Technical Guidance on Development of a REDD+ Reference level

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ABBREVIATIONS & ACRONYMS

AFOLU	**Agriculture, Forestry and Other Land Use**
A/R	Afforestation/Reforestation
ASTER	*Advanced Spaceborne Thermal Emission and Reflection*
BAU	Business-as-usual
CB	Compensation baseline
CDM	Clean Development Mechanism
CLAS	Carnegie Landsat Analysis System
CO_2	Carbon dioxide
COP	Conference of the Parties
FCMS	Forest Carbon Monitoring System
GHG	Greenhouse gas
GIS	Geographic Information Systems
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing Satellite
JNR	Jurisdictional and Nested REDD+
LC/LU	Land Cover and Land Use
LiDAR	Light Detection and Ranging
MODIS	Moderate Resolution Imaging Spectroradiometer
MRV	Measuring, Reporting, and Verification
PC	Potential for Change
PFC	Potential Future Change
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RL	Reference Level
ROC	Relative Operating Characteristic
R-PP	Readiness Preparation Plan
RS	Remote Sensing
SBSTA	Subsidiary Body for Scientific and Technological Advice
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Voluntary Carbon Standard
WMO	World Meteorological Organization

CHAPTER 1: PURPOSE AND SCOPE OF MANUAL

1.1 Background

When forests are cleared or degraded, the carbon stored in trees, non-tree vegetation, roots, deadwood, litter, and soil is released into the atmosphere as carbon dioxide (CO_2, a major greenhouse gas [GHG]). In addition, the forest's capacity for additional carbon sequestration is lost or reduced. Emissions of greenhouse gases (GHGs) from deforestation and forest degradation are significant, and have been estimated to account for about 10% or more of global anthropogenic CO_2 emissions.[1] Therefore, policies related to reducing emissions from deforestation and forest degradation and other measures to reduce emissions and increase sequestration (REDD+) in developing countries have the potential to play a significant role in climate change mitigation.

Although terrestrial carbon sequestration has always been recognized as a means to reduce atmospheric greenhouse gas concentrations under the UNFCCC, initial agreements under the Clean Development Mechanism of the Kyoto Protocol recognized only Afforestation/Reforestation (A/R) as an eligible project type. Starting in 2005, a mechanism to reduce emissions from deforestation (RED) while raising developing country incomes was proposed to the UNFCCC. During yearly subsequent UNFCCC meetings, this mechanism and associated potential regulations have continued to develop (See Box 1).

Decisions from recent UNFCCC meetings make it clear that a REDD+ 'reference level' (RL) of emissions and removals must be developed. Within the context of the UNFCCC, REDD+ RLs are needed for two purposes[2]: (1) RLs establish business-as-usual (BAU) baselines (i.e. emissions scenario in the absence of REDD+ implementation) against which actual emissions are compared, and net emission reductions are estimated as the difference between RLs and actual emissions; and (2) RLs are needed to determine the eligibility of countries for international, results-based support for REDD+, and to calculate that support on the basis of measured, reported, and verified (MRV) emission reductions. Thus it is clear that RLs are a critical determinant of REDD+ financing.

Many countries are already beginning to develop relevant capacities to establish RLs in anticipation of the creation of a REDD+ mechanism. This manual provides guidance on the technical requirements for estimating historical emissions to assist countries in establishing RLs and discusses the options that countries have for adjusting the historical emissions according to national circumstances.

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[1] Harris, NL, Brown, S, Hagen, SC, Saatchi, SS, Petrova, S, Salas, W, Hansen, M, Potapov, P, Lotsch, A. 2012. Baseline map of carbon emissions from deforestation in tropical regions. Science 336: 1573 – 1576.

[2] Angelsen, A., D. Boucher, S. Brown, V. Merckx, C. Streck, and D. Zarin. 2011. "Modalities for REDD+ Reference Levels: Technical and Procedural Issues." Prepared for the Government of Norway, Meridian Institute, Washington, DC. Available at: http://www.REDD-OAR.org

Box 1. The Evolution of REDD+ within UNFCCC

In 2005 at Conference of the Parties (COP) 11, the countries of Papua New Guinea and Costa Rica, supported by eight other countries, proposed a mechanism for Reducing Emissions from Deforestation (RED) in developing countries as a means for decreasing atmospheric greenhouse gas emissions while raising income for sustainable development and climate change adaptation[3]. Discussions began with RED but were broadened in the 2007 Bali Action Plan to include forest degradation, forest conservation, sustainable management of forest, and enhancement of forest carbon stocks (what is now referred to as REDD+)[4].

Strong support for REDD+ continued at the 2009 COP 15 in Copenhagen[5], and initiatives to prepare for a system of positive incentives post-2012 that includes REDD+ through capacity building and pilot performance-based payments were also outlined. Outcomes from COP 16 in Cancun were an important step forward for the realization of an international REDD+ mechanism. Although a post-2012 agreement was not reached in Cancun, COP 16 decisions included the key elements and the framework needed to support the development of national level REDD+ programs over the next two years[6]. A phased approach to REDD+ at the national level with sub-national elements was adopted, with development of national strategies and action plans followed by the development of a **Reference Level** (RL) and a robust and transparent national forest monitoring system to measure, report and verify (MRV) reductions in net emissions from forests. The decisions achieved at COP 16 basically guaranteed that REDD+ negotiations and activities can move forward.

At COP 17 in Durban in 2011, additional progress was made on defining an incentive framework for REDD+ that may include multiple sources and channels of funding, including market-based approaches. In addition, further guidance was provided on safeguards and reference levels[7]. Per suggestions from COP 17, the approach to development of RLs should be flexible, allowing for some choice in pools, gases, and activities; step-wise, allowing for improvements over time in data and methodologies; and transparent, requiring countries to submit information and rationale. Although the relationship between REDD+ interventions at the subnational and national level over the long term has not been defined, subnational and project level activities are likely to play a critical role in the development of national capacity for REDD+, especially over the fast start phase as countries field test REDD+ interventions and RLs, forest carbon monitoring systems (FCMS), and MRV systems.

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[3] UNFCCC Document FCCC/CP/2005/MISC.1
[4] UNFCCC Document FCCC/CP/2007/6/Add.1
[5] UNFCCC Document FCCC/CP/2009/11/Add.1
[6] UNFCCC Document FCCC/CP/2010/7/Add.1
[7] UNFCCC Document FCCC/CP/2011/9/Add.1

1.2 Purpose and Scope of this Document

This document is directed at national and regional governmental staff and partners assigned to the design and implementation of the technical components of a national and subnational REDD+ program. The document is also designed to provide technical guidance to potential project developers and implementers of REDD+ interventions. The focus of the technical information in this document is on how to design and implement a RL. Details on how to develop a FCMS and MRV system are not provided, however, it will be important for RL designers to consider how it will interact with these two components.

The document is organized into multiple chapters that describe the several components needed to develop a RL. Although an attempt was made to provide readers of various backgrounds to benefit from all chapters of the document, some users may want to focus their attention on specific sections most relevant to their responsibilities and expertise areas. The document is not a prescriptive step-by-step guide, but rather describes how the technical components of establishing a RL fits within the Intergovernmental Panel on Climate Change (IPCC) framework and the best practices that can be used to produce transparent, consistent and accurate estimates of historic emissions with low uncertainties that feed into the RL projection.

Chapter 2 provides an overview on what REDD+ is and the main technical components that need to be developed to estimate emissions. Chapter 3 delineates the key policy decisions that will need to be made during the design of the RL. Chapter 4 describes the specific technical components required for developing a RL. This chapter is directed at readers with technical backgrounds in remote sensing, GIS, forestry, and carbon accounting.

CHAPTER 2: REVIEW OF REDD+ NATIONAL STRATEGY

The development of a national REDD+ program can be envisioned to include five key components, (Figure 1), with each component requiring a series of steps to attain the outcome:

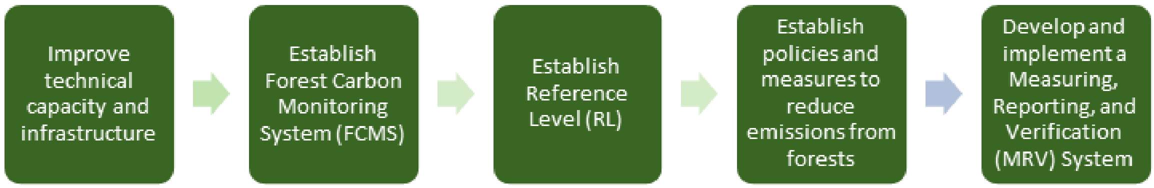

Figure 1. Key components for developing a national or subnational REDD+ program.

Component 1: Capacity Development: The first step here will be assessing and developing the technical capacity and infrastructure necessary for the establishment of a REDD+ program, for which dedication of government resources are required. This will likely involve a combination of increasing and enhancing public and private sector capacity.

Component 2: Develop a national or subnational forest carbon monitoring system (FCMS): This is the system that will be used to design the collection and analyses of all the data needed to produce estimates of carbon emissions and removals from changes in forest land cover. The outcomes of this system feed into the historic emission component of the RL and also into the MRV.

Component 3: Establish the RL: The RL is a likely projection of emissions in the absence of any REDD+ program and is based on the historic emissions. It will then serve as the emissions projection against which the performance of REDD+ interventions will be assessed. An analysis of historical and expected drivers of emissions will be needed.

Component 4: Design policies and measures (PAMs) to reduce net emissions: To achieve emissions reductions, PAMs must be developed and implemented that will result in reductions in emissions or enhancing removals (e.g. sequestration) from forests, including those, e.g., that provide alternative livelihoods and enhance income for the people engaged in deforestation and forest degradation activities and promote activities that enhance forest carbon stocks such as reforestation.

Component 5: Develop a MRV system: The actual emissions and removals that take place over time will be compared with the projected RL to measure the performance of the REDD+ interventions. Therefore, a system must be developed for how to report on this performance taking place across the landscape. This system will also require steps for verifying the reported net emissions.

Many of these components can take place both consecutively and concurrently, however without first understanding the historical emissions by driver and location within a country it will be difficult to develop a meaningful strategy to reduce emissions and/or enhance removals. Each of these components will require input from various government and private institutions including input from

scientists, statisticians and field crews that can produce robust estimates of forest carbon stocks and emission factors, GIS specialists that compile and manage the necessary spatial databases, and remote sensing specialists that can map land cover change using satellite imagery.

This manual focuses on the inputs and activities required for the establishment of the reference level (RL). First, however, a short overview of each of the four components is provided in the next section.

Box 2. Why RLs matter irrespective of REDD+

Historical emissions of GHGs provide information on the magnitude, location, and causes of emissions/removals, helping to identify strategies that have the most impact on reducing deforestation and forest degradation as well as enhancement of forest carbon stocks. RLs also contribute to the development of low emission development strategies by providing improved knowledge on the role of forests in national GHG inventory and potential REDD+ interventions to reduce net GHG emissions. Establishing historical emissions provides opportunities to “learn by doing” and design the forest measurement and monitoring system in the process of developing the RL. Countries can start at the subnational level as an interim step. As well, development of the RL can enhance GHG inventory for the forest sector of a country’s National Communications.

2.1 Technical Capacity Building and Infrastructure Development

National, sub-national, and project-level efforts to monitor and estimate emissions from the forest sector will succeed only if supported by sound technical knowledge and capacity in five key areas: (1) IPCC framework and its application to national GHG inventories; (2) statistical sampling design; (3) collection of field measurements and interpretation of remote sensing imagery; (4) QA/QC procedures, and (5) data synthesis and analysis.

Capabilities in these five key areas can be strengthened through capacity building efforts in:

- Remote sensing and spatial analysis: These are important tools for: 1) conducting an assessment of the historic forest area change, 2) projecting the potential for future change, and 3) stratifying forests. Capacity must be developed in conducting regional carbon analyses using satellite data and spatial analyses to map land cover and land use classes that meet the criteria of the IPCC 2006 Good Practice Guidelines for LULUCF.
- A Forest Carbon Monitoring System (FCMS): In addition to the remote sensing and spatial analysis, other system components include the selection of key carbon pools; the determination of type, number and location of field plots necessary to achieve accuracy and precision targets; and QA/QC protocols for field measurements and data analysis and storage.
- Carbon accounting methods: After all fieldwork is completed, capacity is needed to conduct analysis of the collected data to create activity data sets, carbon conversion factors, and emission factors, including estimates of uncertainty around the factors and emission estimates developed.
- Monitoring infrastructure: A long-term monitoring plan with adequate infrastructure and human resources will be needed to ensure QA/QC plans are implemented and data and documents are properly archived, allowing countries to update the measurement and reporting as needed.

2.2 Develop a Forest Carbon Monitoring System

A national or subnational forest carbon monitoring system (FCMS) will be used to design the collection and analyses of all the data needed to produce estimates of carbon emissions and removals from changes in forest land cover in the past and in the future during REDD+ implementation. The FCMS system will need to include systematic and repeated measurement methods to estimate GHG emissions and removals at the national or subnational level. These methods should be in-line with the approaches and methods used in the IPCC Good Practice Guidance 2006[8] and promote transparency, consistency, comparability, and accuracy.[9] The outcomes of this system will feed into both the historic emission component of the RL and the MRV.

When REDD+ systems are designed, it is important to consider how and what methods will be used to conduct the FCMS. Different systems may require different types of monitoring tools and methods. The methods selected for application depend on national capacity, needed resources and realized benefits, and patterns and characteristics of the types of emissions and removals.[10]

Technical solutions for FCMS typically combine remotely sensed data with ground-based data. Data and information collection processes for the FCMS need to use an appropriate combination of documentation, remote sensing, field measurements, and QA/QC plans. Sampling designs and standard operating procedures for all data collection and analysis must be developed to ensure consistency and comparability throughout the monitoring system.

To assess the actual emissions and removals that take place over time after the implementation of any REDD+ interventions, the change in activity data, emission factors, and net emissions will need to be monitored and accounted over time. Therefore countries will need to invest in the establishment and long-term maintenance of a national FCMS for REDD+. The FCMS system will need to include an array of remote sensing, spatial analysis, and field-based technologies and methods that are suitable and cost effective for monitoring land use/land cover changes, degradation activities, and other activities causing emissions/removals. In addition, data infrastructure must be developed to gather, store, archive, and analyze data required for national reporting (as part of MRV) on emissions under the implementation of REDD+.[11]

2.2.1 Monitoring Multiple Benefits, Other Impacts, and Safeguards

In addition to reducing GHG emissions from forests, REDD+ is expected to generate additional benefits including strengthening indigenous rights, poverty alleviation, and conservation of biodiversity among

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[8] http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

[9] UNFCCC Document FCPF/TP/2009/1

[10] Bottcher, H, Eisbrener, K, Fritz, S, Kindermann, G, Kraxner, F, McCallum, I, Obersteiner, M. 2009. An assessment of monitoring requirements and costs of 'Reduced Emissions from Deforestation and Degradation. *Carbon Balance and Management*, 4:7.

[11] UNFCCC. 2009. Cost of implementing methodologies and monitoring systems relating to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and greenhouse gas emissions from changes in forest cover, and the enhancement of forest carbon stocks. Technical Paper. FCCC/TP/2009/1.

other impacts.[12] The Cancun Agreements included safeguards to ensure that above all REDD+ does not cause negative social or environmental impacts. Safeguards are essentially policies and measures to address the direct and indirect impacts of REDD+, and imply that monitoring of multiple benefits in addition to emissions reductions should be included in a forest monitoring system. At a minimum, the monitoring of the direct and indirect impacts of REDD+ must be included in the monitoring system to ensure that the implementation of REDD+ does not have negative social or environmental impacts.

Safeguards imply that the institutional framework for monitoring of transactions should be directly linked to the requirements for providing estimates of performance, so that compensation transactions give incentives to all actors and reflect their different roles and responsibilities within the country.[13] In addition, safeguards should include accessible, transparent, and accountable recourse mechanisms to avoid the risk of negative impacts on biodiversity and communities.[14] Community monitoring of carbon stocks has been shown to be effective, cost efficient, and to increase participation in activities that provide compensations for the protection and enhancement of forest carbon stocks.[15] However, gaps exist in understanding of how to build on existing systems to effectively implement safeguards.[16] At COP 17 in Durban an agreement was reached that the SBSTA would consider the need for further guidance on safeguards.

In addition, in the absence of any REDD+ framework, countries already undertake different levels of forest monitoring depending on a number of economic, sociocultural and environmental policies. It may be possible to integrate monitoring emissions and removals of GHGs into current forest monitoring by adapting current systems. This integration of monitoring systems should reduce the overall cost of monitoring for multiple benefits. Forests monitored for carbon can more easily be assessed for timber supply and provision of non-timber forest products, and other ecosystem services such as biodiversity and watershed protection can be better measured and identified.[17]

2.3 Establishment of the Reference Level

2.3.1 Definition of Reference Levels

Under the UNFCCC, RLs are used to demonstrate GHG emission reductions. RLs are the quantity of GHG emissions and removals that are projected to take place in the absence of a REDD+ program, and

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[12] Murphy, D. 2011. Safeguards and Multiple Benefits in a REDD+ Mechanism. IISD. 29 p.
[13] Herold, M. and Skutsch, M. 2009. Measurement, reporting, and verification for REDD+: Objectives, capacities, and institutions. In A. Angelsen (Ed.), *Realising REDD+: National strategy and policy options.* CIFOR.
[14] Moss, N, Nussbaum, R. 2011. A Review of Three REDD+ Safeguard Initiatives. Forest Carbon Partnership Facility and UN-REDD Programme.
[15] Skutch, M, Van Laake, P, Zahabu, E, Karky, B, Phartiyal, P. 2009. Community monitoring in REDD+. In: Angelsen, A. (Ed.) 2009. Realizing REDD+: National strategy and policy options. CIFOR, Bogor, Indonesia.
[16] Additional Guidance on REDD+ Safeguards Information Systems. Briefing Paper to the 36th Session of the SBSTA UNFCCC. REDD+ Safeguards Information System Working Group.
[17] Bottcher, H, Eisbrener, K, Fritz, S, Kindermann, G, Kraxner, F, McCallum, I, Obersteiner, M. 2009. An assessment of monitoring requirements and costs of ‘Reduced Emissions from Deforestation and Degradation. *Carbon Balance and Management*, 4:7.

they are needed to establish business-as-usual (BAU) benchmarks against which actual emissions are compared (Figure 2). As such they are a critical determinant of compensation for reduction of emissions through the REDD+ mechanism[18]. RLs can also inform the development and implementation of REDD+ policies, underpin the credibility of REDD+, and inform performance of results-based payments for REDD+.

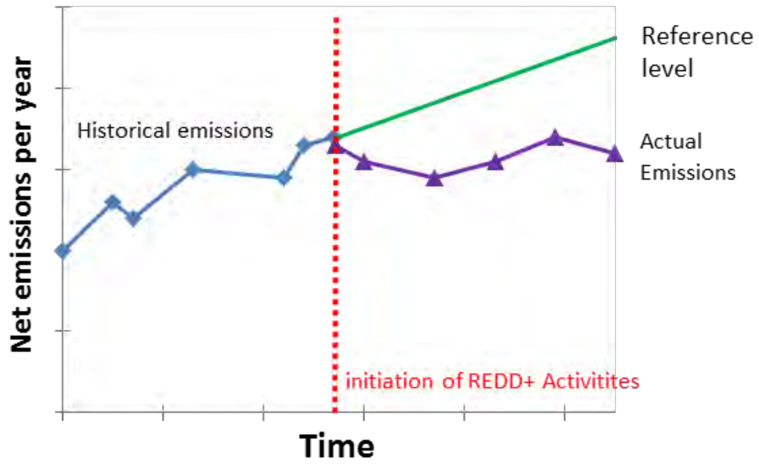

Figure 2. An example of historical net GHG emissions from deforestation, a projected reference level, and actual annual emissions after initiation of REDD+ interventions.

The terms RL and REL (Reference Emission Level) are not used consistently in the literature (see Box 3). The inconsistent use of these two terms has the potential to cause confusion. REL commonly refers to net emissions from gross deforestation and forest degradation (REDD) in a given time period while RL refers to net emissions and removals from all of the REDD+ activities. Here the term RL is used generically and covers both situations.

[18] Angelsen, A, Boucher, D, Brown, S, Merckx, V, Streck, C, Zarin, D. 2011. Modalities for REDD+ Reference levels: Technical and Procedural Issues. Meridian Institute, 18 pp.

Box 3. Evolution of the term RL within the UNFCCC

Prior to 2007, reference emission levels were related to reducing emissions from deforestation only. Forest degradation, conservation, and enhancement were not mentioned in relation to reference levels until the 2007 COP in Bali. The term was then divided into RL and REL at the UNFCCC Climate Change Conference at Poznan in 2008. This was done for several different reasons. The term REL implies only "emissions" and not net emissions by including removals from afforestation/reforestation activities. The term RL was supported to ensure the inclusion of afforestation/reforestation that may play an important role in determining the impact of forestry related activities on greenhouse gas emissions. Another reason that RL was supported was related to concerns regarding capacity issues. Countries might be able to measure forest cover but not estimate emissions, and therefore forest cover was an attractive proxy for emissions. The term RL implies forest cover as an acceptable proxy for emissions. However, RLs were less attractive to NGOs and other groups because they "reduce forests to sticks" where emissions gives a more holistic view of the role of forests in climate change.

Another level of complexity was added to the terms RL and REL by introducing "and/or" into text at the 2010 COP in Cancun. At COP 16 the UNFCCC adopted a decision encouraging developing countries to establish "a national forest reference emission level and/or forest reference level, or if appropriate, as an interim measure, subnational forest reference emission levels and/or forest reference levels, in accordance with national circumstances." Thus this new text implies that a country can have multiple subnational RLs.

2.3.2 Development of a Reference Level

The UNFCCC decisions state that a projection of future emissions in a country in the absence of a REDD+ mechanism ("business as usual" or BAU) should be formulated to create the RL.[19] This can be created by: 1) first establishing *historical emissions* and 2) then projecting emissions based on consideration of national circumstances[20]. Per suggestions from COP 17, the approach to development of RLs should be 1) flexible, allowing for some choice in pools, gases, and activities; 2) step-wise, allowing for improvements over time in data and methodologies; and 3) transparent, requiring countries to submit information and rationale. Countries may also choose to develop data on historical emissions and removals in a stepwise manner, beginning with selected states and provinces where data are more readily available or of better quality, and develop subnational RLs as an interim step in the establishment of national RLs.[21]

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[19] The UNFCCC decision at COP 13 in Bali, Annex 2/CP.13 states that reference levels *"…should be based on historical emissions, taking into account national circumstances*." UNFCCC Document FCCC/CP/2007/6/Add.1 http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf

[20]Decision 4/CP.15: *"Recognizes that developing country Parties in establishing forest reference emission levels and forest reference levels should do so transparently taking into account historic data, and adjust for national circumstances…"* UNFCCC Document FCCC/CP/2009/11/Add.1 http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf

[21] Meridian Institute. 2011. "Modalities for REDD+ Reference levels: Technical and Procedural Issues." Prepared for the Government of Norway, by Arild Angelsen, Doug Boucher, Sandra Brown, Valérie Merckx, Charlotte Streck, and Daniel Zarin. Available at: http://www.REDD-OAR.org

A *historical reference period* will need to be chosen. This is the span of time during which emissions taking place in the past will be estimated. This time period will be based on a combination of factors including data availability and the relevance of the past as a predictor of the future. The historical emissions and removals from deforestation, forest degradation, and reforestation (activities that enhance forest carbon stocks)[22] taking place over the historical reference period can be estimated using an IPCC approach (Box 4). Under this commonly used approach, the quantity of various activities that result in emissions/removals is estimated (referred to as 'activity data') along with an estimate of the amount of emissions/removals per unit of that activity (referred to as 'emission factors'). Activity data combined with emission factors will produce an estimate of the total amount of emissions/removals taking place in a given year as a result of that activity.

