in helicopter logging; and water transport of logs from the forest. Stationary equipment, which, for most LULUCF projects, will typically constitute a less significant source of greenhouse gas emissions than mobile sources, could include machinery such as soil mixers and potting equipment in nurseries, irrigation pumps, and lighting. Project operators need to determine and report the greenhouse gas emissions from direct fossil fuel and electricity use in mobile and stationary equipment.

Carbon dioxide is the primary greenhouse gas emitted from fossil fuel consumption in stationary and mobile equipment. Because N_2O and CH_4 emissions are likely to make up a relatively small proportion of overall energy use emissions from projects, estimation of these emissions is at the discretion of the user.

Greenhouse gas emissions from stationary sources can be estimated by applying appropriate emission factors to the fuel quantity or electricity consumed (see the Energy chapters of the *IPCC Guidelines* and the *GPG2000*). Emissions from mobile sources can be estimated with either a fuel-based approach, or a distance-based approach (see Box 4.3.5 and the Energy chapters of the *IPCC Guidelines* and the *GPG2000*).

BOX 4.3.5

GUIDANCE ON ESTIMATING GREENHOUSE GAS EMISSIONS FROM MOBILE SOURCES

Direct greenhouse gas emissions from the use of vehicles can be estimated through either of two methodologies:

Fuel-based approach

Distance-based approach

The choice of methodology is dependent on data availability. However, the fuel-based method is the preferred method for all modes of transport as the method is associated with lower uncertainty. In this case, the quantity of fossil fuel, usually gasoline and/or diesel fuel that is combusted during project practices needs to be monitored and recorded. For a detailed description of the methodologies, see the *IPCC Guidelines* and the *GPG2000*.

4.3.3.8 CONSIDERATIONS FOR THE MONITORING PLAN

The monitoring plan has specific meaning in the context of Articles 6 and 12 of the Kyoto Protocol. The plan includes, but is not limited to, planning of the measurement that will show how the project affects carbon stocks and emissions of non-CO_2 greenhouse gases over time. This subsection provides general advice relevant to measurement aspects of the plan only.

4.3.3.8.1 MONITORING PROJECTS WITH SMALL-SCALE LANDOWNERS

Monitoring projects that could involve multiple small-scale landholders, working on small but discrete parcels of land spread over a region requires attention. As described above (Section 4.3.3.2), whether the project is one contiguous parcel made up of one or two large land owners or many small parcels spread over a large area with many small land owners, the project land can be delineated and stratified using standard techniques. It is not expected that each parcel would be monitored as if constituting a separate project, but instead can be treated as one project and monitored for carbon at the project level as described above. However, because the project is spread out over many land owners, it is *good practice* to develop monitoring protocols for the project level, and then to develop indicators that can be monitored at the parcel level to ensure project-level performance (see Box 4.3.6).

BOX 4.3.6

MONITORING PROJECTS INVOLVING MULTIPLE SMALL-SCALE LANDHOLDERS

Monitoring the changes in carbon stocks and non-CO_2 greenhouse gas emissions and removals when projects are constituted by multiple small-scale landholders will require the monitoring system to be split between two levels: (1) the project level and (2) the parcel level, as follows:

Level 1: project level

For each activity to be implemented within the project area, it is *good practice* to develop a technical description, setting out the management objectives, the species, the soil, climatic and vegetation conditions suitable for the activity, the expected inputs in terms of materials and labour and the expected outputs in terms of growth and yield of products. The technical descriptions should also include tables relating readily measured indicators at the parcel level (for example *diameter at breast height* or *top height*) to estimates of carbon stocks. These tables may be produced with reference to Section 4.3.3.5, using either direct or indirect methods. *Good practice* also entails establishment of a number of sample plots within the project area to maintain and improve the calibration of these tables (according to Section 4.3.3.4). Each technical description should also include a set of parameters used to determine the baseline carbon stocks, against which the carbon uptake is to be measured. A similar set of indicators that are readily measured at the plot level should be tabulated against baseline carbon stocks.

Level 2: parcel level

Within each parcel the following measurements can then be taken: 1) cross-check to determine whether the activity implemented in the parcel falls within the parameters set out in the technical description (e.g., correct species, planting density, climate, etc); 2) measurement of baseline indicators; and 3) measurement of activity indicators.

The changes in carbon stocks are then estimated with reference to the tables in the relevant technical descriptions. Quality assurance procedures should examine the data collection procedures at both levels within such projects.

4.3.3.8.2 FREQUENCY OF CARBON MONITORING

The frequency of monitoring should take into consideration the carbon dynamics of the project and costs involved. In the tropics, changes in the carbon stock in trees and soils in an afforestation/reforestation project can be detected with measurements at intervals of about 3 years or less (Shepherd and Montagnini, 2001). In the temperate zone, given the dynamics of forest processes, they are generally measured at 5-year intervals (e.g., many national forest inventories). For carbon pools that respond more slowly, such as soil, even longer periods could be used. Thus it is recommended that for carbon accumulating in the trees, the frequency of monitoring should be defined in accordance with the rate of change of the carbon stock, and be in accordance with the rotation length (for plantations) and cultivation cycle (for croplands and grazing lands).