Box 4. The IPCC and REDD+

The Intergovernmental Panel on Climate Change (IPCC) is an international scientific body that reviews and evaluates information relevant to the understanding of climate change. The IPCC has produced two key documents on methodologies for conducting GHG inventories for assessments of land use/land cover change that provide a framework for GHG inventories in the agriculture, forests, and other land use (AFOLU) sector. These are the 2003 Good Practice Guidance for Land Use, Land Use Change and Forestry and the 2006 IPCC Guidelines for National GHG Inventories (Volume 4 Agriculture, Forestry and Other Land Use).

The IPCC present five general principles that guide the reporting of estimates of national emissions and removals of greenhouse gases (GHGs), and these are equally applicable to the preparation of RLs. These principles are: (i) transparency, (ii) completeness, (iii) consistency, (iv) comparability, and (v) accuracy

Based on the Cancun Agreements from COP 16[23] the following activities aimed at reducing emissions from forests are eligible for inclusion under REDD+:

- Reducing emissions from deforestation
- Reducing emissions from forest degradation
- Conservation of forest carbon stocks
- Sustainable management of forests
- Enhancement of forest carbon stocks

These mitigation activities under the full scope of REDD+ correspond to the three categories in the IPCC Good Practice Guidance framework:

- "Forests converted to other lands" corresponds to deforestation
- "Forest remaining as forest" includes forest degradation, conservation of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks (through increases in the carbon density of degraded forests).

[22] IPCC. 2006. Guidelines for National Greenhouse Gas Inventories available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html
[23] UNFCCC Document FCCC/CP/2010/7/Add.1

- "Other lands converted to forest" includes enhancement of carbon stocks through afforestation/reforestation (A/R) of nonforest land

RLs are equal to the combined outcome of all these process in terms of emissions and/or removals. However, existing text is ambiguous in regards to the inclusion of A/R activities in REDD+. "Enhancement of forest carbon stocks" could be limited to enhancement of carbon stocks in existing forest areas[24].

The IPCC presents a methodological framework for estimating emissions. The quantity of an activity that results in emissions/removals is referred to as "activity data" and the estimate of the amount of emissions/removals per unit of that activity is referred to as an "emission factor". "Activity data" combined with "emission factors" estimates the total amount of emissions/removals taking place in a given year as a result of that activity. Three **Approaches** (Approaches 1-3) are presented as options in the IPCC guidance documents for obtaining activity data, and three **Tiers** (Tiers 1-3) are presented as options for obtaining emission factors (Table 1). Higher Approaches and Tiers correspond to greater detail in the underlying data, whereas lower tiers rely extensively on generalized default factors.

Table 1. Comparison of IPCC Approaches and Tiers[25]

Approach for activity data: Area change
1. Total area for each land use category, but no information on conversions (only net changes)
2. Tracking of conversions between land-use categories
3. Spatially explicit tracking of land-use conversions
Tiers for emission factors:
1. IPCC default factors
2. Country specific data for key categories
3. Detailed national inventory of carbon stocks for key categories, repeated measurements of through time or modeling

While moving from Tier 1 to Tier 3 increases the certainty of GHG estimates, it also increases the complexity and costs of measurement and monitoring. Likewise, achieving greater completeness and certainty in a measurement and monitoring system means higher costs as it is likely that more carbon pools would need to be monitored and that the monitoring would need to result in accurate and precise estimates of emissions and removals.

To establish the *reference level*, the estimate of historical emissions must be projected into the future, based on what is expected to take place under a business-as-usual scenario. The amount of emissions that has historically taken place for various activities will not necessarily be constant from year to year (Figure 2) and therefore the method chosen to project emissions (Box 5) into the future must be

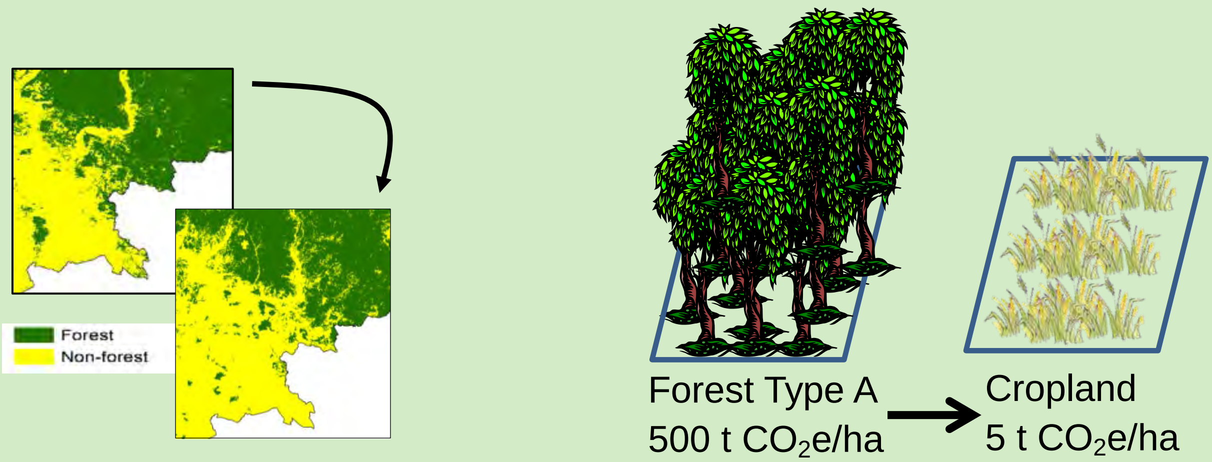
[24] Angelsen, A, Boucher, D, Brown, S, Merckx, V, Streck, C, Zarin, D. Modalities for REDD+ Reference levels: Technical and Procedural Issues. Meridian Institute, 18 pp.

[25] IPCC. 2006. Chapter 1 Overview. Guidelines for National Greenhouse Gas Inventories.

justifiable given the actual situation in the country, including laws, area of remaining forests, population trends, development plans, and recent political or economic history compared to the future (e.g. recent civil war, depression, etc.). A country with a high historical rate of deforestation may not be able to justify a high future rate of deforestation if the situation in the future is expected to be substantially different compared to the past. Likewise, in order to justify a high future rate of deforestation in a country with a low historical rate of deforestation, evidence must demonstrate that the situation in the future will be conducive to increased rates of deforestation, such as acceleration of economic development. Circumstances that may be relevant to the future rate of emissions include drivers of deforestation and degradation, stage in forest transition, development plans and policies, and expected population changes.

Box 5. Example: Development of historical emission estimation for deforestation activities

To determine the historical GHG emissions that have resulted from, for example, the deforestation activity ‘forest type A converted to cropland’, activity data and emission factors will need to be developed. The historical annual area of deforestation of forest type A to cropland (the activity data), could be obtained by analyzing a series of remote sensing images from the selected historical period (e.g. 2000-2010) to estimate the area of the specific forest type that was converted to cropland. The emission factor for this ‘activity data’ will be based on the emissions that result from the act of deforestation along with any sequestration under the post-deforestation land use. Often these estimates of emissions are developed through field measurements of standing carbon stocks of each land use type.



Activity Data:
1000 ha in year *x*

Emission Factor:
495 t CO_2e/ha

Figure 3. Example of Activity Data and Emission Factor development

The total emissions associated with a particular activity are then obtained by multiplying the activity data by the emission factor:

Activity Data	*	Emission Factor	=	Emissions from deforestation of forest type A to cropland
1000 ha/yr	*	495 t CO_2e/ha	=	495,000 t CO_2e/yr

If this is repeated for various years from the past, the historical emissions from deforestation can be estimated (Figure 4). Assuming for this example that it is reasonable to expect the future to be similar to the past, future emissions from deforestation can be estimated based on a linear projection of past emissions, or, if more appropriate, an average of the historical emissions.

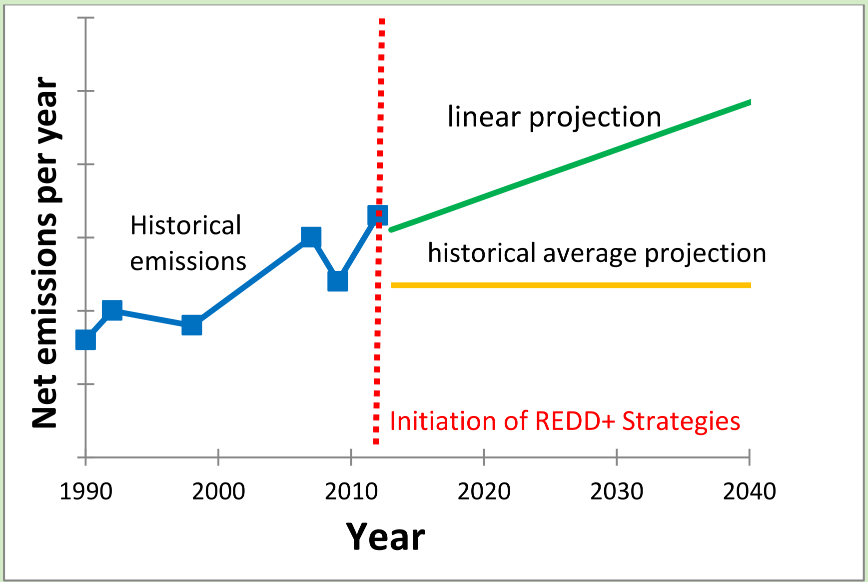


Figure 4. Example of historical emissions from deforestation and a linear and historical average projection of future deforestation emissions

2.3.3 Official Adoption of RLs

Although a process for approval and adoption of national RLs within the UNFCCC context has not been established, RLs could potentially be adopted through either a top-down process led by UN policy makers and/or technical experts; a country-led process that then requires technical review and approval of country developed RLs at the international level; or a combined approach that joins elements of both processes.

Because it is difficult to project emissions and removals from land use and land cover change into the future, RLs will need to be revisited in the future and adjusted for changing circumstances. Currently it is not clear how this process will be implemented, although it is likely that RLs will be established for periods of 5-10 years.

2.4 Measures to Reduce Emissions from Forests

The development of effective policies, measures and interventions that will result in enhancements or reduced emissions requires a comprehensive understanding of land use and land use change drivers. A range of interventions to reduce emissions from deforestation and forest degradation as well as activities that enhance forest carbon stocks will likely be included in a national REDD+ strategy.

To design effective REDD+ interventions, the agents and forces driving change in forest cover and emissions must be well understood. The first step is to understand the hierarchy of causes:

- At one level are the agents and their actions, in other words, the actual entities actively causing deforestation, forest degradation, and carbon stock enhancement, such as logging operations or small-scale agriculturalists that are driven by poverty and landlessness.
- At another, higher level, are the influences of commodity prices, access to markets, agricultural technologies, etc. [26]
- At the third and highest level are the broader national and international policies that influence the decision parameters

To achieve the successful implementation of REDD+ interventions, it will be essential to include multilevel, multi-actor governance structures. Without the support of all resource users, long-term success of REDD+ schemes are unlikely, and the effectiveness of REDD+ interventions in reducing poverty depends in part on the extent to which the interests of the poor are prioritized in the design and implementation of the REDD+ program[27].

The Cancun Agreements included safeguards to ensure that above all REDD+ does not cause negative social or environmental impacts. Safeguards are essentially policies and measures to address the direct and indirect impacts of REDD+ and must be included to ensure that the implementation of REDD+ does not have negative social or environmental impacts. Currently multiple initiatives to promote the implementation of REDD+ safeguards exist, such as the the UN-REDD Programme's Social and Environmental Principles and Criteria, World Bank Safeguards and Strategic Environmental and Social Assessment (SESA), REDD+ Social and Environmental Standards (REDD+ SES) and the REDD+ safeguards outlined in the Cancun Agreements.

2.5 Develop a Measurement, Reporting, and Verification (MRV) System

The actual emissions and removals that take place over time will be compared with the projected RL to measure the performance of the REDD+ interventions. Therefore, an MRV system must be developed that includes the approach for measuring the performance, reporting the performance that takes place across the landscape, and verifying the performance (the difference between the RL and actual

[26] Angelsen, A. 2009. Policy options to reduce deforestation. In A. Angelsen (Ed.), *Realising REDD+: National strategy and policy options.* CIFOR.

[27] REDD-net. 2010. The impact of REDD+ on poverty reduction. Available at: http://redd-net.org/resource-library/the-impact-of-redd+-on-poverty-reduction.

emissions in Figure 5). There are no decisions from the UNFCCC regarding the modalities for MRV as of the Doha COP (2012).

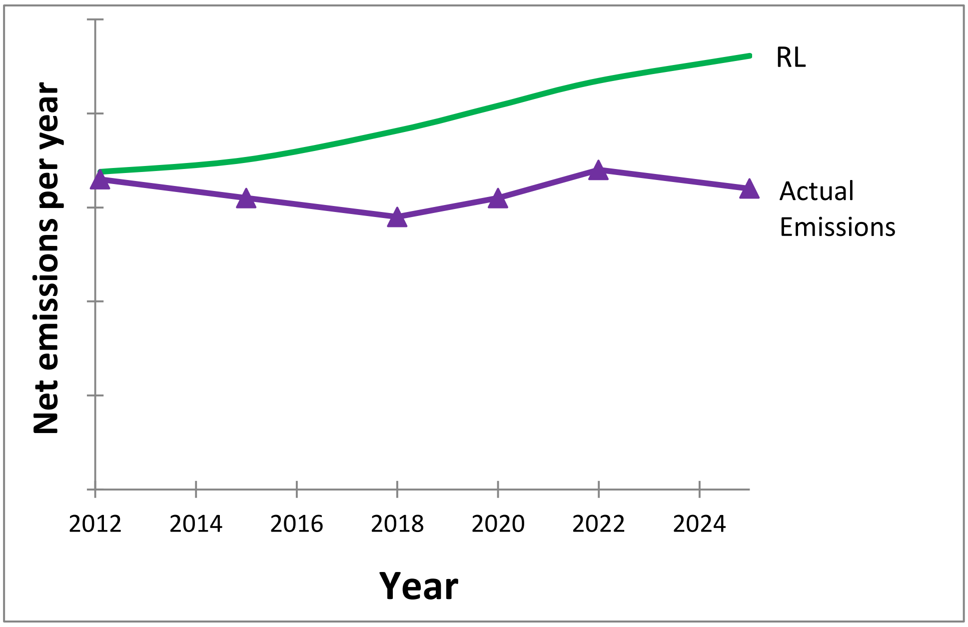


Figure 5. Emissions under REDD+ are compared to the RL and the difference is a measure of the performance that will be reported in an MRV.

CHAPTER 3: KEY DECISIONS IN SETTING A REFERENCE LEVEL

Participation in a REDD+ mechanism will require countries to develop their RLs, but to date there has been little practical guidance on how RLs should be quantified. Winrock International is presently developing a methodological framework for the World Bank's Forest Carbon Partnership Facility (FCPF) and Carbon Fund (CF) to assist participant countries in enhancing their near-term capacity for producing RLs at the national scale as part of their eventual REDD+ Readiness Package.[28] The framework enables countries to become familiar with 1) key decisions that need to be made early in the process, and2) methods, available data, and tools that can be used so that participant countries can be better prepared in the near term to engage in analytic activities proposed in their national Readiness Preparation Plans (R-PPs).

An overview of the framework provides guidelines for how a credible national RL should be established. Seven key decisions need to be addressed at the outset (Figure 6) that will potentially be made by the government ministries or departments responsible for monitoring land use and forestry sector activities. Technical inputs are required to inform these decisions and the outcome of these decisions and will largely determine the design of the RL.

3.1 Determine Scope of Activities

Many land use activities are incorporated into REDD+, and all fall into broad categories of deforestation, forest degradation, sustainable management of forests, or enhancement of carbon stocks. There are many drivers of **deforestation**, including conversion to agriculture, mineral extraction, infrastructure expansion, etc. but the end result is generally the same regardless of driver: a reduction in forest cover below thresholds that define a forest. There are also many drivers of forest **degradation**, but these are considered separately by degradation source because the impacts of different activities can degrade forests to different degrees, and the data needed to estimate emissions vary by activity. The same is true for enhancement of forest carbon stocks that includes activities such as planting new forests and enriching existing forests.

Because a national RL can be developed in a stepwise manner, i.e., start with subnational level or only with a certain activity), for some countries it may make sense to include only the REDD+ interventions or only the subnational jurisdiction that will make the most significant reduction in emissions, adding in additional activities (as well as intervention programs to address these) and subnational jurisdictions as time, data, and resources allow.

[28] Harris, N, Pearson, T, Brown, S. 2012. *Decision support tool for developing* Reference levels *for REDD+*. Report prepared by Winrock International for the World Bank's Forest Carbon Partnership Facility

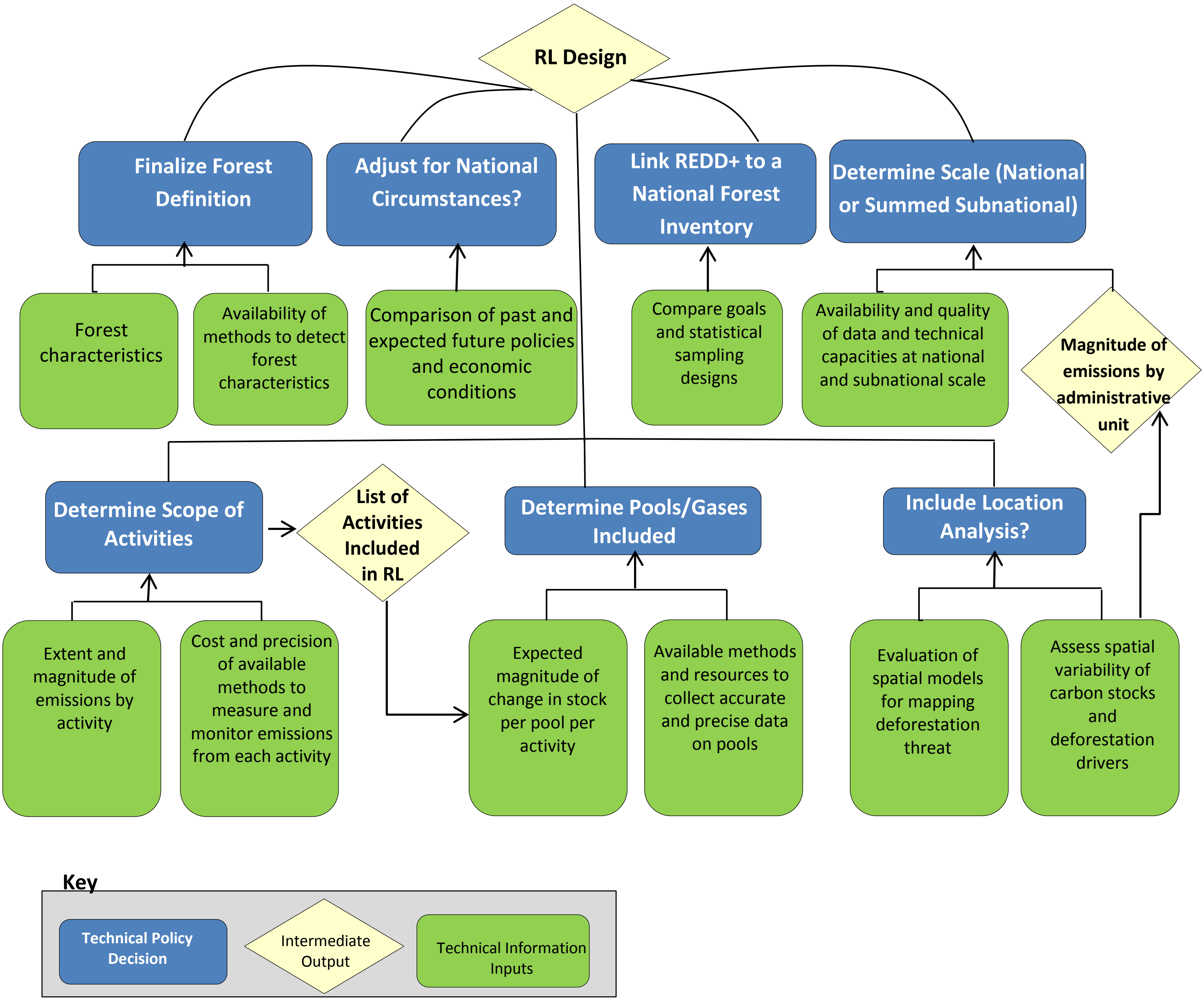


Figure 6. Key technical policy decisions to be made by countries when designing their reference levels for REDD+[29].

Based on the Cancun Agreements from COP 16[30] the following activities aimed at reducing emissions from forests are eligible for inclusion under REDD+:

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[29] Adapted from: Harris, N, Pearson, T, Brown, S. 2012. Decision support tool for developing reference levels for REDD+. Report prepared by Winrock International for the World Bank's Forest Carbon Partnership Facility.

[30] UNFCCC Document FCCC/CP/2010/7/Add.1

- Reducing emissions from deforestation
- Reducing emissions from forest degradation, including
    - Timber harvesting
    - Fuelwood collection
    - Human-induced fires
    - Overgrazing
    - Land use change (including shifting cultivation)
- Conservation of forest carbon stocks
- Sustainable management of forests
- Enhancement of forest carbon stocks

To inform this decision-making, an analysis of the extent and magnitude of emissions generated by each activity is needed. A study on the cost, accuracy, and precision of available methods to measure and monitor emission from each activity will also be required. This analysis will need to examine data and methods to access historical emissions along with expected future monitoring. From these studies a comparison of the various activities and costs to measure and monitor those activities can be made. For example, if the contribution of forest degradation to total emissions from forests is small compared to the impact of deforestation, and cost effective methods to measure emissions from degradation are not available, a country may decide to exclude forest degradation from the scope of activities included in REDD+, at least initially.

3.2 Determine Scale of the RL

The basic decisions and steps for developing RLs are relevant at both national and subnational scales. At COP 17 in Durban, the UNFCCC stated that countries may opt to work on their historical emissions and removals data in a stepwise fashion, starting with selected states or provinces where changes in forest cover have historically been high; and/or or on one activity such as deforestation.[31]

The advantage of starting with subnational RLs is that it may provide the opportunity to fast-track development of RLs in areas of the country where emissions are high, data are more readily available and/or of better quality, and interventions are possible. On the other hand, an advantage of a national approach to developing a RL is that the integration of separate subnational RLs and monitoring systems is not necessary. Therefore, the process of developing a RL does not require subnational datasets and standards to be harmonized. This harmonization would require agreement to be

[31] Further decisions were made on the scale issue of RL/RELs in 4/CP.17 as follows "*…that subnational to national forest reference emission levels and/or forest* reference levels *development may be elaborated as an interim measure, while transitioning to a national forest reference emission levels and/or forest reference levels. …the interim forest reference emission levels and/or forest reference levels of a Party may cover less than its entire national territory of forest area.*"

achieved among all stakeholders on the nature of the standards and their requirements, which could delay progress on developing the RL. Ultimately, the scale of the RL will be decided by policy makers within the institutions responsible for the managing forest and other lands within the country.

3.3 Finalize Forest Definition

Text from the UNFCCC's SBSTA in Durban states that countries should provide a national definition for forests to the UNFCCC and that it must be justified if it differs from the one used in the national greenhouse gas inventory or reporting to other international organizations.[32] Aspects to consider when choosing a forest definition for REDD+ include:

- Did a national definition exist already before REDD+?
- Should there be one national definition or can the definition vary sub-nationally?
- What parameters should be used to define forests?
- Should the definition maximize forest area?
- How does the selection of REDD+ activities affect the forest definition?

Forest definition is critical to the success of a national REDD+ program. Forest definition and historical reference period should be defined in collaboration with forest experts and remote sensing specialists. Typically, forest definitions (including national UNFCCC definitions) include minimum thresholds for crown area, tree height and land area. However, different definitions for forest can exist, and they should be assessed on a country by country basis. Further details on establishing a national definition of forest are given in Box 6.

To identify areas eligible for specific national scale REDD+ activities it is necessary to distinguish between areas of forest and non-forest within the country. This distinction requires a single consistent national definition of "forest" that is appropriate for local conditions. The forest definition should comply with any guidelines set-forth by the adopted REDD+ framework and consider remote sensing capabilities for detecting forest characteristics from satellite images. As future frameworks for crediting of REDD+ interventions will likely build on modalities already established under the UNFCCC, definitions used in the UNFCCC context that could be applied to REDD+ are a good starting point for establishing a national definition of "forest". Under the UNFCCC the definition of forest for a particular country includes all land with woody vegetation consistent with thresholds used to define 'Forest Land' in its national greenhouse gas inventory. Systems with vegetation structure that *in situ* could potentially reach threshold values used by a country to define Forest Land also qualify as forest if the predominant use is forest land.

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[32] Text from Decision 12/CP.17 on modalities and guidelines for RLs at COP 17 in Durban - "*provide information on the definition of forest used in the construction of forest RL/RELs and, if appropriate, in case there is a difference with the definition of forest used in the national greenhouse gas inventory or in reporting to other international organizations, an explanation of why and how the definition used in the construction of forest RL/RELs was chosen*."

Consistency in forest classifications for all REDD+ activities is critical for integrating different types of information, including forest inventory and remote sensing data, for establishing the RL and implementing the FCMS. The use of different definitions impacts the technical earth observation requirements and could influence cost, availability of data, and abilities to integrate and compare data through time. Furthermore, unresolved differences over forest definitions can significantly affect benefits and their distribution, representing a key barrier to implementation of REDD+. It is important that the national definition of forest remain consistent over time to allow for comparison.

Box 6. Factors in determining the forest definition

A forest definition includes threshold values for minimum level of crown cover, minimum height, and minimum area. The three thresholds agreed to in the Marrakesh Accords of the UNFCCC are: 10% - 30% for crown cover, 2 - 5 m for height, and 0.1 - 1 ha for minimum area. The definition should be appropriate for the specific ecological conditions and agree with the common perception of forest in the country. Under the Marrakesh Accords, Parties to the Kyoto Protocol select a single value of crown area, tree height and area to define forests from a range of values for implementation of CDM activities.

Deforestation is the long-term or permanent conversion of land from forested to non-forested. In practice this means a reduction in crown cover from above the threshold for a forest definition to below the threshold and a permanent change in the land use practice. For example, if the minimum level of crown cover in the national definition of forest is 30%, then deforestation would not occur in a given forested area until the crown cover in that area was reduced below this limit. If forest cover decreases below the threshold only temporarily due, for example, to logging and the forest is expected to regrow the crown cover to above threshold, then this decrease is not considered deforestation. Deforestation implies both a change in land cover *and* land use. Common changes include: conversion of forests to annual cropland, conversion to perennial plants (oil palm, pastures, shrubs), conversion to agricultural land through shifting cultivation, and conversion to urban lands or other human infrastructure.[33] Under the IPCC framework deforestation is included in the category of “forests converted to other land uses”.

The IPCC 2003 special report[34] suggested that degradation can be characterized as direct human-induced, long-term loss (persisting for X years or more) of at least Y% of forest carbon stocks (and forest values) since time T and not qualifying as deforestation. (The values for X and Y still need to be defined to make this definition operational.) Thus degradation represents a direct human-induced decrease in carbon stocks with measured canopy cover remaining above the threshold for the definition of forest and with no change in land use. Under the IPCC framework degradation is included in the category of “forests remaining forests”.

Figure 7 illustrates the relationship between the forest definition and implications for measuring and monitoring for two scenarios. With a forest definition that includes a threshold value for canopy cover of 30%, any disturbance that reduces canopy cover from 80% to 20% qualifies as deforestation and is monitored and registered as such. With a threshold value of 15% canopy cover, a reduction of canopy cover from 80% to 20% would qualify as *degradation*, not deforestation. However, reduction in canopy cover from 20% to 10% would qualify as deforestation. The quantity of potential avoided emissions generated under these two scenarios is different as devegetation – removal of vegetation in a

[33] GOFC-GOLD, 2009
[34] Entitled: “Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types”.

nonforest area – is not considered under REDD+. The implications for measuring and monitoring approaches would be different for the two threshold canopy cover values. In the first scenario, measuring and monitoring methods would be focused on measuring the extent of deforestation and associated emissions, while in the second scenario measuring and monitoring would be focused on detecting and measuring forest degradation as well. In reality, monitoring of degradation may be limited by technical capacity to detect and measure its impacts.

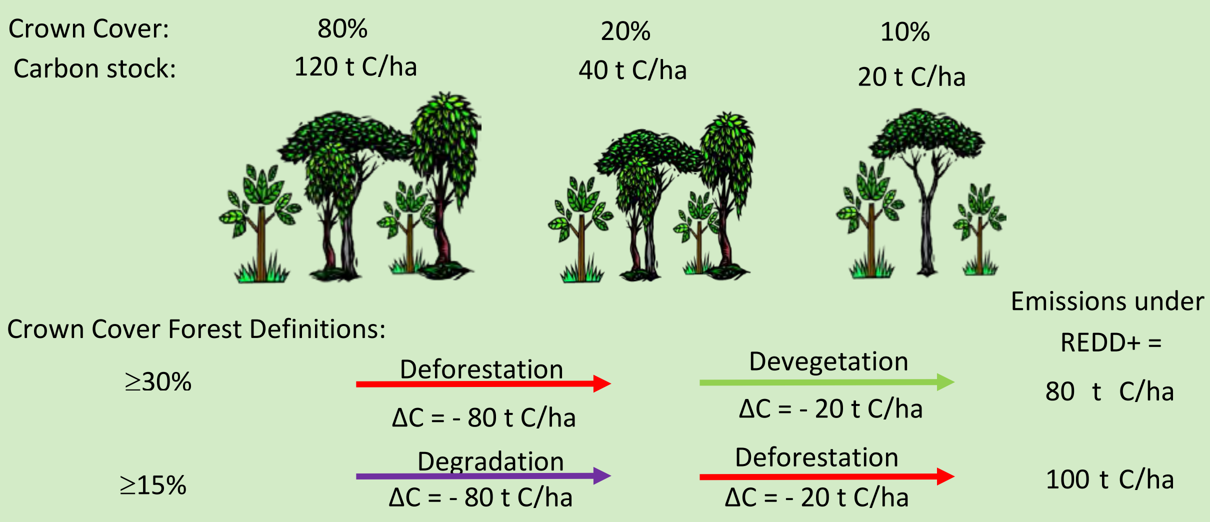


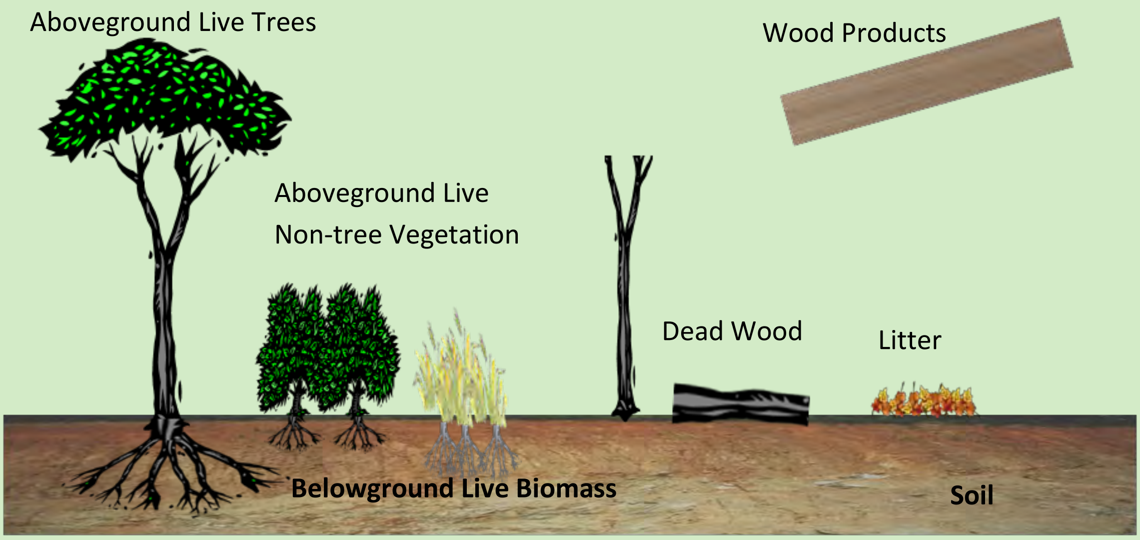
Figure 7. Illustration of the relationship between the forest definition and measuring and monitoring for deforestation and forest degradation **(taken from: Harris, N, Pearson, T, Brown, S. 2012. *Decision support tool for developing reference levels for REDD+*. Report prepared by Winrock International for the World Bank's Forest Carbon Partnership Facility.)**

3.4 Determine Pools/Gases

The Durban SBSTA[35] text indicates that Parties should give reasons for omitting a pool or a gas from the construction of forest RL and that significant pools and gases should not be excluded. The selection of pools is based on the expected magnitude of the change in stock in a given pool as a result of deforestation or degradation as well as the resources required to collect accurate and precise data. Box 7 below describes each of the terrestrial carbon pools.

[35] 35th session of the Subsidiary Body for Scientific and Technological Advice, Durban, 2011

Box 7. Description of various terrestrial carbon pools



Aboveground Live Trees: The biomass and carbon stocks of live trees, with a defined minimum DBH (commonly >10 cm) are estimated using appropriate equations applied to the tree measurements. For practical purposes, tree biomass is often estimated from equations that relate biomass to, for example, DBH, DBH and height, or DBH and wood density.

Aboveground Non-Tree Vegetation: Mature forests generally contain an insignificant amount of undergrowth (<3% of aboveground biomass in trees), thus for REDD-related activities it does not make too much sense to measure this pool. For non-forest strata, a variety of destructive and non-destructive sampling methods can be used.

Live Belowground (Roots): For most forest and non-forest strata, root biomass can be estimated using standard relationships with aboveground live biomass. Direct field measurements of roots are resource intensive and the IPCC relationships are acceptable.

Standing and Lying Dead Wood: This pool generally includes dead wood with a diameter of ≥10 cm, and can represent a significant quantity of biomass carbon, thus it generally makes sense to measure this pool. Within plots delineated for live trees, standing dead trees are also measured and lying dead wood is most efficiently measured along the line-intersect method. The decomposition state (e.g. sound, intermediate and rotten), and thus density, of the dead wood is recorded.

Wood Products: Measurements to estimate the volume of wood extracted for wood products are needed if wood is harvested for commercial markets prior to or in the process of deforestation.

Forest Floor (Litter Layer): The forest floor, or litter layer, is defined as all dead organic surface material on top of the mineral soil, including small woody twigs and branches not considered to be coarse dead wood. It is collected from sample plots and dried and weighed.

Soil: If forests are converted to nonforest or vice versa, it is generally recommended to sample the soil. For other conversions soil C can be neglected as the change is likely to be zero or very small.

The decision on whether to include non-CO_2 GHGs such as methane (CH_4) and nitrous oxide (N_2O) released by biomass burning in forest fires or from fertilizer use will depend on the whether sources of non-CO_2 GHGs significantly contribute to emissions from forests within the country. A quantitative analysis of non-CO_2 emissions from forests sources should be completed to determine which sources to include or exclude from accounting from REDD+.

3.5 REDD+ Linkages to Forest Inventories

Many tropical countries have performed national to subnational forest inventories in the past usually for estimating the quantity of commercial timber. The design of these inventories is statistically sound and provides for systematically sampling across the forest areas, and the data collected can be used for estimating carbon stocks of the aboveground biomass[36]. Where an inventory system has been in place and monitored over time, the compatibility of goals and statistical sampling design for historical emission estimation and emission factor development will need to be evaluated. The data and measurements collected from existing forest monitoring systems may or may not line-up with the information required for a national REDD+ program. For example, the sampling design of timber inventories may not include all tree species or all small smaller diameter trees (e.g. down to 10 cm DBH) for estimating forest carbon stocks. In addition, depending on historical deforestation, and needed forest stratification, the existing plot network may not provide estimates with high level of precision acceptable for REDD+ applications or may be more expensive to monitor rather than focusing directly on areas under threat of deforestation/degradation.

Regardless of whether the existing forest inventory system will be used for the future FCMS, it is recommended that the existing data be examined for potential forest stratification, emission factor estimation, and to assist in creating historical activity data.

3.6 RL Adjustment for National Circumstances

As stated previously, when projecting historical emissions into the future, national socio-economic and environmental circumstances may result in an adjustment to the RL. This must be justifiable given the actual situation in the country, including laws, area of remaining forests, population trends, development plans, and recent political or economic history compared to the future. Three overall potential options for adjusting to national circumstances include:

1. A direct correlation with historical emissions.
   Decisions still will need to be made regarding how to project emissions into the future, including whether an average rate is applied or emissions are projected linearly into the future and whether a spatial analysis will be applied;
2. A statistical association of emissions with national data on socio-economic factors;

[36] Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, FAO, Rome Italy.

3. A third party analysis of how the implementation of new policies and programs would affect future emissions

The decision of which approach to use depends on whether or not historical trends are evident and justifiable, and which factors, if any, can justifiably be used to adjust the historical RL.

3.7 Potential Inclusion of a Spatial Location Analysis

A location analysis identifies areas within a country where emissions or removals are projected to likely occur in any given year in the future past on past trends (Figure 8). This can be useful for reducing uncertainty in estimates of emissions from deforestation, planning strategic sampling of forest carbon stocks, and developing effective policies and plans to mitigate the direct and indirect causes of deforestation in areas under the greatest threat of conversion. It may be used during the creation of the reference level.

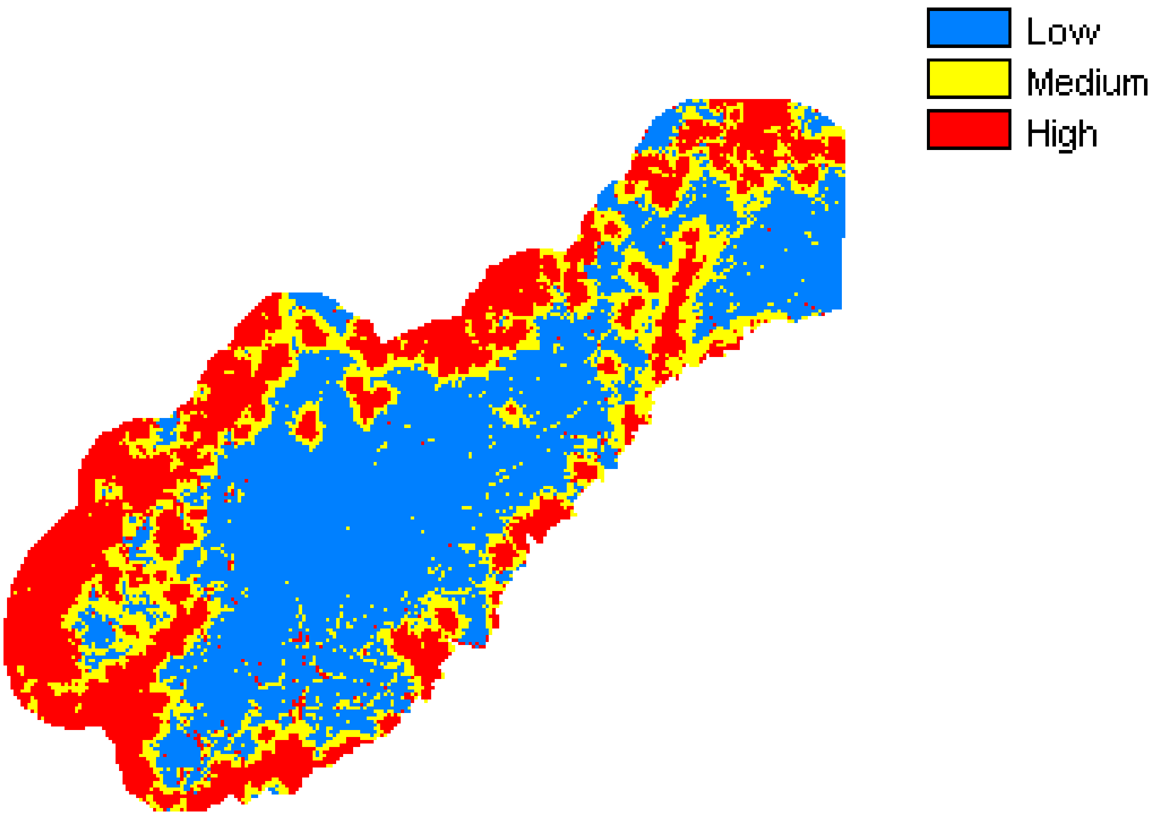


Figure 8. An example of a map displaying the potential for future deforestation, displayed in three classes from low to high potential for change, developed through spatial modeling of historical land cover change and factors associated with deforestation (such as roads, rivers, elevation, slope, populated places, etc.) See Annex II for more details.

Analysis of historical data allows for the calculation of a rate of deforestation, and this information can be used to extrapolate a future deforestation rate. However, the projected rate cannot be applied broadly to any selected area of forest and used to project future emissions if forest carbon stocks vary

significantly across the landscape. For deforestation, estimates of emissions per unit area are relatively large; thus potential for errors in the projected emissions estimate is also large if emissions are incorrectly projected to occur in areas under no threat of deforestation.

A location analysis that projects likely areas of future deforestation within a country can be performed using different modeling techniques and at different spatial scales. A location analysis will include examining how spatial factors (such as roads, settlements, rivers, land under different management practices, elevation, etc.) potentially contribute to historical deforestation patterns. A location analysis can be useful for projecting broad areas or "zones" where emission reduction efforts could be targeted, or can be used in a more detailed manner to project specific pixels of future deforestation.

Modeling deforestation threat or "location analysis" is a complex task requiring specific software, skills and knowledge of how different spatial factors could be combined to project deforestation and modeling expertise. Different spatial models should be evaluated for mapping deforestation threat based on following criteria: accuracy in the validation stage, simplicity, transparency and ease of use. More information on spatial location analysis can be found in Annex II.

Even if a location analysis will not be used for the purpose of projecting specific pixels of future deforestation, a broad location analysis during the forest carbon stock stratification and sampling process may be conducted to identify areas under high deforestation threat. This allows a targeted sampling plan to be established, with the high threat stratum sampled first to a high level of accuracy and precision. Medium and low threat strata can then be sampled at a later stage. Furthermore, by knowing what forest area is projected to be deforested or degraded and what are the most important drivers of land use and land use change in that area, policies and interventions can be strategically designed to effectively target the causes of emissions from these forests.

CHAPTER 4: TECHNICAL COMPONENTS OF DEVELOPING A REFERENCE LEVEL

As stated previously in this manual, two basic inputs are needed to estimate emissions and removals of GHGs associated with land use change: activity data and emission factors. “Activity data” refer to the quantity of an activity that results in emissions/removals, such as area of land deforested or volume of timber removed. “Emission factors” are the estimated amount of emissions or removals of GHGs per unit of activity, such as tons of carbon emitted per unit area deforested or volume of timber removed. Emission factors will be combined with activity data in the FCMS to estimate total historic and future emissions and removals from deforestation, degradation, and enhancements.

The development of the RL can be broken down into steps by the main activity data types (Figure 9). For deforestation, degradation, and enhancements strong interactions will be required between the staff developing the activity data and those developing emissions factors. Often steps will be iterative, as additional information is developed and data are refined. For example, the final forest types and forest strata used will require feedback between entities working on the land cover mapping and those working on carbon stocks and emissions.

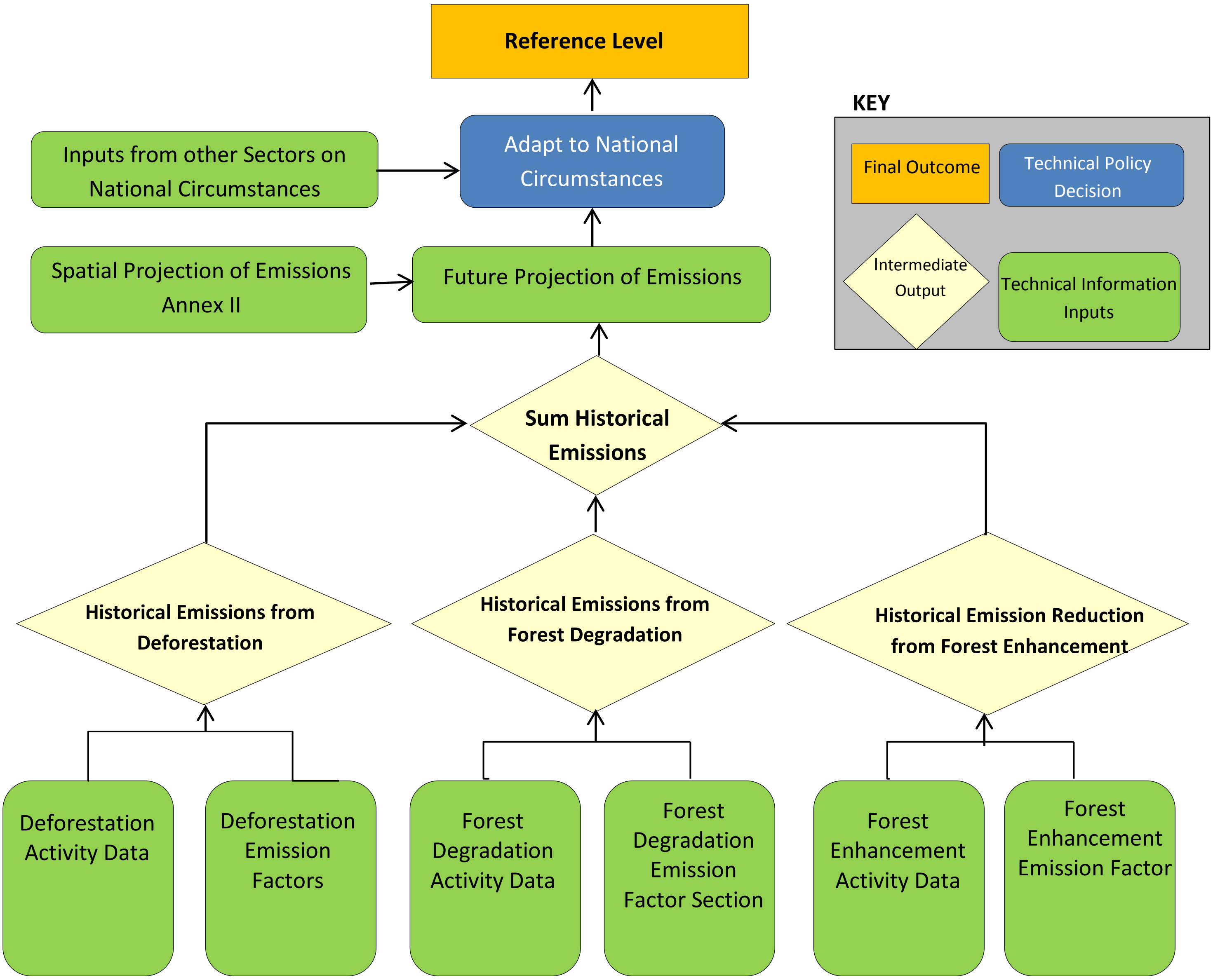


Figure 9. Components of needed to generate a Reference Level

The RS/GIS component to define activity data involves individuals who are responsible for the GIS maps and spatial analysis of land cover/land use (LC/LU) and change in LC/LU. These individuals are RS and GIS experts. Their maps and analysis will support the development of the FCMS, determine the historical LC/LU change rate, and through the use of satellite imagery monitor the changes in the extent of forest cover. These changes in extent of LC/LU will constitute the “activity data” required for the RL.