4.3.3.8.3 OVERALL PROJECT SITE PERFORMANCE

Monitoring only the changes in carbon stocks and non-CO_2 greenhouse gases in the permanent monitoring plots does not necessarily provide the information for assessing whether the project is accomplishing the same changes in carbon stocks across the entire project and whether the project is accomplishing what it set out to do— e.g., plant several thousand hectares of trees. Periodic visits to the carbon monitoring plots will only show that the carbon in those plots (which were randomly located and should be representative of the population) is accumulating with known accuracy and precision at a given confidence level. As the project developers will know the location of the plots, it is also important that through time comprehensive checks are made to ensure that the overall project is performing the same way as the plots. This can be accomplished through third-party field verification using indicators of carbon stock changes, such as tree height for afforestation/reforestation projects and crop productivity for cropland management projects. It is *good practice* for project developers to produce such indicators that can readily be field-verified across the project area. To monitor overall project site performance (i.e., project activities are being performed over the entire project area), one of several methods can be used, depending upon the level of technology and resources available, such as:

- Visual site visits with photographic documentation. It is recommended to thoroughly inspect the total area planted in each region and that a selection of photographs be taken and dated. The field reports and photos should be part of the permanent record.

- Digital aerial imagery, using multi-spectral sensors (particularly infra-red), of GPS located transects across each planted area. As above, full documentation and digital photographs, dated, should be part of the project's records.
- Remote sensing with use of very high-resolution satellite data (e.g., Ikonos, QuickBird) or high resolution satellite data (e.g., Spot, Landsat, RadarSat, Envisat ASAR). The decision on which satellite imagery to use will depend on size of project (100s to 1,000s of ha), location (mostly under high cloud cover or often free of clouds), and project resources.

4.3.4 Quality Assurance and Quality Control Plan

Monitoring requires provisions for quality assurance (QA) and quality control (QC) to be implemented via a QA/QC plan. The plan should become part of project documentation and cover procedures as described below for: (1) collecting reliable field measurements; (2) verifying methods used to collect field data; (3) verifying data entry and analysis techniques; and (4) data maintenance and archiving. If after implementing the QA/QC plan it is found that the targeted precision level is not met, then additional field measurements need to be conducted until the targeted precision level is achieved.

4.3.4.1 PROCEDURES TO ENSURE RELIABLE FIELD MEASUREMENTS

Collecting reliable field measurement data is an important step in the quality assurance plan. Those responsible for the measurement work should be fully trained in all aspects of the field data collection and data analyses. It is *good practice* to develop Standard Operating Procedures (SOPs) for each step of the field measurements, which should be adhered to at all times. These SOPs should detail all phases of the field measurements and contain provisions for documentation for verification purposes and so that future field personnel can check past results and repeat the measurements in a consistent fashion.

To ensure the collection of reliable field data, it is *good practice* to ensure that:

- Field-team members are fully cognisant of all procedures and the importance of collecting data as accurately as possible;
- Field teams install test plots if needed in the field and measure all pertinent components using the SOPs;
- All field measurements are checked by a qualified person in cooperation with the field team and correct any errors in techniques;
- A document is filed with the project documents that show that these steps have been followed. The document will list all names of the field team and the project leader will certify that the team is trained;
- New staff are adequately trained.

4.3.4.2 PROCEDURES TO VERIFY FIELD DATA COLLECTION

To verify that plots have been installed and the measurements taken correctly, it is *good practice*:

- To re-measure independently every 8-10 plots, and to compare the measurements to check for errors; any errors found should be resolved, corrected and recorded. The re-measurement of permanent plots is to verify that measurement procedures were conducted properly.
- At the end of the field work, to check independently 10-20% of the plots. Field data collected at this stage will be compared with the original data. Any errors found should be corrected and recorded. Any errors discovered should be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

4.3.4.3 PROCEDURES TO VERIFY DATA ENTRY AND ANALYSIS

Reliable carbon estimates require proper entry of data into the data analyses spreadsheets. Possible errors in this process can be minimised if the entry of both field data and laboratory data are reviewed using expert judgement and, where necessary, comparison with independent data to ensure that the data are realistic. Communication between all personnel involved in measuring and analysing data should be used to resolve any apparent anomalies before the final analysis of the monitoring data is completed. If there are any problems with the monitoring plot data that cannot be resolved, the plot should not be used in the analysis.

4.3.4.4 DATA MAINTENANCE AND STORAGE

Because of the relatively long-term nature of these projects, data archiving (maintenance and storage) will be an important component of the work (see also Section 5.5.6). Data archiving should take several forms and copies of all data should be provided to each project participant.

Copies (electronic and/or paper) of all field data, data analyses, and models; estimates of the changes in carbon stocks and non-CO_2 greenhouse gases and corresponding calculations and models used; any GIS products; and copies of the measuring and monitoring reports should all be stored in a dedicated and safe place, preferably offsite.

Given the time frame over which the project will take place and the pace of production of updated versions of software and new hardware for storing data, it is recommended that the electronic copies of the data and report be updated periodically or converted to a format that could be accessed by any future software application.