Developing emission factors involves individuals who will be responsible for the organization and implementation of activities to measure and monitor forest carbon stocks. This group is generally made up of scientists, statisticians and forestry experts. Their work will be used to estimate emissions and removals of greenhouse gases associated with deforestation, forest degradation, and activities that enhance forest carbon stocks to establish emission factors. These “emission factors” will be combined with activity data from the GIS/RS component in the FCMS to feed into the RL and MRV system.

This section focusses on estimating historical emissions that is the key component of a RL. The FCMS is the system that is used to obtain: the activity data, the carbon stocks data for estimating emission factors, and the total net emissions from combining the activity data and emission factors. An uncertainty analysis of all the data is also part of the FCMS.

4.1 Activity Data Development

The IPCC Guidelines describe three different Approaches for representing the activity data, or the change in area of different land categories. Approach 1 identifies the total area for each land category - typically from non-spatial country statistics - but does not provide information on the nature and area of conversions between land uses, i.e. it only provides "net" area changes (i.e. deforestation minus forestation) and thus is not suitable for REDD. Approach 2 involves tracking of land conversions between categories, resulting in a non-spatially explicit land-use conversion matrix. Approach 3 extends Approach 2 by using spatially explicit land conversion information, derived from sampling or wall-to-wall mapping techniques. Under a REDD+ mechanism, land use changes will need to be identifiable and traceable in the future, i.e. it is likely that only Approach 3 can be used for REDD+ implementation. While both Approaches 2 and 3 give gross-net changes among land categories, only Approach 3 will give estimates of gross-net changes within a category, i.e. will detect a deforestation event followed by an afforestation event. This change detection within a category is not possible with Approach 2 unless detailed supplementary information is provided.

Earth observation satellites have been orbiting the Earth, providing continuous coverage since the 1970s with their number increasing over the years. Currently, more than 10 countries[37] have developed, alone or in collaboration, optical or active satellite systems that observe the Earth every day collecting information from sub-meter to kilometers of ground unit within visible to microwave wavelength range.

Satellite images have been used to monitor changes in forest cover since the 1990s. New methods and techniques have been developed for assessing and monitoring the forest dynamics, allowing for accurate estimation for activity data. For example, countries such as India and Brazil have developed systems for monitoring their forests for more than a decade. The first Forest Survey of India (1987) assessed the forest cover from Landsat-MSS for 1981-1983. Since then, using data from the Indian Remote Sensing Satellite (IRS), India has created forest cover maps every 2 years with improvements in resolution from 80m to 23.5m. Another example is Brazil, where the Amazonian forest has been monitored by satellites since 1997/98 using Landsat imagery. In addition, improvements in remote sensing technology and techniques allow for forest mapping and monitoring at the national and sub-national level.

Activity data for RLs will be developed using spatial datasets and expertise along with non-spatial data. Land cover maps from several intervals in the past will need to be defined, thereby establishing historical land cover changes (especially forest cover changes) and *benchmark map*. The "benchmark

[37]Countries that have satellite systems in place are: Belgium, China, Germany, France, India, Italy, Japan, Russia, Sweden, and USA

map" is the land cover map from which all future activity data will be measured. The benchmark map is the extent of forest and other land cover classes at a pre-determined start year. All future activity is measured against the benchmark map to establish emissions/reduction in relation to the BAU scenario. Guidance is provided on the steps needed to develop historical deforestation, degradation, and enhancement activity data.

An assessment should be conducted to determine the main types of activities, i.e. drivers, that result in deforestation and degradation. A decision should then be made on the criteria for listing an action as deforestation and when that action will need to be considered a degradation event. This will be based on the definition of 'forest' that the country has defined. For example, some actions may result in a clearing of forest, but there may be instances where the size of each clearing may be below the forest definition threshold. This could include actions such as some forms of shifting cultivation, small scale mining, road construction, and natural disturbances such as fire, mudslides, tornados, and strong tropical storms (cyclones or typhoons).

Because the GIS/RS field is relatively new compared to standard field based forestry activities, it is important that the current GIS and RS capacity in the country is carefully evaluated. If a country does not possess the GIS and RS capacity at government level, steps toward building this capacity, including help from local or international consultants, should be taken. This means that in some cases the government might decide to work with expert consultants who work independently and/ or with designated government personnel to create the activity data for the REDD+ program, while building capacity at government level. In other cases, the country might decide to outsource the GIS and RS tasks to local or international independent consultant without building these capacities within its own governmental structure.

The following sections describe the type of analysis that need to be done to estimate activity data for deforestation, forest degradation and carbon stock enhancement activities under a national or sub-national REDD+ program.

4.1.1 Activity Data for Deforestation

The historical deforestation rate is calculated as the loss in area of forest to non-forest. When forest is converted to non-forest (e.g. to croplands or urban development) this is associated with emissions of CO_2 and other GHG into the atmosphere. The activity data for deforestation refers to the historical area of deforestation (deforestation rate). The deforestation rate projected into the future is referred to as the Business as Usual (BAU) deforestation scenario. The BAU is what is expected to have happened had a REDD+ program never been established.

To estimate the amount of deforestation that has occurred historically, generally a series of land cover maps are developed. The latest of the maps will serve as the "benchmark map" from which all future activity data will be measured.

A stepwise approach for identifying historical activity data and creating the benchmark map is presented in Figure 10 and then described in detail.

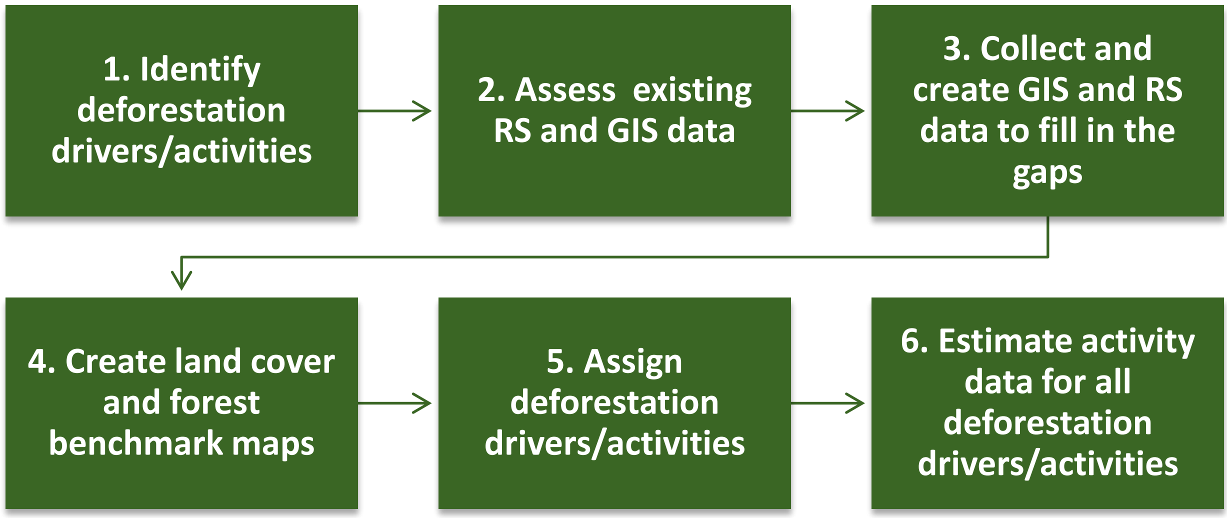


Figure 10. Steps to estimate historical deforestation activity data and create a benchmark map

Step 1: Identify deforestation activities

An analysis will need to take place to determine the deforestation activities that will be assessed. This is based on the causes/drivers of deforestation and the agents of deforestation. Both spatial and non-spatial data should be used. These types must be discrete and mutually exclusive. For example, deforestation may be caused by a natural disturbance, licensed commercial agricultural expansion, non-licensed small holder agriculture, mining construction, etc. The list of deforestation activities will need to include the types of deforestation that have taken place at different times across the historical reference period.

Step 2: Assess existing RS and GIS data

Many types of deforestation activities can be correlated with spatial data; therefore it will be important to catalog and assess existing data and its resolution/scale, development methods, data extent, accuracy, and historical time frame of the data.

The **resolution** of the land cover data (vector and raster) should be compatible to the minimum forest area defined in the country's forest definition. For example, if the forest definition of the minimum forest area is specified between 0.5 and 1.0 ha and the existing land cover maps are derived from satellite images such as Landsat (30m), SPOT (28.5m & 20m), DMC (32m), IRS-P2, LISS-II and AWIFS (23.5 & 56m), and CBERS-2 HRCCD (20m) (see Table 3), these maps will be able to detect change in forests that matches the size of the minimum forest area.

Land cover maps must be developed using scientifically accepted methods and standards. This means that the **methods** used for developing these maps should be based on peer reviewed methods.

Methods must also be verifiable and repeatable.[38] If land cover maps for various points in time already exist, the methods used must allow the maps to be compared. The land cover maps also need to be assessed for accuracy. No hard standards have yet been set for the accuracy requirement of a land cover maps used for REDD+, but suggestions that they achieve ≥85-90% accuracy have been proposed.[39]

Each country should decide the **historical reference period** for defining the RL, but the 2000 - 2010 time period is preferred as the quantity and quality of RS data for this period is readily and freely available and complementary data are likely more available. In addition, the 2000-2010 time-frame facilitates obtaining IPCC Tier 2 data for carbon stocks of forest lands that have undergone change, and improves the ability to include some emissions from degradation using statistical data and field measures. Spatial data from the selected historical reference period should be collected and assessed against the other assessment criteria. For example, if the historical reference period is defined with 2000, 2005 and 2010 time points, the existing road spatial data should coincide with these years, otherwise new road data should be created to match the years defined in the historical reference period. However, the country's recent history may impact the historical reference period used. For example, anomalies such as wars, major natural disasters, etc. may impact land use and land cover over a short period of time. It is recommended that the forest benchmark map be no older than one year from the beginning of the REDD+ program start date.

The GIS/RS data assessment can take the following steps in Figure 11.

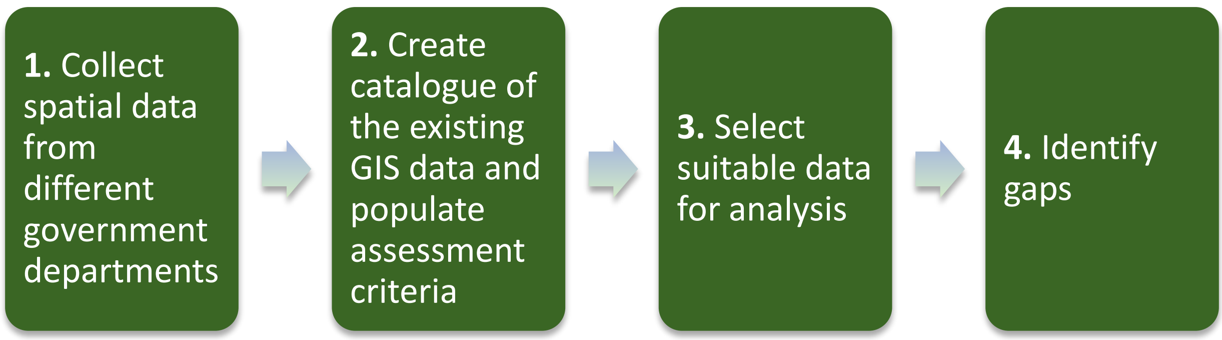


Figure 11. Specific steps in designing an assessment of GIS and RS data

Spatial analysis might include data for roads, rivers, towns, villages, topography, and land use designation/ownership (e.g. conservation land, logging concessions, private, public, protected areas, etc.), and more. All GIS data layers must have national coverage and be projected in the same coordinate system to allow for accurate spatial overlays and analysis.

Often these types of data are housed across government departments; therefore all potential government sectors will need to be approached to determine what data exist and how they may be useful in assessing both historical and potentially future emissions.

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[38] See Step 4 "Creating land cover maps."

[39] See "Perform accuracy assessments on landcover and benchmark maps, pg. 69."

A list of all available GIS and RS data should be compiled and catalogued including year, coverage, resolution/scale, accuracy assessment, and notes on the quality of the data (see Table 2 for example). Tables should be designed to allow for easy identification of (1) suitable data for further spatial analysis under RL development and (2) data gaps.

Table 2. Example of table used to catalogue GIS data in spatial data assessment

Name of the spatial dataset	Spatial extent/ resolution	Coordinate system	Metadata available	Temporal Information	Accuracy assessment	Source	Contact person
Administrative vector GIS data layer							
Transportation vector data							
River data							
Land cover/ land use vector data (be sure to include MMU)							
Land cover/ land use raster data							
Spatial Planning data							
Logging and other forest management vector GIS data							
Protected area non-spatial GIS data							
Ancillary spatial data							

Step 3: Collect and create GIS and RS data to fill in the gaps

If the existing land cover products do not satisfy the assessment requirements or there are none available, new remote sensing images should be obtained and interpreted following the requirements for year, methods and accuracy. All land cover maps across the country and for the historical reference period must be developed using a similar method and if possible the same or similar type of remote sensing data. Therefore, availability of satellite imagery should be assessed. Spatial, temporal and spectral resolution must be considered in this assessment. For the development of land cover maps, the satellite imagery must cover the entire country. The quality of the imagery should be assessed for its ability to accurately map different land cover types. For example if the imagery has considerable cloud cover (e.g. >10% of the area has clouds), or has other technical problems (e.g. striping in Landsat imagery) it may not be of good enough quality for accurate land cover mapping. If this is the case then multiple images for the same time period will need to be acquired and mosaicked.

To develop a national REDD+ program, remote sensing data and ancillary GIS data should be collected to address the key elements of developing an estimate of historical emissions. Any data that are not available at a national level with required quality must be created using GIS/RS techniques and standards.

Currently, RS data from optical, radar and Light Detection and Ranging (LiDAR) sensors are available for mapping forest cover and forest change. The data produced by optical sensors are dependent on the atmospheric conditions. Given the ranges in spatial, spectral and temporal resolution for optical sensors, not all data (satellite images) are appropriate for forest monitoring at a national and sub-national level (Table 3).

Table 3. Review of optical sensors according to the spatial resolution and to their appropriateness for forest monitoring under REDD+ initiative

Spatial resolution	Examples of current sensors	Appropriateness for forest monitoring	Cost
Coarse (250-1000 m)	SPOT-VGT, Terra-MODIS, Envisat-MERIS	Appropriate for identifying large clearings and locating "hot spots" at global and continental scale	Low or free
Medium (10-60 m)	Landsat TM or ETM+, Terra-ASTER, IRS AWiFs or LISS III,CBERS HRCCD, DMC, SPOT HRV	Proven appropriateness for mapping deforestation and estimating area change at small scale (project, sub-national and national)	low to medium ($0.02/km^2$ to $0.5/km^2$) for recent data (except Landsat, all of which are free)
High (Fine) (<5 m)	IKONOS, QuickBird, Aerial photos	Appropriate for validation of results from coarser resolution imagery, and training of algorithms	high, ($2 -30 /km^2$)

Cloud cover prevents frequent observations of cloudy areas (such as tropical forests) using optical satellite images. Therefore, the use of radar imagery is a promising method for monitoring forests that are under perpetual cloud cover. Combining different types of imagery (optical, lidar, radar) can enhance the accuracy of resulting land cover maps and, in some cases, estimates of biomass carbon stocks.[40] However, radar imagery (e.g. JERS) has only been available since about 2006. Because deforestation typically requires imagery to be at least 3 years apart, radar imagery is useful for documenting recent land cover changes but optical data will still be necessary for documenting land cover pre-2006.

Light Detection and Ranging (LiDAR) remote sensing technology has evolved in the last decades as a tool for measuring and understanding forest structure. The advantage of using LiDAR imagery for forestry applications is that it can provide information about forest structure and can therefore characterize features such as tree height, vertical distribution of the canopy, and crown volume. The use of LiDAR data by itself is not typically used for creating land cover maps, but combining forest

[40] Treuhaft R N, Law B E, Asner G P. 2004. Forest Attributes from Radar Interferometric Structure and its Fusion with Optical Remote Sensing. BioScience. (56):6

structure characteristics with other data can be useful for distinguishing among different forest types. These features are also being used to map forest biomass across large areas.[41]

The choice of RS data for use in a RL should be made considering the following factors:

Size and pattern of deforestation: Clearings for small agriculture practices and settlement establishment (0.5 -1 ha) require resolution of the remote sensing data in order of 10s of meters.[42]

Forest seasonality: Depending of the type of tropical forest, annual climatic variations should be considered when remote sensing data are acquired. In areas where forests are seasonal, data may need to be collected at multiple times of the year as deciduous forests without leaves can be mistaken as bare ground. Moist evergreen tropical forest could be observed during any time of the year and acquiring of images is more dependent on the cloud free data availability.

Cost of the data: Cost of data acquisition and processing should be considered. For a country where collection of medium resolution satellite images at the national scale is an expensive option, coarse resolution images (MODIS) could be collected and deforestation 'hot spot' mapping conducted. Once the deforestation 'hot spots' are identified medium resolution images could be collected and analyzed to reduce the cost of the data. However, all Landsat data are now available for free. However, given the potential magnitude of the financial rewards for REDD+ activities and projects, efforts should be made to acquire high resolution imagery (e.g. <10 m resolution) so that accuracy of interpretation is greatly enhanced—the cost of the imagery should not be a factor in this decision.

Ground truth data and high resolution images: All images interpreted for all time periods should be validated with either ground truth data or higher resolution images or aerial photographs to assess the accuracy of the created land cover/ forest cover maps. For historical period this can be problematic, and it will be necessary to assume that classification algorithms based on present-day ground truthing are applicable for the past times.

Technical capabilities and appropriate methods: The procedures of interpreting satellite images should be reproducible. Methods selected for interpreting satellite images should be well documented, standard operating procedures should be established, and accuracy assessment should be performed for all forest and land cover categories produced under national REDD+ program.

If ancillary GIS data such as roads, towns, rivers, topography and logging do not satisfy the assessment criteria or are not available for certain years of the historical reference period, these data sets should

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[41] Asner, G P. 2009. Tropical forest carbon assessment: integrated satellite and airborne mapping approach. Environmental Research Letters. (4):034009. Available online at: http://iopscience.iop.org/1748-9326/4/3/034009/fulltext

[42] Satellite images appropriate for detecting this size of clearings are Landsat (30m), SPOT (28.5m & 20m), DMC (32m), IRS-P2, LISS-II and AWIFS (23.5 & 56m), and CBERS-2 HRCCD (20m). Smaller clearing (<0.5) with more heterogeneous patters will require satellite images collected from sensors with higher resolution such as SPOT 5 (10m), Terra ASTER (15m).

be created using standard RS/ GIS methods. National land use designations, such as 'protected land' and 'production/development land,' will be another key datasets to consider. Other key datasets would be forest management plans for tree plantation that could be used to identify where reforestation activity happened and/or will happen. If these data exist only as paper maps, they should be digitized for the use in the analysis under RL.

Step 4: Create land cover and benchmark maps

The development of land cover maps for multiple points in time is essential for developing a RL under a national REDD+ program. The development of land cover maps from imagery can be broken into three components (Figure 12). A detailed description of land cover map creation is presented in Annex I.

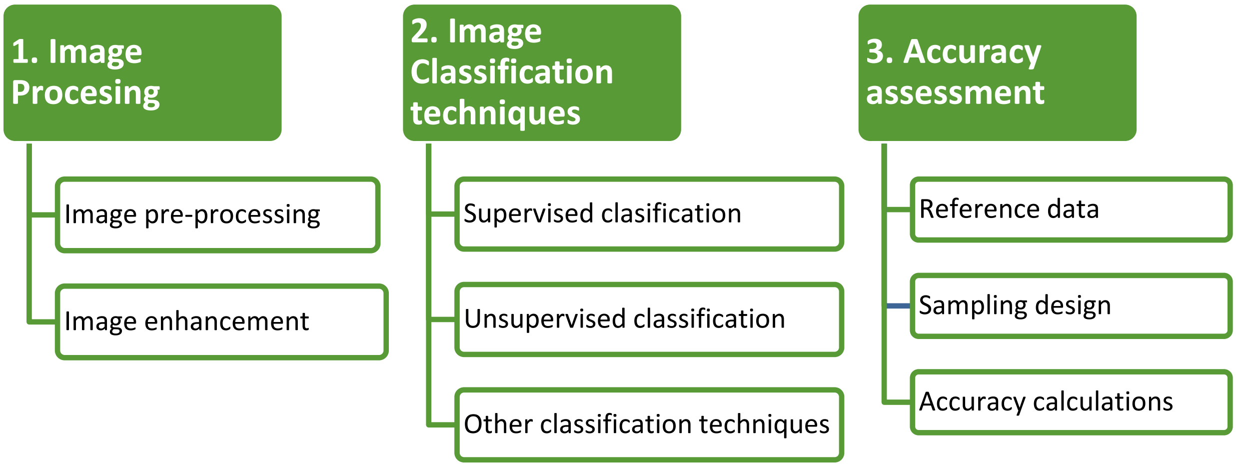

Figure 12. Components of land cover map development

Step 5: Assign deforestation activities

A list of deforestation activities will need to be finalized. Based on the land cover maps created, updates to the list of deforestation activities may need to be made.

All areas of deforestation that have taken place will need to be assigned to one deforestation activity. Both spatial data, such as land cover maps and GIS data, along with non-spatial data such as records of weather events and permits/concession documents will likely need to be used. Decision making rules will need to be created to classify all deforestation into a deforestation activity. These will be used by the GIS staff to provide objective, consistent, repeatable, and documented results.

Step 6: Estimate activity data for all deforestation types

The area deforested for each deforestation type should be calculated for each time period and for the total historical reference period. The deforestation can be annualized for each time period as well.

4.1.2 Activity Data for Forest Degradation

Activity data for degradation will depend on the specific degradation activities selected to be included in the historical emissions and reference level. Key components for estimating activity data for forest degradation are outline in Figure 13.

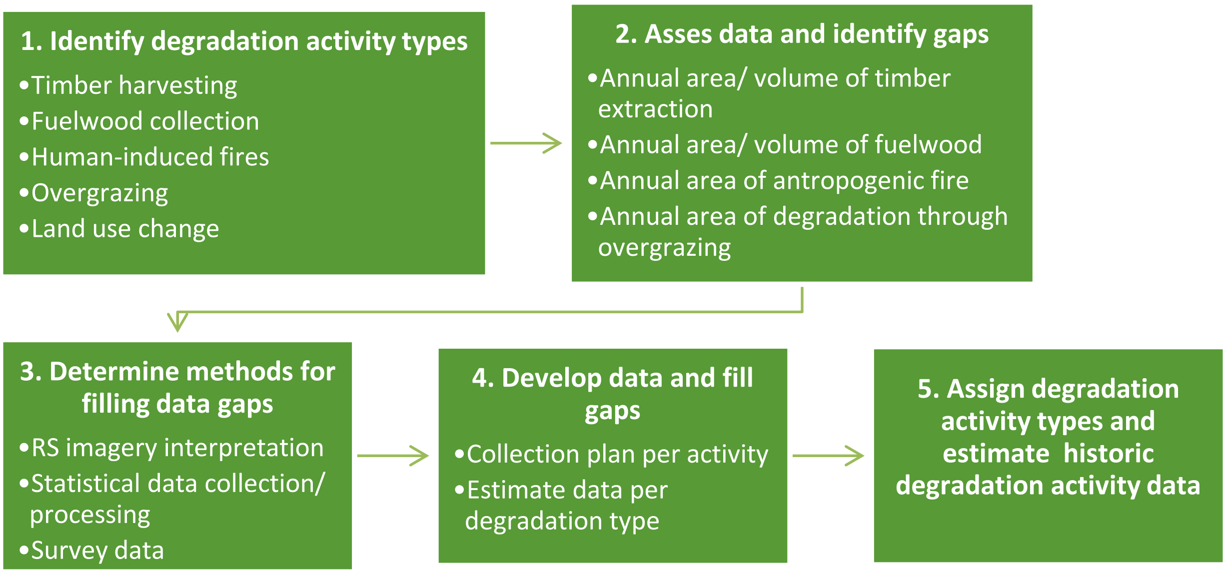

Figure 13. Key components for estimating activity data for forest degradation and examples of actions

Step 1: Identify Degradation Activities Types

Several potential sources of forest degradation may exist in a given country, each of which should be considered separately to determine whether potential emissions are significant to include in the RL, whether they can be included at reasonable cost, and whether there is a strong likelihood that interventions could be implemented to reduce such emissions. Examples of common sources of forest degradation are: legal timber harvesting, illegal timber harvesting, fuelwood collection, human induced fires, overgrazing and other land use changes. Such causes of degradation will need to be delineated into discrete and non-overlapping degradation activities.

Step 2: Assess existing data and identify data gaps

Both spatial and non-spatial data can be used to estimate historical degradation. Usually a historical assessment of degradation will be much less straightforward than estimating deforestation levels. In addition, different points in time may require different types of data to be used. Significant effort may be required to compile existing data that can be used to estimate degradation rates.

Existing data that can be used to estimate degradation will likely exist in many different formats across multiple government departments and the private sector. In areas where timber extraction takes place, both the government and timber companies may have both spatial and non-spatial documentation on things such as concession areas and volumes of timber extraction rates per year.

Studies may exist that can be used to estimate amounts of fuelwood extraction and forest degradation caused by anthropogenic fires or overgrazing.

Following this data analysis, data gaps will need to be identified for each degradation activity.

Step 3: Determine methods for filling data gaps

Methods for filling the data gaps may include interpretation of satellite imagery, statistical data compilation, or surveys. When interpretation of satellite imagery is selected as a method of filling degradation data gaps, the complex spectral signature of degraded forest (mixture of soil, vegetation, trees and dead wood), and intensity and scale of forest disturbance (e.g. illegal logging and presence of the built infrastructure such as roads) should be considered.

Methods for mapping forest degradation range from visual interpretation (using multiple scenes) to highly complex automated algorithms. Most of these techniques do not distinguish between natural and anthropogenic forest changes and the classification or segmentation rules are location dependent.

More recently advanced approaches of detecting forest disturbance include the Carnegie Landsat Analysis System (CLAS), which maps selective logging[43,44] and CLASlite,[45] which maps forest cover, deforestation and disturbance using a satellite images such as Landsat, ASTER, MODIS and SPOT.[46] Both approaches may be appropriate for defining forest degradation at national and sub-national level under RL scenario.

The reduction of carbon stocks from selective logging (legal and illegal) can be detected from high resolution images (e.g. IKONOS, aerial images or similar), while the extent of large scale logging activities can be monitored using Landsat or other medium resolution satellite images.

Forest degradation due to anthropogenic forest fire for the application in national and sub-national REDD+ program is constrained to identification of post fire burned areas and fire characteristics (e.g. fire severity, energy released). Burned area detection requires Satellite images at fine and moderate resolution to be used. Although still being used at research stage SAR radar data can complement optical data in places with constant cloud cover to identify burned areas. They may be identifiable using the medium resolution images.[47]

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[43] Asner G. P., Knapp D.E., Broadbent E. N., Oliveira R.J.C., Keller M., Silva J. N. M. 2005. Selective logging in the Brazilian Amazon. Science 310 480-2

[44] Asner G.P., Broadbent E. N., Oliveira P.J., Keller M., Knapp D.E., Silva J. N. M. 2006. Condition and fate of logged forests in the Brazilian Amazon. Proceedings of the National Academy of Science. USA 103 12947-50

[45] http://claslite.ciw.edu/en/index.html

[46] Asner G. P., Knapp D. E., Balaji A., Paez-Acosta G. 2009.Automated mapping of tropical deforestation and forest degradation: CLASlite. Journal of Applied Remote Sensing, Vol.3, 033543

[47] GOFC-GOLD, 2011, A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation.

Because of complexity and scale of forest degradation there are no clear steps for how to use GIS and RS for accurate detection of forest degradation. However there are some preliminary steps that can be taken to assess if forest degradation can be identified.

1. Identify what data can be used to indicate degradation. For example, identify logging roads or gaps in the canopy where trees have been felled.
2. Define the necessary spatial resolution for the identification of the degradation activity. Thirty meter resolution Landsat data are unlikely to be able to detect 10, 20, or even 30 meter canopy gaps. Higher resolution imagery may be needed.
3. Conduct an experiment on an area where there is known to be forest degradation using the appropriate resolution imagery. Using field data and GPS unit assess and locate areas of forest degradation. Analyze those areas of forest degradation in the imagery and attempt to develop a unique spectral identification for areas that have undergone forest degradation.

In some cases, statistical data on volume of timber extraction may exist. The format of the data may allow for direct use or additional data processing and analysis might be needed to convert the volume data to annual area of timber extraction. For a fuelwood collection degradation activity, statistical data may not exist, but surveys can be design to get a better understanding of annual area affected by fuelwood extraction.

Step 4: Assign degradation activities and estimate historical degradation activity data

The forest area degraded for each degradation type should be calculated for each historical reference period and for the total historical reference period. The forest degradation area can be annualized for each time period as well.

4.1.3 Activity Data for Forest Carbon Stock Enhancement

Increase of forest area occurs for a variety of reasons, including for example direct tree planting, recovery from fire, natural forest regrowth, or fallow periods in the shifting cultivation cycle. Key components for estimating activity data for forest carbon stock enhancement are outlined in Figure 14.

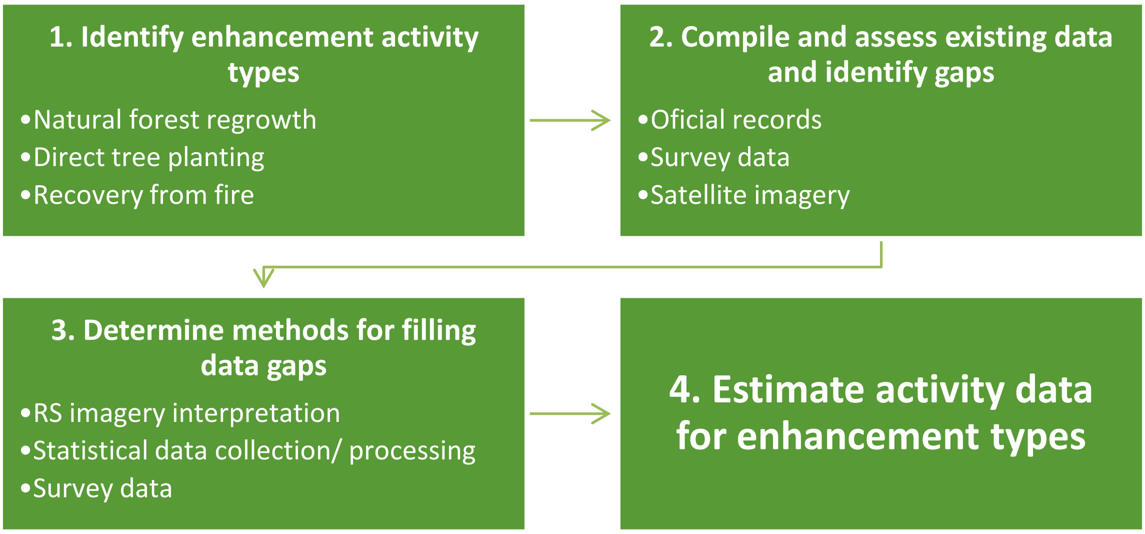

Figure 14. Key components for estimating activity data for forest carbon stock enhancement

Using satellite imagery to detect historical increase of forest cover is more difficult than detecting decrease in forest cover, because increases in forest cover usually occur slowly and cannot be easily detected after only a few years of growth. Therefore, using RS products alone, new forest growth often goes undetected for sufficiently long periods of time. This can lead to errors in the estimate of enhancement areas. Reduction in errors will require leaving sufficient time between land cover mapping events or combining mapping efforts with nonspatial data, such as official records and survey data. The same RS methods used for detecting forest cover and land cover change should be used to detect increases in forest cover from remote sensing. These methods include image classification, spatial mixture analysis and vegetation indexes.

Evolving technologies, including LIDAR and hyprospectral images can be used in combination with optical images to delineate plantation or natural regeneration by using long time-series data. If actual locations of plantations are not available, plantations can be mapped through automatic remote sensing techniques due to the spatial pattern of equal spacing between the trees or by cycles of clearing and/or harvesting and planting. Activity data can be estimated based on official records and survey data as well.

To assist with the identification of historical enhancements both GIS and nonspatial data will need to be compiled and assessed. Where necessary, field verifications may need to take place.

4.2 Emission Factor Development

Emissions/removals resulting from activities that result in land cover and sometimes land use change are usually expressed based on the emissions per unit area of change, specifically tonnes of carbon dioxide per hectare (t CO_2e ha^{-1}). For those emissions/removals that occur overtime in one location, for example, enhancement through tree planting, emissions will also include a temporal component (t CO_2e ha^{-1} yr^{-1}). Alternatively, the amount of emissions resulting from some activities will be more

appropriately estimated based on not area but another unit of measure, e.g., per unit volume of timber extracted, per tons of fertilizer applied, and per quantity of fossil fuel consumed.

There are two different but equally valid ways to estimate emissions factors: (1) the gain-loss approach, in which the net balance of additions to and removals from a carbon pool is estimated; and (2) the stock-difference approach, in which the difference in carbon stocks caused by a change in forest cover is estimated (Table 4).

The distinction between these two approaches is a critical concept to understand before sampling design considerations in a REDD+ context can be discussed. When estimating emission factors for deforestation and afforestation/reforestation, the stock-change method is most appropriate because carbon stocks can be obtained both before and after the events. When estimating emission factors for forest degradation or enhancement of carbon stocks in existing forests, the gain-loss method may be more appropriate.

Table 4. Main features of the two methods for estimating emission factors.

	Stock-Change	Gain-Loss
Definition	Difference in C stocks in a particular pool in pre- and post-forest cover change	Net balance of additions to and removals from a carbon pool
Data requirements	Data needed on forest carbon stocks in key pools and fate of carbon after conversion	Annual data needed on C losses associated with tree harvest (e.g. felled tree and collateral damage in gap and from skid trails), and gains such as annual rates of forest growth post-harvest
Applications	Most appropriate for avoided deforestation and afforestation/ reforestation	Most appropriate for forest degradation caused by tree harvest and enhancement of carbon stocks in existing forests

The steps for developing emission factors for deforestation, forest degradation, and enhancement of forest carbon stocks are described in detail in the following sections. In some locations one emission factor will be used for each activity for the entire historical period and for future monitoring events while in other locations the emission factors may change or be updated over time. For example, an emission factor that was developed for a mature, unlogged forest will need to be reassessed if the forest experiences degradation.

4.2.1 Emission Factors for Deforestation

The overall steps in developing emission factors for deforestation and degradation by each driver identified (and for which activity data produced, cf. section 4.1.1), shown in Figure 15, are described in detail in the following sections.

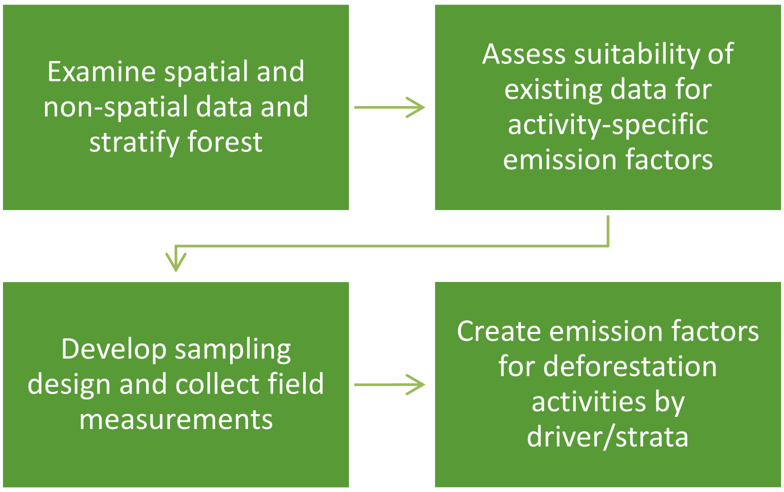

Figure 15. Steps in development of emission factors for deforestation by drivers and strata.

Step 1: Examine spatial and non-spatial data and stratify forested areas

To develop emission factors for deforestation using the stock-difference approach, both forest carbon stocks and carbon stocks of post-deforestation land cover classes must be known. Forest carbon stocks will not be homogenous within a country, that is to say, forest carbon stocks will vary by forest type and ecological regions depending on physical factors such as soil type, vegetation type, precipitation, elevation, slope and aspect, drainage, disturbance history, rural population density, distance to transportation networks or settlements, distance to deforested land or forest edge, and other factors.[48] Associating a given area of deforestation with a specific carbon stock that is relevant to the location that is deforested will result in more accurate and precise estimates of carbon emissions. It is important to note that certain factors that are relevant for other biological inventories, such as fine-scale species compositions or ecological variables, may not have a significant impact on forest carbon stocks. Therefore a key first step in developing emission factors is to stratify the forest taking into account the variations in carbon stocks across forest types. Because emission factors will be linked to different drivers as reported by the activity data, drivers of forest change are considered in stratification.

Stratification is the delineation of all land into discrete groups or 'strata' based on a common attribute – in this case, average carbon stocks. Stratification by carbon stocks is used to decrease the resources required to estimate the carbon stocks with a specific level of precision. It does so because there is a

[48] GOFC-GOLD, 2009

smaller variation in carbon stocks within each stratum in comparison to the variation across all strata in the area. Stratification is a key step in designing a forest carbon monitoring system (FCMS) as it ensures optimal use of resources and higher certainty in the carbon stocks of relevant forest classes.

Stratification of forestland for national carbon accounting will require coordination with the team responsible for GIS/RS components of the RL and FCMS. It is highly recommended that this coordination of forest land cover types take place prior to final land cover classes being determined and used to create land cover maps.

In addition to quantifying land use change and creating emission factors to estimate historical emissions, emission factors must be developed to estimate emissions from future land use change. However, deforestation is generally not uniform across the country. Some locations are more likely than others to undergo land use change. In areas where large areas of forest still exist, geospatial modeling can be used to project what areas will likely be deforested in the future under a BAU scenario. This can assist in prioritization of forest strata and locations where field measurements will take place. In addition, by knowing what forest area is projected to be deforested and what the most important drivers of land use change are in that area, policies and interventions can be strategically designed to effectively target the causes of emissions from forests. Details on conducting geospatial modeling of future deforestation are presented in Annex II.

Stratification criteria should include both *ecological considerations* that affect how much carbon is contained within a given area of land as well as *human pressure considerations* related to how the land is being used (and how it will be used in the future). For example, all lands of similar carbon stocks under similarly high pressure of future deforestation could be grouped into one stratum, and other lands that are of similar carbon stocks but under little to no pressure into a separate stratum. In this way, resources can be optimized so that sampling intensity is greater (thus precision is higher) in the areas most likely to undergo change in the future. For some countries it is inefficient and unrealistic to measure all of the forested areas across the country; therefore it is reasonable to focus on specific areas of interest—that is those areas (strata) that are most likely to experience change (deforestation or forest degradation) in next 10 years or so.

Step 2: Compile existing carbon stock inventory data and assess suitability

As a critical step in developing emission factors, forest inventory data collected previously should be evaluated against criteria of age (e.g. more or less than 10 years ago), accuracy/precision targets, and spatial coverage of measurements[49]. Data for estimating forest carbon stocks may be obtained from existing carbon stock inventories, timber inventories, and scientific studies. After the inventory of existing data is completed, data gaps should be identified to inform the design and implementation of the measurement plan.

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[49] Pearson, T, Harris N, Shoch D, and Brown S. 2010, Estimation of aboveground carbon stocks. In GOFC-GOLD, A sourcebook of methods and procedures for monitoring, measuring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. GOFC-GOLD Report version COP16-1, Ch. 2.3 (GOFC-GOLD Project Office, Natural Resources Canada, Alberta, Canada).

Existing data that meet high standards could be used for both estimating historical emissions and emissions under a future monitoring plan. Previously collected data could serve a valuable role in creation of emission factors. These existing data may include forest inventories, past scientific studies, or location specific data collection. A thorough evaluation should be conducted to determine what field measurements have previously been taken and how they can be used. Figure 16 outlines the overall steps for compiling and assessing existing forest carbon stock data.

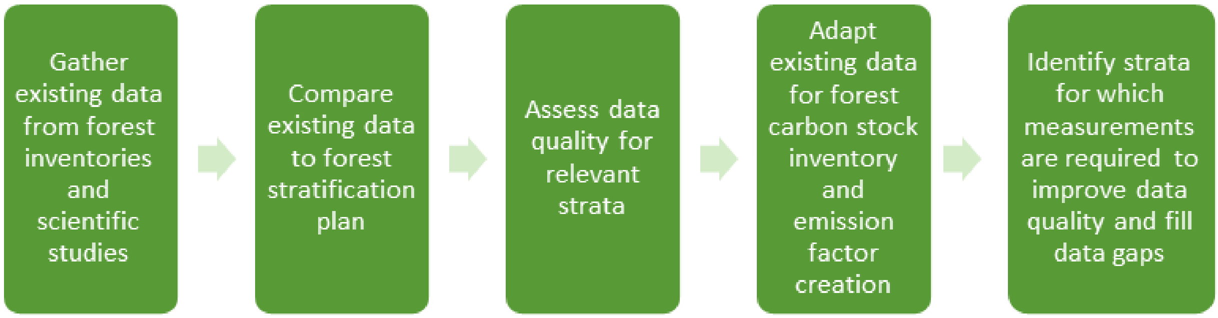

Figure 16. Steps for compiling, assessing, and integrating existing data of forest carbon stocks for developing emission factors for deforestation

For data to be used in the creation of emissions factors, the existing data should fulfill the following criteria: they are less than 10 years old, they are derived from multiple measurement plots, they include all tree species in the inventories, they are sampled from good coverage of the strata over which they will be extrapolated, and they attain acceptable levels of uncertainty.[50] There is no definitive guidance at present from the IPCC on an acceptable level of uncertainty. However, it is generally accepted that a 95% confidence interval (CI) be calculated and that the 95% CI be about 10-15% of the mean across all relevant carbon pools.

Ideally, data from existing forest inventories should include all trees with a minimum dbh of 10 cm or less. However, this is often not the case and methods for deriving values for smaller size classes with information in truncated stand tables is described in Box 8.

If existing data do not meet the above criteria, it should still be mined for important information. Such data can be used to help determine appropriate strata and the variability of carbon stocks in a given stratum.

[50] Pearson, T, Harris N, Shoch D, and Brown S. 2010, Estimation of aboveground carbon stocks. In GOFC-GOLD, A sourcebook of methods and procedures for monitoring, measuring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. GOFC-GOLD Report version COP16-1, Ch. 2.3 (GOFC-GOLD Project Office, Natural Resources Canada, Alberta, Canada).

Box 8. Incorporating existing forest inventory data[51]

Stand tables - Stand table data from a traditional forest inventory can provide useful data for the estimating tree carbon stocks. Generally, stand tables include a count of all trees in a series of diameter classes. The method for converting stand table data to carbon stock data basically involves estimating the biomass per average tree of each diameter (DBH) class of the stand table, multiplied by the number of trees in the class, and summing across all classes. The mid-point diameter of the class can be used to compute biomass using appropriate allometric biomass regression equations. However, for the open-ended largest diameter classes it is not obvious what diameter to assign that class. Sometimes additional information that allows educated estimates is available, but this is not always so. It is generally conservative to assume the same width of the diameter class and take the midpoint, for example if the highest class is >110 cm and the other classes are in 10 cm widths, then the midpoint to apply to the highest classes should be 115 cm.

It is important that the diameter classes are not overly large so as to decrease how representative the average tree biomass is for that class. Generally the rule should be that the width of diameter classes should not exceed 15 cm.

Stock tables – In addition to stand tables, stock tables of merchantable timber volume may be available. In many cases, stock tables will include volume of commercial species only. If this is the case then these data cannot be used for estimating carbon stocks, as a large and unknown proportion of total volume and therefore total biomass is excluded.

Biomass density can be calculated from volume over bark of merchantable growing stock wood (VOB) by "expanding" this value to take into account the biomass of the other aboveground components – this is referred to as the biomass expansion factor (BEF).

In addition to forest carbon stock inventory data, existing data on conversion factors should be compiled and evaluated to identify gaps. Conversion factors include allometric equations, wood density values, biomass expansion factors, etc. for converting field measurements into carbon stock values.

Step 3: Develop sampling design for field measurements

The steps in this section focus on developing a sampling design for estimating carbon stocks in the main carbon pools of the forests pre deforestation. The carbon stocks in post deforestation land cover are often based on default values according to the post deforestation land cover. Often the post deforestation carbon stocks in all vegetation pools are conservatively estimated to be zero for many of the post deforestation land cover classes such as annual croplands, grasslands, mining areas, and roads. Changes in soil carbon stocks are related to the post deforestation land use, and it is recommended that the changes be estimated using the IPCC 2006[52] guidelines for this process. This

[51] Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy.

[52] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4, Agriculture, Forestry and Other Land Use

IPCC method estimates the changes in soil carbon stocks based on the use of soil factors that account for how the soil is tilled, what sort of management is applied, and inputs in the post deforestation land use.

Step 3A: Design sampling locations

For each stratum, a sampling design will need to be created to determine where to collect the field samples and measurements. Typical field measurements and samples are collected from plots of various sizes and shapes—the sampling design includes determining the shape, size, number needed, and location of the plots. A stratified random sampling design is recommended – a sampling grid is commonly used. The number of field sampling plots will vary by stratum depending on the variability of carbon stocks and the desired precision of carbon stock measurements as well as the selected plot size. Data from a relatively small number of preliminary plots will be needed to determine the variability of carbon stocks in each stratum. Standard equations can be used to estimate the number of plots required for each stratum, such as Winrock's Sampling Calculator[53]

Step 3B: Plot design

Field sampling can either take place within single independent plots or sampling can be completed in clusters of multiple plots. When cluster plots are used, at each cluster location field measurements take place within several plots with a defined configuration relative to each other. This type of plot design will generally increase field measurement efficiency and thus is the recommended design.[54] Further guidance on cluster plot design can be found in Winrock's manual on Standard Operating Procedures for Terrestrial Carbon Measurement. [55]

The size and shape of the sample plots is a trade-off between accuracy, precision, time and cost for measurement. There are two types of plots – single plots of a fixed size or nested plots containing smaller sub-units of various shapes and sizes. Nested plots are a practical design for sampling and recording discrete size classes of trees. They are well-suited to stands with a wide range of tree diameters or to stands with changing diameters and stem densities. Single plots may be more appropriate for post-deforestation strata. In addition to determining the number of field plots to be sampled, data from preliminary plots are also useful for setting the tree size thresholds in nested plots. Additional guidance can be found in Winrock's manual on Standard Operating Procedures for Terrestrial Carbon Measurement.[56]

[53] http://www.winrock.org/Ecosystems/files/Winrock_Sampling_Calculator.xls

[54] Tomppo, E. and M. Katila. Comparing alternative sampling designs for national and regional forest monitoring. Appendix 4 in Tomppo, E. and K. Andersson, Technical review of FAO's approach and methods for national forest monitoring and assessment (NFMA), NFMA Working Paper No. 38, Rome, 2008.

[55] Walker, SM, TRH Pearson, FM Casarim, N Harris, S Petrova, A Grais, E Swails, M Netzer, KM Goslee and S Brown. 2012. Standard Operating Procedures for Terrestrial Carbon Measurement: Version 2012. Winrock International. http://www.winrock.org/ecosystems/

[56] Walker et al 2012 http://www.winrock.org/ecosystems/

Step 3C: Selection of carbon pools to include

The amount of net emissions taking place from deforestation will vary by land cover stratum and by magnitude of the carbon pools within each stratum. It is possible that some carbon pools may not be selected for measurement or may vary by forest stratum (See Box 6 in Section 3.4). The decision on which carbon pools to measure as part of a REDD+ accounting scheme will likely be governed by the following factors: available financial resources, availability of existing data, ease and cost of measurement, magnitude of potential change in the pool, and the principle of conservativeness. Both time-zero estimations of carbon stocks (the benchmark map, start of REDD program) and subsequent estimations in a given stratum must include exactly the same pools. For minor pools (or non-key categories) default estimates from different IPCC Tiers are appropriate. Higher tier methods (e.g. direct measurements) should be implemented for key pools (or key categories) while lower tier methods may be applied to non-key categories.[57]

For all forest strata, the tree carbon pool should be included. Estimates of tree carbon stocks are relatively easy to obtain through field measurements and the change in tree carbon pool will likely represent the dominant change in carbon stocks resulting from land cover change. Belowground tree biomass (roots) is almost never measured, but instead is estimated based on a relationship to aboveground biomass (usually a root-to-shoot ratio). Downed and standing dead wood is a key category in more mature forest where it can represent up to 10% of total biomass, but in young successional forests, for example, it will not be a key category. Litter and understory herbaceous material are generally minor carbon pools, but experience shows that they are relatively low cost to sample and could be included in any sampling design. It is good practice to identify the carbon pools that have the greatest contribution to emissions and removals of GHGs and to the overall uncertainty of the estimates to the make the most efficient use of resources available for measuring and monitoring carbon stocks.[58] The soil pool is a key category in peat swamp forests and mangrove forests where carbon emissions will be high when the land is deforested and drained. It is also a key category in all forests if the deforestation is driven by conversion to annual croplands.

When deciding which pools should be included or not in a FCMS, it is important to remember that whichever pools are initially included will need to be included in all future monitoring events, or their future exclusion will need to be adequately justified. Although national or global default values can be used, such defaults for a key category will make the overall emissions estimates more uncertain. It is possible that once a pool is selected for monitoring, default values could be used initially with the idea of improving these values through time.

Step 3D: Develop standard operating procedures

Standard procedures for field data collection and analysis should be developed that are specific to the data being collected—these are key components of any quality assurance and quality control (QA/QC) plan. Creating standard approaches for each stage in data collection, analysis, and storage allows for

[57] IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 4, Agriculture, Forestry and Other Land Use.
[58] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4, Agriculture, Forestry and Other Land Use.

consistency and increases accuracy. Several manuals exist on standard field measurement techniques, including Winrock's manual on Standard Operating Procedures for Terrestrial Carbon Measurement. [59]

Step 4: Collect field measurements

The field sampling plan should be implemented to collect field measurements as defined in standard operating procedures. Box 8 gives a general description of the different kinds of field measurements that may be required for each carbon pool. The biomass and carbon stock of trees are estimated using appropriate equations applied to the tree measurements. For practical purposes, tree biomass is often estimated from equations that relate biomass to dbh; dbh and height; or dbh, height, and wood density. In forests where the wood density of the tree species varies widely, inclusion of this variable in the equation can improve the accuracy of estimates. Non-tree carbon pools (down dead wood, litter, non-tree vegetation, and soil organic carbon) samples of fresh material are collected, weighed dried in an oven, and reweighed to generate dry-to-fresh-weight ratios. Further guidance on field measurements of carbon stocks can be found in Winrock's manual on Standard Operating Procedures for Terrestrial Carbon Measurement. [60]

Step 5: Calculate carbon stocks

After all field work has been completed, data will need to be analyzed to estimate the carbon stocks for each pool and the total for all pools included. At this time the uncertainty associated with the estimates of carbon stocks will need to be calculated, including the 95% confidence interval. The total carbon stock for each land cover stratum is the sum of all carbon stocks from measured pools, excluding soil carbon pool, which is reported separately. It is recommended that for each land cover stratum the mean standing carbon stock along with its 95% CI be presented.

In this step, the post deforestation change in soil C stock should be estimated based on the IPCC guidelines for AFOLU sector methodology briefly described above (Step 3). For simplicity in accounting, we recommend that the emissions from the total estimated loss of soil carbon in the year of clearing be used, rather than spreading the emission over 20 years (the default time period suggested by IPCC 2006).

Table 5 provides an example of how changes of soil carbon can be estimated based on the IPCC soil stock change method and factors[61]. The dimensionless soil factors are: F_{LU}= Stock change factor for land-use systems, F_{MG} = Stock change factor for management regime, and F_I = Stock change factor for input of organic matter.

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[59] Walker et al 2012 http://www.winrock.org/ecosystems/

[60] Walker et al 2012 http://www.winrock.org/ecosystems/

[61] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4, Agriculture, Forestry and Other Land Use

Table 5. Example of soil carbon factors based on IPCC soil stock change methods.

Stratum/driver	C stock (t C/ha)	F_{LU}	F_{MG}	F_I	C stock at 20 yr (t C/ha)	Change in Soil C (t C/ha)
Evergreen forest	105.5					
Conversion to permanent agriculture		0.48	1.00	1.00	50.6	**54.9**
Conversion to unpaved roads		0.82	1.00	0.92	79.6	**25.9**
Mixed evergreen-deciduous forest	87.9					
Conversion to permanent agriculture		0.48	1.00	1.00	42.2	**45.7**
Conversion to unpaved roads		0.82	1.00	0.92	66.3	**21.62**

Step 6 Create emission factors for deforestation activity

Emission factors are **not** the same as forest carbon stocks, but rather they are the difference between the carbon stocks in the selected pools for the pre- (forest) and post-deforestation land cover. If the post deforestation land cover is assumed to contain zero carbon in the vegetation and no carbon losses from soil occur, then the carbon stock pre-deforestation is a reasonable approximation of the emission factor.

Emission factor should be calculated separately for each specific driver of deforestation as the post-deforestation land cover varies by driver. The emission factors are based on the field data collected from implementing the sampling plan and other factors and guidance in the IPCC (2006) guidelines for doing a GHG inventory in the AFOLU sector. The carbon stocks of the post-deforestation land cover are also needed at this stage (see Step 3 above). The change in soil carbon values in the last column of the above table represent the emission factors that can then be added to the emission factor from the vegetation pools. The sum of the two emission factors represents the total emission factor for deforestation for each driver by forest strata.

4.2.2 Forest Degradation Emission Factors

While it is relatively straightforward to detect and measure areas of deforestation with remote sensing imagery and fieldwork, this is not the case for degradation. Due to the array of drivers, agents and consequent activities causing forest degradation and resulting emissions, activity-specific methods addressing forest degradation must be discussed and tested, and if successful, implemented. Procedures for estimating the impact on carbon stocks for many agents, such as selective logging and

fuelwood extraction, already exist in IPCC guidance documents but for other agents such as overgrazing and degradation by fire there are no defined procedures.

Figure 17 outlines the overall steps needed to develop emission factors for degradation. These steps are described in detail in the following sections.

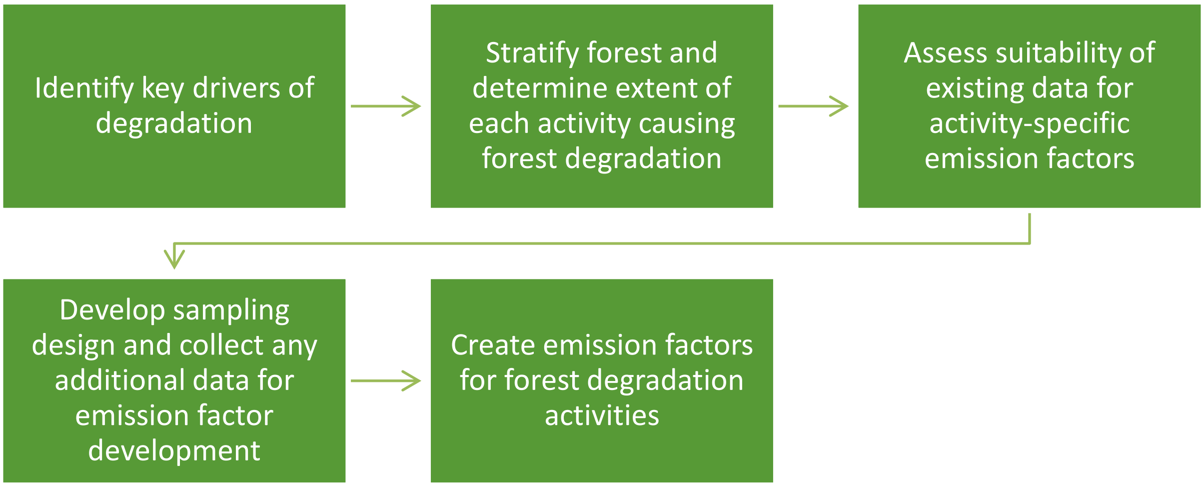

Figure 17. Steps to create degradation emission factors

Step 1: Define drivers of forest degradation

Due to the potential array of drivers, agents and consequent activities causing forest degradation and resulting emissions (e.g. timber harvesting, fuelwood collection, human-induced fires, and overgrazing) activity-specific methods are needed to develop degradation emission factors. Section 4.1.2 above describes the process to determine which sources of forest degradation should be addressed and how to develop activity data for degradation. Emission factors must be developed only for those degradation sources for which activity data are estimated.

Key causes of degradation are commonly those associated with tree felling and extraction (legal and illegal) for timber and fuelwood, human induced fires that reduce the C stocks, overgrazing in the forest understory preventing regeneration, and shifting cultivation

Step 2: Stratify forest and determine extent of each activity causing forest degradation

The first step in developing emission factors for forest degradation is to compile spatial and non-spatial data, stratify forests, and determine the aerial extent of each forest degradation activity. It is recommended that this stratification be based on existing carbon stocks, expected timber stocks, and the degradation activity. Such data may be based on information such as logging concession data (location and timber volumes extracted, annual allowable cut, forest code of practices), protection status, and the same type of geospatial modeling described in Annex II.

Step 3: Assess suitability of existing data for deriving activity-specific emission factors from forest degradation

In some cases it may be possible to use existing data from previous carbon stock inventories, timber inventories, and scientific studies, as described under Step 2 of deforestation emission factors. However, the units of emission factors must agree with the units for activity data, and in the case of degradation, the measure is not always unit of area. For instance, activity data for human-induced fires may be measured in hectares per year, but timber harvesting is more likely to be measured in volume harvested per year. For this reason, forest degradation emission factors are activity specific, and it is generally necessary to collect new data.

Step 4: Develop sampling design and collect any additional data for emission factor development

A sampling design should be developed to decide where field sampling shall take place based on the kind of degradation activity and what type of data needs to be collected. To determine carbon stock changes resulting from selective logging operations, measurements should be collected on active logging concessions. Measurements of carbon stock changes from fuelwood collection or charcoal production may be collected from areas that are at high risk for degradation – such areas may be identified by their proximity to risk factors such as settlements and roads. Similar measurements must be undertaken for fires and overgrazing.

The gain-loss method described earlier in this manual is recommended for developing emission factors associated with degradation from selective logging. Sampling is therefore conducted in active concessions to determine: (i) the loss of carbon stocks through tree felling and extraction, incidental damage in the gaps caused by the felling, and infrastructure establishment for extracting the timber (i.e. skid trails, log landings, roads), and (ii) gain of carbon as a result of canopy gap creation and the resulting regrowth in the residual trees and new recruits. Losses are assessed with data collected at "logging impact plots" and skid trails (losses from construction of log landings and roads are accounted for as deforestation). Gains would ideally be obtained from measurements of permanent plots over many years from which "growth and yield" models could be developed. However, as data for gains are usually needed over the short term for the development of the historic emissions, alternative approaches such as chronosequence method (i.e. a number of plots established and measured around stumps in past known years) may be used. If it is possible to install permanent growth plots for data collection in the future, this would be the preferred approach, but it is not regarded as essential.

Carbon emissions from logging could vary as a function of different logging intensities and practices, defined by stand re-entry, extraction rates and intensity, and reduced impact logging practices. These differences are captured by classifying concessions based on logging intensities and practices. The goal of this component is to develop emission factors relating total biomass damaged, and thus carbon emissions, to the volume of timber extracted. This relationship will allow the estimation of the total emissions generated by selective logging for different concession sizes across the entirety of the country.

Guidance on the field measurements methods can be found in Winrock's manual on Standard Operating Procedures for Terrestrial Carbon Measurement. [62] Winrock has developed a series of data collection and analysis methods that can be used to estimate emissions taking place from selective logging (Box 9). To use this method, the volume of timber extracted for a given forest degradation activity must be known. Other degradation activities can follow the SOP guidance for field measurement of carbon stocks. For all degradation activities, sampling design must ensure that accuracy and precision targets are met, and QA/QC guidelines must be established and followed rigorously.

The stock difference method may be the most appropriate for certain degradation activities, such as human-induced fire and overgrazing. By definition, not all carbon stocks are removed as a result of these activities, so it is not possible to simply establish the carbon stocks prior to degradation. Rather, it is necessary to measure carbon stocks in the relevant pools before degradation (time 1) and after degradation (time 2); the difference between these provides the emission factor. It is not always possible to know where a degradation activity will occur, so the time 1 measurements may, in most cases, be conducted in a nearby forest that approximates the forest type, age, and condition of the pre-degraded forest. The measurements will occur in the degraded forest for the time 2 measurements.

In some cases, such as fuelwood collection, specific quantitative data may not be readily available, but more qualitative data may be used to derive estimates of change in carbon stocks. This can include social data such as rural population density and fuelwood use, and economic data, such as dependence on fuelwood for livelihood. Emerging remote sensing technologies may be an efficient and cost-effective option for measuring degradation. These methods are closely linked to activity data, and therefore the decision on how to conduct measurements needs to be done in conjunction with development of activity data. Use of this method is, of course, dependent on available technologies and knowledge of their applicability.

Step 5: Create emission factors for forest degradation activities

Following completion of field work, data will need to be analyzed to estimate activity-specific emission factors. Each stratum degradation driver combination should have an activity-specific emission factor. It is recommended that for each stratum the emission factor is presented along with its uncertainty estimate.

Using the stock-difference approach, the degradation emission factors are the total carbon stocks from all measured pools in a given stratum, along with the estimate of uncertainty, at pre-degradation disturbance (Time 1) minus post-degradation disturbance (Time 2). Using the gain-loss method, degradation emission factors are calculated as the lost carbon stocks minus the increased carbon stocks due to the specific activity.

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[62] Walker et al 2012 http://www.winrock.org/ecosystems/

Box 9. Example of method to account for emissions from selective logging

Winrock International has developed a gain-loss method for estimating emissions from degradation due selective logging. It entails the development of emission factors related to the volume of timber extracted and the area/length of logging infrastructure created. Volume extracted and the amount of infrastructure created must then be monitored over time for a known given logging area.

Accounting for the impact of selective logging on carbon stocks involves the estimation of a number of different components:

Emissions:

- Biomass removed in the commercial tree felled
- Dead wood created as a result of tree felling (e.g. stump and top of felled tree plus other trees killed in the felling process)
- Damage from logging infrastructure (roads, skid trails, logging decks)

Removals:

- Carbon stored in long term wood products from extracted timber
- Regrowth within gaps created by tree felling and abandoned infrastructure

Logging plots are established in freshly harvested concession areas and experience has shown that about 100 plots or more across a few logging operations will produce estimates of the carbon impact factors to acceptable precision levels. Plots must be located at the site of recently cut trees where the volume and biomass removed in timber trees can be determined (especially the DBH of the logged tree). In addition, for the measurement of damage that results from tree felling, it is not possible to establish a set plot size. Instead, one or more felled trees that create one gap define a “logging plot”, and it is necessary to identify and measure all of the surrounding trees damaged during the felling. In this way, it is possible to calculate the emissions per unit of biomass or volume removed in timber trees, or per unit area of gap produced (one of measures made in logging plot).

To quantify the carbon stock change that is damaged and dead as a result of logging infrastructure (skid-trails, roads, and decks), additional pieces of information are needed: a sample of widths, the total length, and the forest carbon stocks damaged during the construction infrastructure. It is generally acceptable to assume that unlogged forests are “deforested” to build the roads and decks, and “degraded” in skidding the logs out (i.e. not all trees are removed).

The carbon stock change in live and dead biomass pools between the “before-logging“ and “after-logging” scenarios, is a result of the extraction of timber, the incidental damage caused to residual trees, and the extraction of trees due to construction of logging infrastructure; minus the carbon storage in long-term wood products and the carbon sequestration due to forest regrowth in logging gaps.

4.2.3 Enhancement Emission Factors

Figure 18 outlines the overall steps in developing emission factors for enhancement.

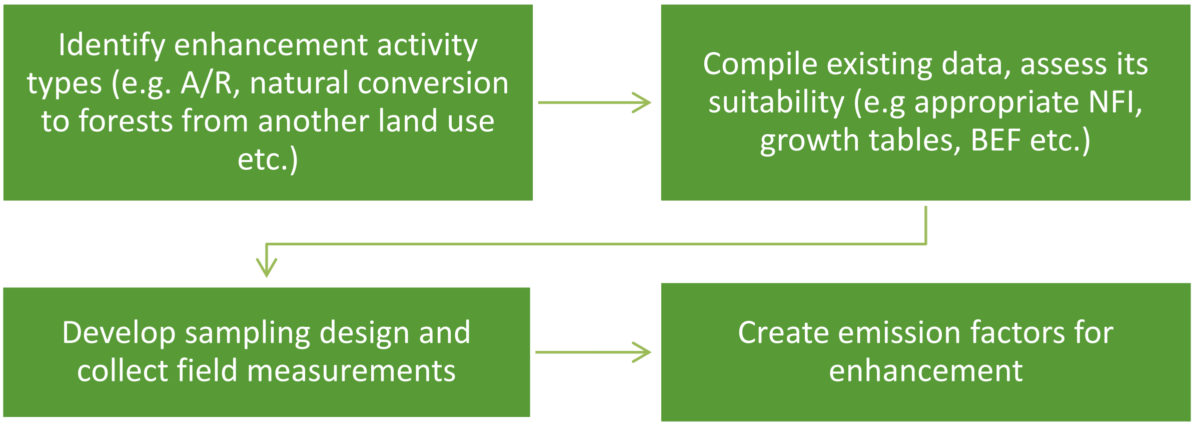

Figure 18. Steps in development of enhancement emission factors

These steps are described in detail in the following sections.

Step 1: Identify enhancement activities

There are numerous activities that result in enhancement of forest carbon stocks, including reforestation/afforestation, natural conversion to forests caused by abandonment from another land use such as agriculture, enrichment planting of poorly stocked forests, and recovery of forest carbon stocks following fire or shifting cultivation. In the initial development of the RL, the focus should be placed on enhancement activities that are both significant and quantifiable. For instance, if a high percentage of the country is currently forested and there are historically few activities related to enhancing forest carbon stocks, then it may be most appropriate to exclude enhancements from the historic emissions, at least initially. However, if much of the land cover has been in agriculture, and reforestation projects are undertaken commonly, then enhancements should be included.

Emission factors for enhancements are likely to vary based on factors such as activity, forest type, and topography. Therefore, enhancement activities should be stratified appropriately.

Step 2: Compile existing data and assess its suitability

Once the relevant enhancement activities are identified, the next step is to determine whether there are existing data that are relevant to developing emission factors. Continuous forest inventories may be a very good source of data if they have been conducted over a long period of time using permanent plots. They provide data on a forest at different ages, and can be used for the development of growth curves. Forest inventories without permanent plots can also be a useful source of data, and may be used to compare forest types and to develop an approximation of forest growth by comparing stands of different ages.

Other important elements that may already exist include:

- Growth tables, especially for timber species;
- Biomass expansion factors such as the ratio of total above-ground tree biomass to merchantable timber;
- The root to shoot biomass ratio;
- Density, by tree species;
- Allometric equations to calculate total tree biomass as a function of an obtainable measurement, usually DBH, wood density, and/or total height.

If there are existing data, ratios, and equations from within the area of interest, they are likely to be appropriate for use in developing emission factors. It is more common, however, for there to be data and equations that are from the general region or from similar forest types in other regions. If this is the case, it is necessary to verify that an existing allometric equation from another country or region, for instance, is relevant in the country or region of interest. This can be done through field measurements or literature reviews, or a combination of both. In this process, the accuracy and precision targets must be clearly defined, and only those data that meet these targets should be considered appropriate.

Following an assessment of all available data and resources, the next step is identifying the gaps that will require collection of new data.

Step 3: Develop sampling design for field measurements

For those elements for which no appropriate data are available, a sampling design must be developed to conduct carbon stock measurements. This will require field data collection in areas where the enhancement activities have occurred in the past. For example, data may be collected from areas planted in past years. However, it will likely be necessary to undertake new measurements in different areas. Potential for change maps (this time for forest gain) could be created to define the area of interest for carbon sampling, and if needed the landscape should be stratified by activity, forest type, and carbon impact.

To best determine carbon stock enhancements, measurements should be conducted for at least two points in time or in at least two forests of the same type but different ages. This enables determination of forest growth per unit area over time. A chronosequence of measurements in forests of different ages may be used to develop initial emissions factors, with later improvements made to emission factors with data gathered from permanent plots in growing forests.

Step 4: Create emission factors for enhancement

Existing and new data can be combined to calculate emission factors for the chosen carbon stocks and enhancement activities. Emission factors for enhancement will usually be quantified as tonnes C (or CO_2) removed per hectare per year.

4.3 Historical Emissions Estimation

The methodological framework produced by Winrock[63] was designed to be applicable to countries participating in a REDD+ mechanism. As many countries have little data with which to estimate historical emissions, the framework recommends the use of coarse-scale estimates of emissions from deforestation as an order of magnitude estimate against which other emissions from various forms of forest degradation can be compared. The framework then recommends that a country choose a proportion of deforestation emissions that is considered 'significant' when considering various degradation sources. This decision will allow an assessment to be made about whether to include or exclude a given degradation source for the RL. If emissions from a forest degradation activity (e.g., fire) represent a very small fraction of emissions from deforestation and no intervention can effectively be applied, then this provides justification to exclude the activity from the RL and allows resources to be focused on reducing the major emission sources for the country.

To facilitate the estimation of historical emissions, it is recommended that a calculator tool be created with separate tables for the input of activity data and emission factors by deforestation and degradation. The calculator can be designed to combine the activity data with emission factors to produce estimates of emissions over different time frames for each activity.

The quantity of the activity (e.g. area of change) should be input based on stratum and activity, and can be broken down into relevant time periods (see example in Table 6). This provides a "look-up table" of activity data for deforestation. A similar table can be created for activity data for degradation, although a different unit of measure will likely be used, such as cubic meters of timber removed, as described in section 6 (see example in Table 7).

Table 6. Example table for area of deforestation, by forest stratum and deforestation activity

Forest Stratum	Deforestation Activity	Area of Change (ha) per Year	
		Period 1	Period 2
Forest Type A	Industrial mechanized cropland		
	Small-holder cropland		
	Large-scale pasture		
Forest Type B	Industrial mechanized cropland		
	Small-holder cropland		
	Large-scale pasture		

[63] Harris, N, Pearson, T, Brown, S. 2012. *Decision support tool for developing Reference levels for REDD+*. Report prepared by Winrock International for the World Bank's Forest Carbon Partnership Facility

Table 7. Example table of activity data for degradation activities

Degradation Activity	Year 1	Year 2	Year 3	Year 4
	Volume per year (m^3 yr^{-1})			
Selective Logging of Forest Type X resulting in sawnwood				
Logging of Forest Type X resulting in fuelwood/charcoal				

To develop emission factors for deforestation, a "look-up table" can be created to estimate the standing carbon stocks of various forest strata and land cover types (Table 8 provides an example). Soil carbon is generally not included in such a look-up table, but is calculated separately as shown in the Table 5 example. Ideally, look-up tables will be updated periodically to account for any improvements in carbon stock estimates, changes in the practices by the drivers of land use/land cover change, and changes in mean biomass stocks attributed to shifts in age distributions, climate, and or disturbance regimes.[64] For example, if the total number of plots is increased to reduce the uncertainty of EFs, the look-up table should be updated to reflect the revised carbon stocks. The carbon stocks in such a table can be used to estimate emission factors for deforestation and degradation as described in the above sections.

Table 8. Example table of carbon stocks in selected pools.

Carbon pool	Forest Type A	Forest Type B	Post-deforestation Land Cover Type C
	Mean carbon Stocks (t C/ha) and % uncertainty		
Aboveground Tree			
Belowground Tree			
Saplings			
Litter			
Dead Wood			

[64] GOFC-GOLD, 2009

Once all activity data are available and all emissions factors have been calculated based on carbon stocks, these can be combined, using the calculator tool to produce historical emissions for deforestation. A separate table can be created, as shown in Table 9.

Table 9. Example table for area of deforestation, by forest stratum and deforestation activity

Forest Stratum	Deforestation Activity	Emissions per Year (t CO_2-e yr^{-1})	
		Period 1	Period 2
Forest Stratum A	Industrial mechanized cropland	Product of AD (Table 6) and ΔC stock pre and post deforestation (Table 8)	
	Small-holder cropland		
	Large-scale pasture		
Forest Stratum B	Industrial mechanized cropland		
	Small-holder cropland		
	Large-scale pasture		

4.4 Projection and Adjustment for National Circumstances

Once historical emissions have been calculated it is necessary to project them forward. Although some text was presented in the SBSTA Decision of COP 17[65] that states that reference levels can be adjusted based on national circumstances, there are currently no specific guidelines for the identification of national circumstances and each country is free to assess these as long as their use can be justified. The business-as-usual projected emissions can be adjusted for national circumstances to achieve different purposes: (i) to improve the accuracy of the BAU projection based on only historical emissions by taking into account relevant circumstances and future events that will affect forest emissions and (ii) to reflect political considerations that are mostly relevant for defining financial support and linking RL to REDD+ results-based finance.[66] Countries with high forest cover low historic emissions will most likely be those countries interested in adjusting their historic emissions upwards; it is unlikely any country would want to adjust their BAU projected emission scenario downward. What “national circumstances” make the most sense for use in adjusting historic emissions upward? Pending further guidance from the UNFCCC, and based on existing guidance, the assessment of national circumstances could consider the following information:

- Geographic characteristics (climate, forest area, land use, other environmental characteristics);

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[65] FCCC/SBSTA/2011/L.25/Add.1

[66] Meridian Institute. 2011. Modalities for REDD+ Reference levels: Technical and Procedural Issues. Prepared for the Government of Norway, by A. Angelsen, D. Boucher, S. Brown, V. Merckx, C. Streck, and D Zarin. Available at: http://www.REDD-OAR.org

- Population (growth rates, distribution, density, etc.);
- Economy (energy, transport, industry, mining, tourism, agriculture, fisheries, waste, health, services)
- Regulatory (land tenure/permitting and land use designation, land use planning, regulatory changes)

What sort of evidence would be needed to justify an upward adjustment to the BAU RL? National policies and programs related to land use can have major impacts on future forest use and thus emissions. For example, if a country can appropriately justify how a national development program such as road building will increase deforestation and thus increase emissions, the policy may be considered for adjusting the RL.[67] However, there is the risk that the actual implementation of a national policy is ineffective thus leading to an overestimation of emissions and threatening the integrity and credibility of a REDD+ mechanism. Spatial modeling can be used to further investigate the potential impacts of development plans on deforestation rates. Additional details on the use of spatial modeling to project future deforestation are found in Section 3.7 and Annex II.

What national circumstances a country should use to adjust the historical emissions in setting their RL can be difficult to ascertain. Clearly it will need to take into consideration any existing plan that will increase or reduce emissions from land use/land use change. It is necessary to make an assessment of the potential emissions from planned development activities that affect forest lands, and how they might be minimized. If a country uses national policies and programs to justify an upward adjustment of the RL, they should provide reasonable proof that they will be indeed impact the future emissions of the country. Such evidence should be in the form of third-party assessments of the likelihood that the development program will be implemented, and if so what are the likely forest impacts of the programs and projects. The evidence should also relate to both to the prospects of realizing the potential impact and the relevant time frame for such realization.

The bottom line is that any adjustment to the historical emissions that proposes that their emissions will increase under a business as usual scenario (that is without any interventions motivated by a REDD+ mechanism) will have to be fully documented and justified. Possible and credible business as usual scenarios and alternative low emission scenarios that could impact forest lands would need to be developed and justified, and spatially displayed on the forest land cover with their associated emission factors.

The term compensation baseline (CB) may be used in an international mechanism that provides developing country Parties with results-based, financial support for successful REDD+ interventions.[68] As REDD+ is a voluntary mechanism it should encourage countries to participate while retaining environmental integrity. In this context, the question then is whether CB should be set equal to or adjusted upward or downward from the BAU projection. Although discussions on compensation

[67] UNFCCC Document FCCC/CP/2007/6/Add.1

[68] Meridian Institute. 2011. Modalities for REDD+ Reference levels: Principles and Recommendation. Prepared for the Government of Norway, by A. Angelsen, D. Boucher, S. Brown, V. Merckx, C. Streck, and D Zarin. Available at: http://www.REDD-OAR.org.

baselines have not yet played out and it is still unknown if even the concept of compensation baselines will be included in the international negotiations, it has been proposed that negotiators only allow upward adjustments of the BAU-RL when a country can justify the adjustment based on empirical evidence.

4.5 Official Adoption of RLs

It is not clear how the modalities for establishing the RL will be set as policy decisions are ongoing under the UNFCCC, but it is clear that RLs will be based on historical data and adjusted for socio-economic factors, drivers of deforestation and the national policy environment as needed to improve accuracy and credibility. The modalities developed by the Subsidiary Body for Scientific and Technological Advice (SBSTA) (see Box 1) could include guidelines on RL development, data submission, notification of preliminary RLs, international adoption of final RLs, and data administration.

It is likely that official RLs could be adopted through one of three ways (Table 12)[69]:

(1) A coordinated top-down, simultaneous process led by political decision makers or technical experts to adopt all RLs for all or most developing countries. Data gaps and differences in national capacity and circumstances make the simultaneous adoption of RLs for a significant number of developing countries difficult and unlikely. Such a simultaneous approach, whether led by political decision makers or experts, would require intensive and likely highly politicized negotiations.

(2) A country-driven process based on COP driven technical guidance to allow Parties to propose their RLs for technical and/or political confirmation at the international level. This approach would allow for adoption of RLs on a Party by Party basis. Data would have to be disclosed and technical experts could be mandated to review the RLs. The final RLs, with or without corrections recommended by the experts, could be adopted by the technical committee or be forwarded to the COP for adoption.

(3) A hybrid approach of the first two approaches.

Table 12. Potential approaches for official preparation and adoption of reference levels developed by Parties

Policy Option	Process
Single undertaking coordinated on the international level **(1a) led by political decision makers**	Allocation principles and RLs are discussed internationally through an eminently political consensus-based process

[69] Meridian Institute. 2011. "Modalities for REDD+ Reference Levels: Technical and Procedural Issues." Prepared for the Government of Norway, by Arild Angelsen, Doug Boucher, Sandra Brown, Valérie Merckx, Charlotte Streck, and Daniel Zarin. Available at: http://www.REDD-OAR.org

(1b) led by government experts	Same as above, but negotiations are handled at expert level, subject to approval by the political level
(2a) Sequential adoption based on technical and political recommendations	National submission of RLs and assessment by SBSTA. Adoption following country submissions, subject to approval at the political level (by the COP)
(2b) Sequential adoption by technical expert teams	National submission of RLs for assessment and endorsement by an international committee of experts. Approval authority is delegated by the COP to this committee, which may be assisted by independent reviewers and panels of experts
(3) Political decision on the international level / consolidation with country submissions	Submission of RLs by Parties to the COP. Process of justification, technical review, and political confirmation through Parties, technical expert review teams, and the COP.

Because it is difficult to reliably project land use and land cover change too far into the future, RLs will need to be revisited on a regular basis (perhaps at each 5-year commitment period) and adjusted for changing circumstances. Currently it is not clear how this process will be implemented. RLs may be revised within a specific timeframe or on a periodic basis and adjusted if needed if justified by results from MRV.

ANNEX I. STEPS IN CREATION OF LAND COVER MAPS

The steps in creation a land cover map are described and are broken down into the following components (Figure A-1).

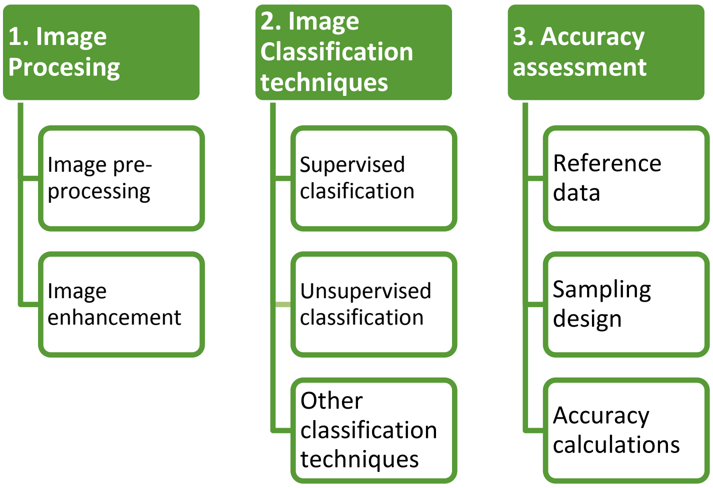

Figure A-1. Components of land cover map development

Image processing

Image pre-processing

Raw data acquired from different satellites undergo different levels of corrections (e.g. geometric corrections for panoramic effect (Earth curvature and rotation). Lowest level data are radiometric corrected only, providing opportunities for the user to perform geometric corrections to the image. The highest level data undergo radiometric and geometric corrections to a standard cartographic projection. After obtaining the satellite images three pre-processing steps should be considered by the image analyst depending on the level of data obtained: (1) radiometric correction; (2) geometric correction; (3) shadow and cloud removal. Specific details on image pre-processing components are described in Box 10.

Box 10. Image Pre-Processing Components

Radiometric correction

Radiometric correction (also referred to as 'image restoration') is used to modify Digital Number (DN) value of each pixel in order to convert DN value to radiance and to remove noise (i.e. noise contributed by the intervening atmosphere, the sun-sensor geometry or the sensor itself). In some cases, where the whole scene is affected, this problem can be overlooked, but in other cases, the image should be corrected.

The typical reasons for performing radiometric corrections are: sensor failure and calibration, atmospheric interference, illumination and topographic distortions and spectral differences in satellite images collected by different sensors or at different times.

- Sensor failure and calibration: Radiometric error in satellite images can be introduced by the sensor system itself when some sensors are not working properly or are not calibrated correctly. Example of sensor system error is when one of the detectors in the multi spectral sensor fails (line drop out) or goes out of adjustment (striping), resulting in the image contains strips with a value of zero. The missing information can be filled in by using information from preceding and seceding lines (e.g. Landsat ETM+ data collected after April 2003 contain strips due to scan line corrector failure and reconstructed imaged are provided by Landsat Corporation).
- Atmospheric interference: Lower wavelength bands are usually affected by haze created by the atmospheric interference, which increase the DN value. The haze could affect resulting values when two scenes are mosaicked with different amount of haze or where band ratio is created. The simplest method for removing haze is called 'dark object subtraction', which subtracts the DN reflectance value of the deep water from all DN reflectance values so that the water DN pixels results in zero. Partially haze affected images can be corrected though a tasseled cap transformation.[70]
- Illumination and topographic distortions: Typically, when two images collected at different times of year and time of day, they are likely to be illuminated by the sun at different angles. To normalize both images all DN reflectance values should be divided by the cosine of the sun elevation (the sun angle value is given when purchasing the data). Topographic normalization is needed for mountainous environments from a Digital Terrain Model (DTM). Many approaches are available (band ratio, backwards radiance correction transformation, aspect partitioning, etc.) utilizing the Shuttle Radar Topographic Model (SRTM) data for DTM for images at medium resolution.[71]
- Comparison of satellite images: When remote sensing data from two difference sensors are used and compared in the analysis e.g. TM and SPOT, or TM versus ETM (Landsat 5 versus 7), it is necessary that the DN reflectance value be converted to absolute radiance value. This can also be the case when mosaicking two images from the same sensor but taken at different times of the year.

Geometric correction

Geometric correction of remote sensing images converts satellite data to ground coordinates by removing any distortion caused by the sensor geometry. This technique is also called georectification. In many cases raw satellite images may contain distortion that prevents accurate performance of further analysis such as comparison of multiple images, merging with other map layers, mosaicking images, or lack of georeferencing.

Sources of error in remote sensing data due to geometric errors in the sensors are both systematic and non-systematic distortions. Scan skew is a systematic distortion resulting from the forward motion of

[70] Lavreau J. 1991. De-hazing Landsat Thematic Mapper images. Photogrammetric engineering & Remote Sensing, 57:1297-1302

[71] Hale, S. R., Rock B. N. 2003. Impact of Topographic Normalization on Land-Cover Classification Accuracy. Photogrammetric Engineering & Remote Sensing.Vol. 69, No. 7, July 2003, pp. 785–791.

the satellite platform during the mirror sweep. Earth rotation during the scanning results in row offsets (e.g. 122 pixels per Landsat scene). Non-systematic distortions are a result of altitude of the satellites or topographic variations on the ground. Some satellite data can be purchased corrected for all these sensor related geometric distortions, but at higher price. Usually two steps should be applied if the data acquired are not geometrically corrected: rectification and resampling.

- Rectification relates the exact ground location for each pixel in the remote sensed data. This allows for correcting data by position, registering different date imagery and different resolutions. Two main methods are widely used: image to already rectified image and image to vector data.
- Resampling is mathematical technique used to register the data in one grid system to a different grid system covering the same area. In some cases the pixels size can stay constant, while in other cases the pixels size (width and/or height) can be changed during this process. There are three typical resampling techniques: nearest neighbour, bilinear interpolation, cubic convolution.

Shadow and cloud removal

Clouds and their shadows obscure the area under and it is hard to identify whether the area is forested or deforested either by visual interpretation or by automatic classification of the image. There are numerous techniques of removing clouds and their shadow.[72,73] Clouds and shadow should be removed from images when automatic approaches for image classification are selected. In general images with less than 10% cloud cover should be selected for classifying the forest area for developing national REL. This ensures a reasonable accuracy, and avoids potential erroneous decrease/increases in the estimation of the forest/non-forest in the project area.

Image enhancement

Image enhancement algorithms are used to improve the appearance of the images for visual or automated analysis. Some of these algorithms involve modifying an image to improve contrast between features in a well-defined spectral range or to improve resolution and detail, while other techniques use complex mathematical calculations to derive an entirely new image from a set of raw image data. Image reduction and magnification, transects, contrast enhancement, band rotation, filtering and spatial transformations are mostly used enhancement techniques allowing for improving the image interpretation analysis, therefore assuring for more accurate forest map delineation.

Image classification

Many methods exist for classifying satellite images and creating land cover maps (Box 11). Regardless of the selection, the methods and techniques should be transparent and results should be repeatable by different analysts. The development of land cover maps is critical for assessing land cover change and establishing the forest benchmark map. A country should decide on image classification methods depending on available resources, image processing software and remote sensing expertise. Common image classification techniques can be separated into three major categories: supervised,

[72] Melesse A.M., Jordan, J.D. 2002. A Comparison of Fuzzy vs. Augmented –ISODATA Classification algorithms for Cloud-Shadow Discrimination from Landsat Images. Photogrammetric Engineering and Remote Sensing. (9):905-912

[73] Dare, P.M. 2005. Shadow Analysis in High Resolution Satellite Imagery of Urban Areas. Photogrammetric Engineering and Remote Sensing. (2):169-178

unsupervised and other image classification. Details on the three image classification techniques could be found in Box 11. All historical national land cover maps and benchmark maps should include the same land cover classes and forest strata.

Box 11. Classification techniques

Supervised classification

In a supervised classification, the analyst identifies homogeneous representative samples of different land cover categories (e.g. forest, water, agriculture, etc.) from the image. These samples are referred to as 'training sites'. The selection of appropriate training sites is based on the image analysts' familiarity with the geographical area and their knowledge of the actual cover categories present on the ground or/and on the availability of ground truth data to support the analyst's interpretation of the land cover categories. The information in all spectral bands for the pixels comprising these training sites are used to 'train' the computer to recognize spectrally similar areas for each land cover class. Signature characteristics are first determined for each of the training site categories using specialized software (IDRISI, ERDAS Imagine, etc.). Then, each pixel in the image is compared to the signature characteristics for each of the training sites to determine the land cover category the pixels belongs to.

Unsupervised classification

In an unsupervised classification the number of classes (discrete clusters) is defined by the user and any individual pixel is compared to the mean value of each class to see which one it is closest to. In other words, the image analyst does not provide specific information on what is presented in the scene prior to the classification; the software separates the pixels in defined classes based on statistical characteristics. After classification, the classes must be interpreted (labelled) by the image analyst as to what they represent in reality on the ground. This requires some level of image classification experience or personal familiarity with the area. If the result from the unsupervised classification is not satisfactory to the user, the number of classes can be adjusted or some classes could be aggregated to represent broader category (e.g. three clusters [classes] representing three different types of forest can be aggregated into one category of forest). Different unsupervised techniques are commonly used to perform unsupervised classification (i.e. Cluster, K-mean, Paralepiped, ISODATA, etc.).

Other image classification techniques

In addition to the most commonly used land cover classification methods, there are other methods such as visual interpretation and image segmentation. Visual interpretation is usually performed on screen as the land cover categories are digitized directly and labelled visually. This approach does not require very sophisticated RS/ GIS software and remote sensing knowledge. Although easy to implement this approach is time consuming and image interpreter biased.

The image segmentation is an automated process in which the pixels are aggregated based on similarity of color, intensity and texture. The result of the image segmentation is a set of segments covering the image. More precisely, image segmentation is the process of assigning a label to every pixel in the image such that all pixels with the same label share certain visual characteristics. This method is closer to visual interpretation but it is much faster.

It is very important that image classification is performed by skilled image analyst and all possible information and prior knowledge are used to create land cover map with high accuracy. The following general recommendations should be considered when one of the most common methods is selected:

- It is recommended that visual interpretation be performed using two or more multi-temporal images of the same area together for better interpretation of the land categories

- Any additional information should be used during the classification process.
- When the area of interest comprises more than one satellite image, image by image classification is recommended unless image enhancement techniques are performed on all images.

Temporal, seasonal and annual variability should be considered when image interpretation is performed. These criteria are important when more than one-year land cover map is produced.

Land cover change maps can be created by using change detection techniques. There are two approaches for identifying deforestation rates at national and sub-national level that can be used: wall-to-wall and hot spot approach. When wall-to-wall approach is selected, the land cover maps covering the entire country are created from medium resolution satellite images (e.g. Landsat, SPOT, etc.). This approach is appropriate for small country covered by relatively small number of satellite images. More cost efficient way of detecting the land cover changes for large countries is using hot spot approach, where the land cover change maps are created using course satellite images (e.g. MODIS) and then the areas with largest deforestation rates are classified using medium and fine resolution images.

After the land cover maps are created and accuracy assessment for them is within the standard norms (see details in next section), all deforestation that has taken place between each land cover map and during the historical time frame should be identified. For most circumstances both gross deforestation and net deforestation should be calculated and reported separately.

Perform accuracy assessment on land cover and benchmark maps

Assessing the accuracy of the land cover maps produced from remote sensing imagery is a critical step. An accuracy assessment typically reports the overall accuracy of the map and the accuracy for each land cover class in the map. This is done through a comparison of the classified land cover and the actual land cover. If any of the land cover classes is less accurate, this can have a significant effect on the value of the map to the user, therefore in some cases some classes should be merged to achieve higher accuracy. To merge two land cover classes, like deciduous and conifer forests, might improve the accuracy of the map and reduce the amount of work to classify the land cover, but it will reduce the accuracy of forest carbon estimates, and will increase the amount of field work required by the forest inventory crews. Therefore, the development of land cover map classes must be done as a collaboration between GIS/RS staff and forest carbon stock staff.

Assessing the accuracy of the benchmark map and land cover change maps is of utmost importance. A proper accuracy assessment can be time consuming and costly. Therefore, appropriate planning and design of sampling techniques for accuracy assessment of the maps should be part of developing the historical emissions. Accuracy assessment of benchmark and land cover change maps should incorporate the three elements as shown in Figure A-2.

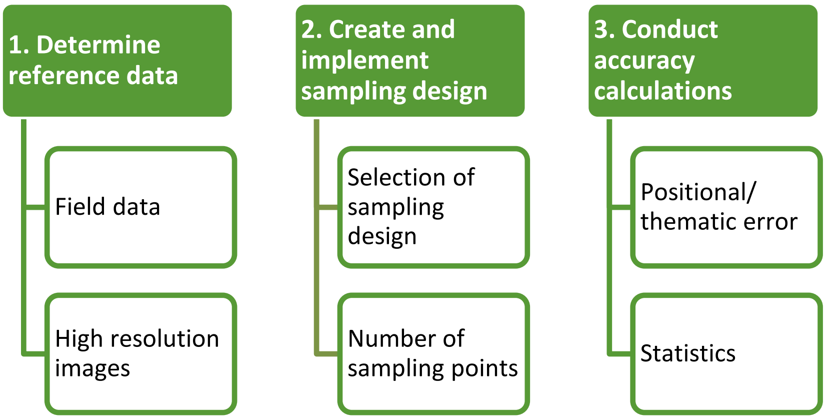

Figure A-2. Elements of proper accuracy assessment of land cover maps

Determine reference data

There are generally 2 types of reference data that are used to assess the accuracy of land cover maps: field verification (i.e. visit select locations on the ground to visually verify that it is that land cover type) and high resolution images.

Field verification can only be used for land cover maps that are recent in time (e.g. within an year of the current date). Therefore field verification should be conducted for the benchmark map. Field work should be collected in the same year and season of the image classification to avoid confusion.

Verification using high resolution images is used when the land cover classification is not of a recent time period (e.g. more than 1 years in the past), or where field data cannot be collected due to remoteness of the location or excessive cost of obtaining field data. In this circumstance high resolution imagery refers to imagery that has significantly higher resolution than the imagery used to do the land cover map (this is usually ≥5m resolution). The purpose of this high resolution imagery is so that the user can view the image and be sure that the land cover class they are looking at is the land cover class they are trying to classify in the land cover maps. If the land cover cannot be identified accurately in the high resolution imagery it cannot be used to assess the accuracy of that class and either the class needs to be merged in to a more broad class (e.g. deciduous forest and broad leaf in to a single forest class), or higher resolution imagery needs to be obtained. The high resolution imagery should be obtained for the same year and season as the satellite images that were used for the land cover classification. It should be noted that in many cases this imagery is freely available through sources like Google Earth.

If there is no reference data available to assess the accuracy of the land cover maps (i.e. field verification can't be done, and there are no applicable high resolution imagery) than the accuracy from a land cover map that has been developed using the same methods (e.g. land cover classification algorithms) and is closest in time can be used.

Create and implement sampling design

The purpose of selecting a sampling design is to ensure the collection of a sufficient number of sampling points so that discrepancies between the true properties of a point or area on the ground (actual land cover) and its representation on the map (classified land cover) can be assessed. The

sampling design should be carefully selected, allowing for statistical assessment of landcover categories on the map. There are number of sampling methods, the most common are random, stratified random, systematic and clustered (nested) sampling.

When developing a sampling design for field verification it is important to take into consideration the ability of crews to locate different land cover types. Field verification will take considerable time, cost and effort. Therefore it might be beneficial to develop a sampling design that uses filed crews for areas that are more accessible (e.g. within 5km of roads and towns), and high resolution imagery for more remote areas. There are many things to take into consideration when doing a field verification, primarily the sampling design must 1) take into consideration the resolution of the land cover map (i.e. if the land cover map is 30m resolution the field crew should be at least >30m inside the designated land cover type), 2) the sampling sites must be appropriately distributed across each land cover type, and 3) there must be enough sites sampled to get proper statistical accuracy for each land cover type. It is critical that field verification follow scientifically approved remote sensing methods.

Developing a sampling design for high resolution imagery is less time and labor intensive than field verification, but is arguably less accurate, and therefore should only be used if field verification cannot be done, it is a very remote location, or to supplement relatively extensive field work. Again there are many things to take into consideration when doing verification using high resolution imagery. Some important points to remember are (1) take into consideration the different resolution (e.g. if your land cover map is 30m resolution make sure that you only asses a land cover >30m within the land cover identified in the high resolution imagery), (2) the sampling design must be appropriately distributed across each land cover type, and (3) there must be enough sites sampled to get proper statistical accuracy for each land cover type. If high resolution imagery is being used in conjunction with filed verification the sampling design must be appropriately integrated. It is critical that field verification should follow scientifically approved remote sensing methods.

Once a comprehensive sampling design has been developed it must be implemented. This will involve coordination between field crews, remote sensing experts and GIS experts.

Conduct accuracy calculations

In general, there are two primary components of error in maps derived from satellite images: positional and thematic error. Positional error refers to error in actual location of the class or feature on the map (e.g. water body can be classified correctly, but its location could be wrong because the image was not rectified). Thematic error refers to wrongly classified landcover class on the map as supposed to the reality (e.g. area is classified as forest but in reality is shrubland).

There are number of statistics that can be used to calculate the accuracy of the land cover map. The most common accuracy statistics are: overall accuracy, producer's accuracy and user's accuracy. A tool for presenting these accuracy statistics is called a contingency (comparison) table that contains information on the comparison of land cover classes derived from satellite image and land cover classes on the ground. Table A-1 shows an example of a contingency table for bamboo, evergreen, grass and barren thematic errors.

- ***Overall accuracy*** of the map represents the accuracy of the entire map. It is calculated as proportion of all pixels classified correctly from overall sampling sites and the total of the

overall sampling sites. Using the contingency table as an example the overall accuracy is calculated at 86.4% *(Overall accuracy = (911+343+176+27) / 1687 =0.864)*

- ***Producer's accuracy*** is computed as percentage of correct pixels classified in the map per land cover class to the total ground sampling sites for this class. Percent of the incorrectly classified pixels is referred to as an error of omission. Based on Table 12, the producer's accuracy for bamboo is 97.7% (*bamboo class producer's accuracy = 911/932=0.977*) and the error of omission is 2.3% (*error of omission = 100-97.7=2.3*)
- ***User's Accuracy*** is computed as percentage of correctly classified pixels in the map per land cover class to the total pixels classified in this land cover class. Proportion of the classified pixels that are in reality other land cover categories is called commission error. Based on this definition, the user's accuracy for bamboo is 95.8% *(bamboo category user's accuracy = 911/951 = 0.958)*

Table A-1. Example of contingency (comparison) table for ground reference land cover classes (actual land cover) and land cover classes derived from satellite images (classified land cover)

Actual land cover class		Land cover class derived from satellite images (pixels count)					***Producer's accuracy (% correct)***
		Bamboo	Evergreen	Grass	Barren	**Total**	
Ground Reference Data	Bamboo	**911**	20	1	0	**932**	***97.7***
	Evergreen	40	**343**	72	2	**457**	***75.1***
	Grass	0	62	**176**	14	**252**	***69.8***
	Barren	0	0	19	**27**	**46**	***58.7***
	Total	**951**	**425**	**268**	**43**	**1687**	
User's accuracy (% correct)		***95.8***	***80.7***	***65.7***	***62.8***		***86.4***

After the accuracy statistics are calculated, a decision must be made on whether the accuracy of the forest category and transition categories satisfy the requirements defined in the standard for the national or sub-national RL scenario. The accuracy of forest categories is recommended to be between 80% and 95% to assure credibility of benchmark maps and land cover change maps.[74] If there are two

[74] GOFC-GOLD, 2009, A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gain and losses of carbon stocks in forests remaining forests, and forestation, GOFC-GOLD Report version COP15-1. Hence forth document referred to as: GOFC-GOLD, 2009

or three forest type classes in the classification map and their accuracy levels are less than the required accuracy for forest category, it could be practical to aggregate these forest type categories into one forest category to bring the accuracy to the required 80-95% level. In cases where the accuracy of the forest category cannot reach the required levels, revision of the methods and approaches used in the image classification should be considered(e.g. new training sites might be created to incorporate the pixels value variability for forest category).

ANNEX II. MODELING POTENTIAL FUTURE DEFORESTATION

Modeling deforestation threat or “location analysis” is a complex task requiring specific software, skills and knowledge of how different spatial factors could be combined to project deforestation, and modeling expertise. Different spatial models should be evaluated for mapping deforestation threat based on following criteria: accuracy in the validation stage, simplicity, transparency, and easy to use. Location analysis is described more in depth in following sections.

To conduct spatial modeling of deforestation threat, it will be necessary to have land cover maps for multiple time periods and spatial datasets for factors expected to be related to deforestation such as soil, roads, rivers, slope, elevation, land tenure, and populated places. For example, humans tend to deforest areas that are close to roads and settlements (accessible for clearing) and ecologically suitable for the post-deforestation land use. Spatial modeling will then provide a basic understanding of the extent to which drivers of REDD+ related activities are active and the magnitude of their impact on forest carbon stocks. This information is essential to establish how policies can be defined and implemented to influence drivers and processes that impact emissions related to forests. Current data, impact on forest carbon stocks, requirement to fill data gap, and policy opportunities for each driver or process should be assessed to prioritize data gathering and policy formulation.

To identify the area where land cover change is most likely to occur in the future, the spatial factors that may be related to land cover change are evaluated against past land cover change trends within a modeling environment. The combination of spatial factors that best explain the pattern and trend of historical deforestation are evaluated to create a map of potential future change. The final map of potential future change can be stratified to identify areas of high, medium and low potential for change (informing REDD+ activities), and can facilitate efficient forest carbon sampling (Figure A-7).

The technical steps in conducting spatial modeling of future deforestation activities are delineated in Figure A-3.

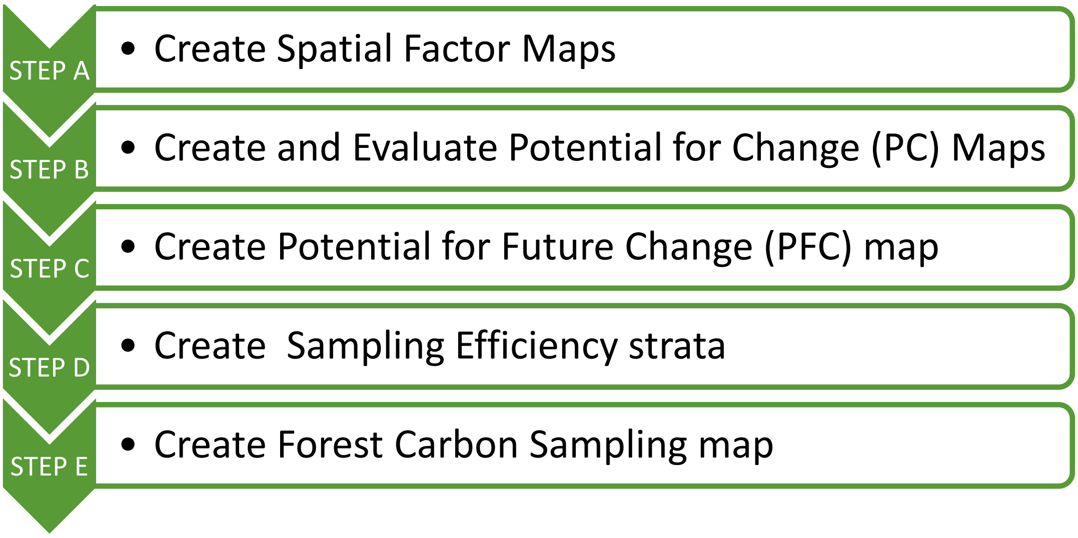

Figure A-3. Overarching spatial analysis framework for developing working Forest Carbon Sampling map

Step A: Create Spatial Factor Maps

Maps for factors contributing to historical deforestation such as roads, settlements, rivers, land under different management practices, elevation, etc. may be created using heuristic and empirical approaches in a spatial modeling framework. Using the heuristic approach, areas close to the factor feature are ranked as higher potential for change than areas further away from the factor feature. This follows the idea that areas close to factors features (roads, settlements, rivers, etc.) have higher potential of future deforestation or forest degradation due to accessibility than do areas further away from these factor features. Using the empirical approach, distance categories are created from the factor features and proportions of historical deforestation are estimated for each distance category.

An example of heuristic and empirical factor maps are shown in Figure A-4. These factor maps show distance to rivers, roads and villages. In the heuristic approach the distance is measure in meters, in the empirical approach distance is categorized into bins. Each bin is defined by the user based on knowledge of land cover change trends. For example, distance to roads is categorized into bins of <100m has very high potential for change, 100-200m slightly less potential, 200-300 less, 300-1000m less, and >1000m very low potential.

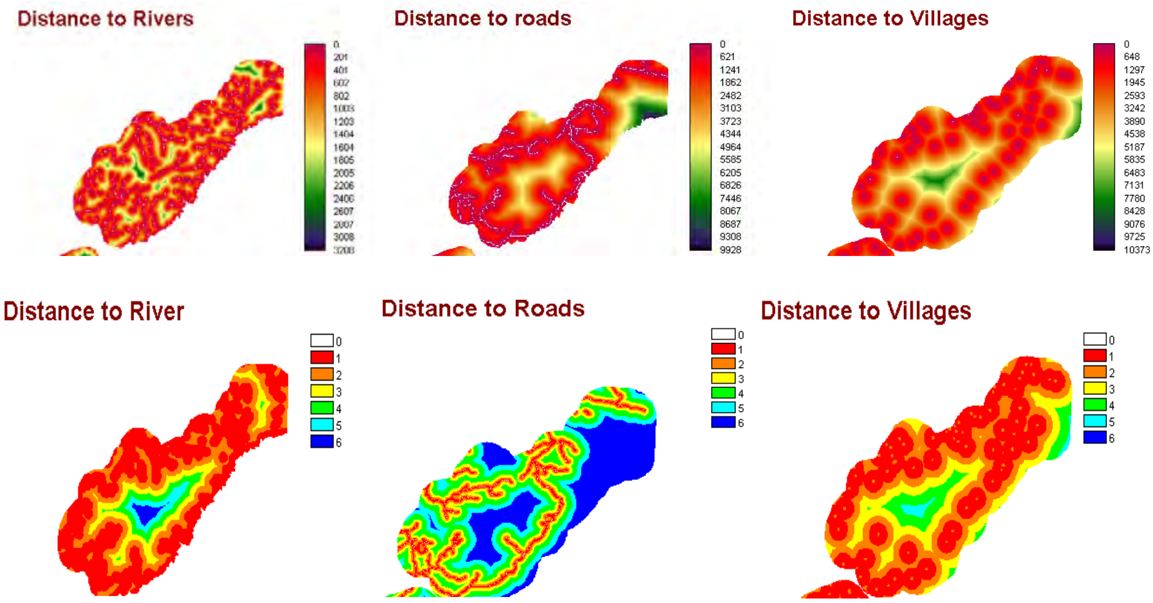

Figure A-4. Examples of heuristic (top 3 maps) and empirical factor maps (bottom 3 maps). Scales refer to proximity of location to a factor, with red indicating close proximity and blue indicating greatest distance from the factor.

Other common factor maps include land tenure and topography (i.e. slope and elevation). Figure A-5 shows land tenure as areas that are legally protected vs. areas that are not protected, and topography of slope and elevation. Each factor needs to be critically assessed for its relevance to land cover change. For example, are protected areas adequately protected, or is it not a legitimate factor in altering land cover change trends? Is elevation really a factor in altering land cover change trends or does land cover change in this area occur at all elevations in a similar fashion?

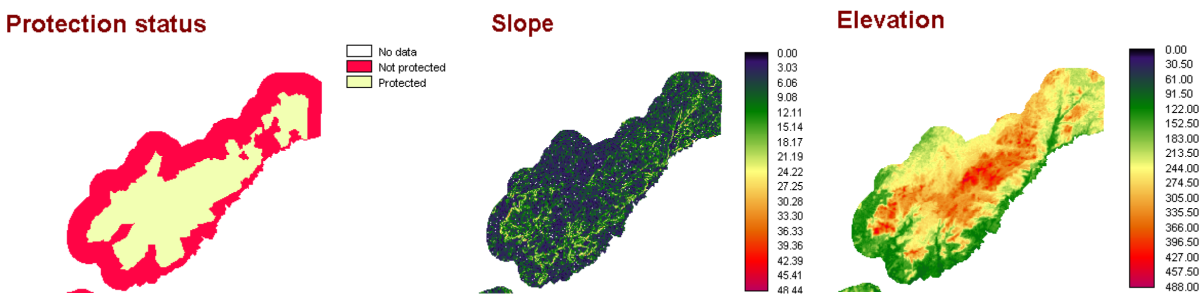

Figure A-5. Example of factor maps for land tenure, slope and elevation. Scale for slope and elevation display small slope/elevation in blue, transitioning to red as highest slope/elevation.

Step B: Create and Evaluate Potential for Change (PC) Maps

All maps of deforestation factors created are evaluated against historical deforestation for time periods, using the statistic of Relative Operating Characteristic (ROC). ROC is a method that assesses how well a factor map portrays the location of forest change for both the time periods without estimating the exact quantity of the change. Factor maps that show high ROC statistics are combined in different combinations to create Potential for Change (PC) maps (Figure A-6). The PC maps are evaluated with ROC to understand which combination of factors contributed most significantly to the historical forest change pattern.

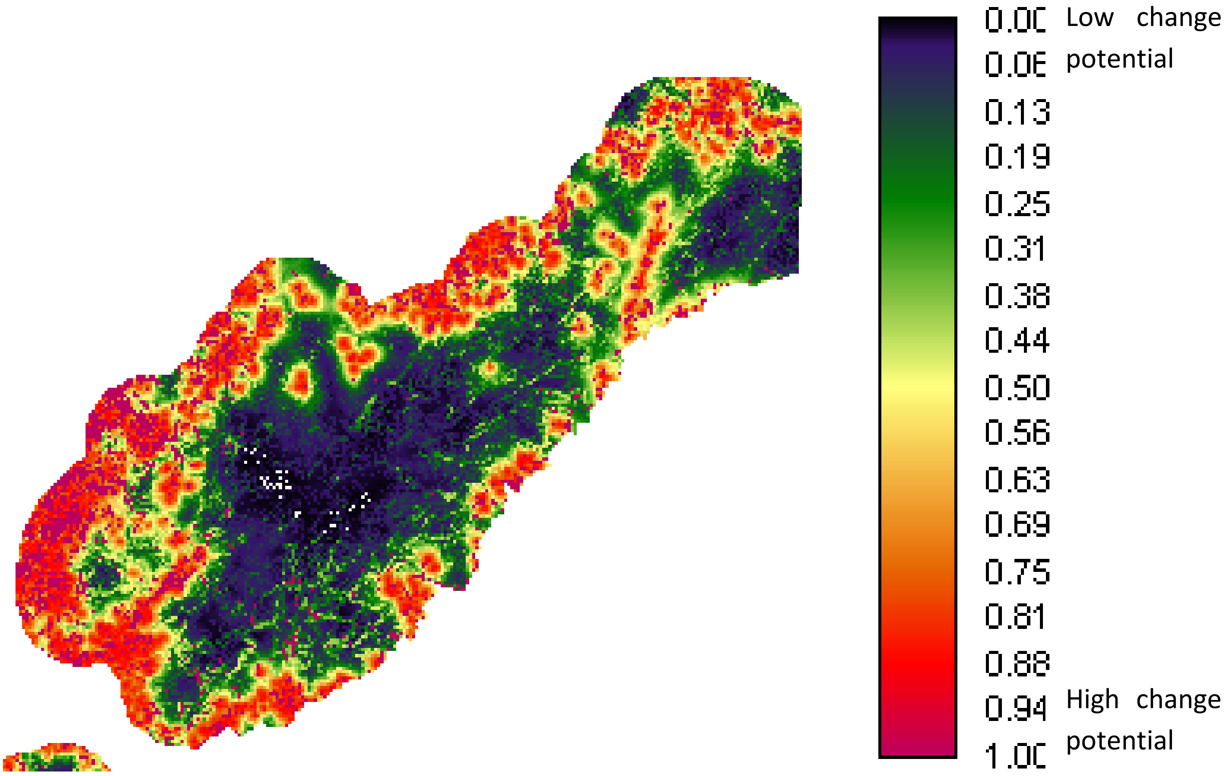

Figure A-6. Example of a potential change (PC) map created from combining all the factor maps. PC maps are evaluated against historic land cover change using Relative Operating Characteristic (ROC) to determine accuracy. Different combinations of factor maps are combined to achieve the best ROC.

Step C: Create Potential for Future Change (PFC) Map

The **Potential for Future Change (PFC)** map is created based on combining the key factors identified in Step B (the historical analysis) that gave the highest ROC statistics. The **PFC** map can be reclassified into three strata based on potential for future change: high, medium and low, using natural breaks for pixel value distribution to set the category break points (Figure A-7).

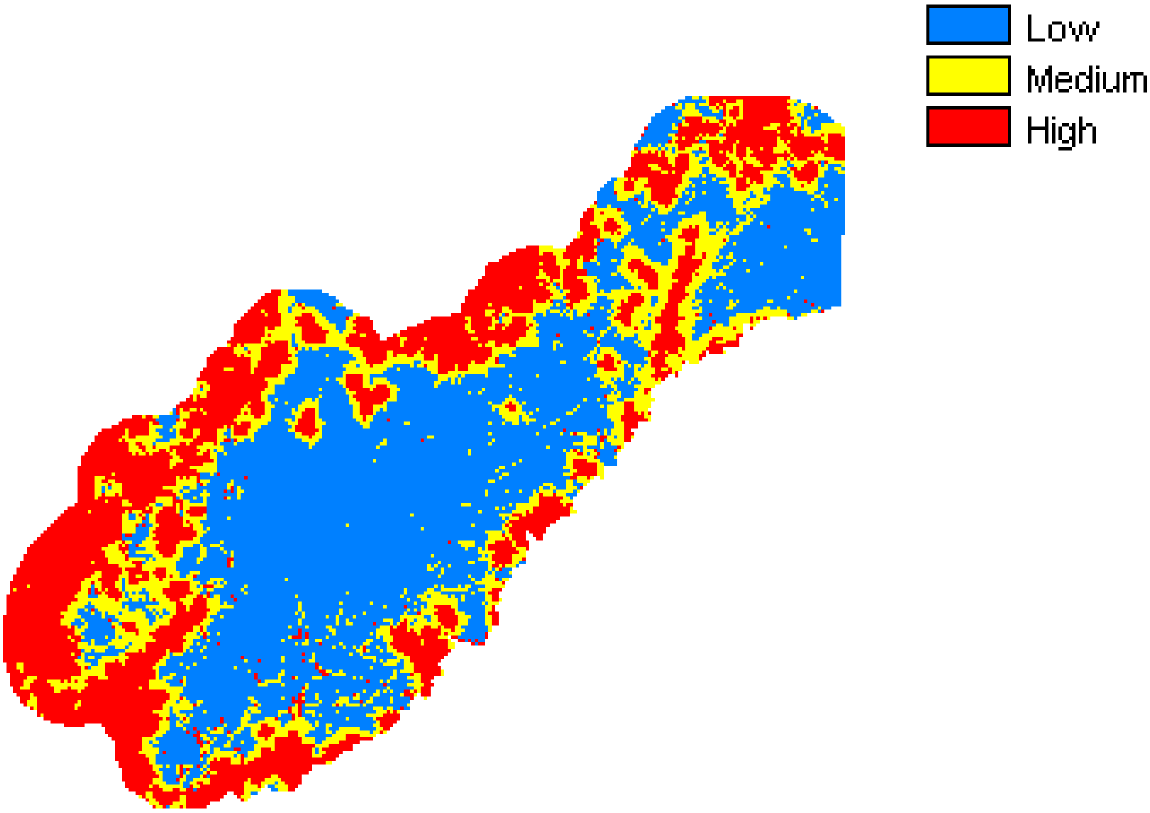

Figure A-7. The final PFC map classified into categories for high, medium and low potential for change.

Step D: Optional: Create Sampling Efficiency strata

Some forestland may not be easily accessible, thus increasing the costs of field sampling at those locations. Therefore, the factor 'accessibility' may be introduced in the sampling stratification methodology to provide a forest carbon sampling framework that allows for efficient collection of carbon samplings.

For example more accessible stratum may be defined as 5 km straight-line distance from both sides of the roads for a total of 10 km, a distance which allows a field team of 4 or 5 people to travel to the sampling point and return to the road within one day. The less accessible stratum is defined as all forestland outside the 5 km road buffer and will require additional travel that may entail camping or air travel for drop off.

Step E: Create Forest Carbon Sampling zones

The forest types can be stratified by potential for change (e.g. high, medium and low) and potentially by accessibility (e.g. more accessible and less accessible). This approach allows phased implementation of the sampling design in order to obtain statistically sound carbon stock data for developing emission factors.