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TECHNICAL GUIDANCE SERIES FOR THE DEVELOPMENT OF A NATIONAL OR SUBNATIONAL FOREST MONITORING SYSTEM FOR REDD+

Forest Degradation Guidance and Decision Support Tool

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Forest Degradation Guidance and Decision Support Tool

This document developed by Winrock International's Ecosystem Services Unit and the United States Forest Service as part of the technical guidance series that has been developed by Winrock International's Ecosystem Services Unit for the USAID Lowering Emissions in Asia's Forests Program

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1.0 INTRODUCTION AND SCOPE

Deforestation has been the primary focus of REDD+ efforts to date for a number of reasons, chiefly because it causes the majority of emissions from the forest sector and methods to estimate emissions from deforestation are well established. However, emissions from forest degradation may be substantial, and in some areas may be higher than those from deforestation. Pearson et al (2014) estimated that in countries with relatively low emissions from deforestation (e.g. Republic of Congo, Guyana, and Peninsular Malaysia) emissions from selective logging were about a third or more of those from deforestation. Herold et al (2011a) claimed disturbances result in annual degradation of approximately 100 million hectares of forests globally, which is nearly 10 times greater than the area impacted by deforestation. Moreover, degradation may ultimately lead to deforestation, indicating the need to monitor and track the impacts of degradation over time.

While measurement and monitoring of deforestation is relatively straight-forward (and may not differ significantly based on the type of deforestation), measurement and monitoring of forest degradation can be quite complex. Forest degradation is difficult to detect using medium resolution remote sensing (RS) imagery (e.g. Landsat) and the impacts of degradation likely differ by location, forest type, and type of degradation[1]. Some types of degradation may contribute a significant portion of total emissions while others may be relatively minor. Emissions may be difficult to estimate (e.g. for illegal logging), and may vary widely over time. Therefore, to determine the most appropriate method of estimating the greenhouse gas (GHG) emissions associated with forest degradation it is important to identify whether degradation is a significant emission source, what types of degradation are occurring, and what measurement and monitoring systems are appropriate.

1.1 Criteria for including forest degradation

Different standards and systems have somewhat different language regarding requirements for degradation and when it must be included in REDD+.

The **United Nations Framework Convention on Climate Change**[2] encourages undertaking activities, including reducing emissions from forest degradation, as deemed appropriate and in accordance with existing capabilities and national circumstances.

The **Verified Carbon Standard (VCS) Jurisdictional and Nested REDD+ Requirements**[3] state that inclusion of degradation does not need to be comprehensive, and can include individual activities (e.g. a jurisdiction may elect to include timber harvesting but not fuelwood collection).

[1] Degrading activities are often referred to as direct drivers in other literature. We prefer to reserve the term "driver" for those things which are the root cause of degradation, such as low employment or demand for raw materials. In this document, we will use the phrases "degrading activities" or "types of degradation."

[2] UNFCCC 1/CP.16 Paragraph 70: http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf

[3] VCS JNR Requirements, 9 October 2013, v3.1: http://www.v-c-s.org/program-documents

The **Forest Carbon Partnership Facility (FCPF) Methodological Framework**[4] states that Emission Reduction (ER) Programs can choose which REDD+ activities and sources and sinks to include in the ER Program Reference Level. ER Programs are required to account for emissions from deforestation at a minimum, and emissions from forest degradation should be included where they are significant:

> *"emissions from forest degradation are accounted for where such emissions are more than 10% of total forest-related emissions in the Accounting Area, during the Reference Period and during the Term of the emission reduction purchase agreement (ERPA). These emissions are estimated using the best available data (including proxy activities or data)"*

In general, deforestation must always be addressed in a REDD+ system, and forest degradation activities should be included when at least one of the following conditions exist:

- A specific forest degradation activity results in significant emissions,
- Capacity and resources exists to reliably measure and monitor those emissions cost-effectively,
- There is potential that interventions could reduce such emissions.

This Decision Support Tool provides guidance on how and when to monitor and measure forest degradation, and how to incorporate forest degradation into the framework of a broader REDD+ measurement and monitoring plan. The intended user will be familiar with basic concepts of REDD+ and measurement and monitoring of forest carbon at a national or subnational level.

Several methods are currently being used in various countries or regions to measure and monitor different forms of forest degradation. While each of these methods may be appropriate in some situations, there has been no comprehensive evaluation or even compilation of all of the existing methods and their utility. This guidance document summarizes the key methods being used at present, offers guidance on critical decisions, and provides a framework for development of a degradation measurement and monitoring plan.

The sections below elaborate the following topics and items that need to be addressed in developing a plan to measure and monitor forest degradation:

- Section 2: Defining forest degradation and its causes
- Section 3: Estimating the significance of emissions from forest degradation
- Section 4: Approaches for the accounting of forest degradation emissions
- Section 5: Overview of data needs
- Section 6: Methods for measurement and monitoring of forest degradation
    - Specific data needs and sources

[4] FCPF Carbon Fund Methodological Framework, December 20, 2013, Criterion 3: https://www.forestcarbonpartnership.org/carbon-fund-methodological-framework

- Section 7: Framework for developing a measurement and monitoring plan for forest degradation

This document does not provide the technical details required to measure and monitor degradation, but rather provides an overview of the requirements for measurement and monitoring and offers guidance for necessary decisions. Throughout this document references are provided for additional resources where technical details can be found.

2.0 DEFINING FOREST DEGRADATION

Numerous definitions of forest degradation exist, but most of them are descriptive and lack specificity, or are not specific to REDD+, and therefore do not enable the implementation of a monitoring and measurement plan. In more general terms, forest degradation is the loss of carbon stocks in forests remaining forests that results from anthropogenic activity. There is no one definition that has been accepted at an international level. The IPCC offers a framework for a definition, adopted at COP9 in 2003, that could be operationalized: "A 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 or an elected activity under Article 3.4 of the Kyoto Protocol[5]". For this guidance document, the general definition of forest degradation will be: *"the reduction in the forest carbon stocks by at least 10% and persisting for 5 years or more."* Jurisdictions may revise these standards to better address their specific conditions as needed.

It is proposed that emissions from forest degradation are accounted where: *annual emissions from all forest degrading activities are more than 10% of the annual total forest-related emissions, and emissions from individual degrading activities are accounted when they represent at least 3% of total annual emissions.*

Three primary activities that result in degradation will be addressed in this guidance document:

1. Timber harvesting
2. Fuelwood and charcoal collection
3. Fires
4. Grazing

Less common activities that may result in forest degradation include land use change within forests remaining forests and forest pollution/toxicity. Each of these will be addressed briefly. Shifting cultivation is also considered degradation by some, but it is more accurately described as a land use change from forest to agriculture, and is therefore deforestation. Shifting cultivation can result in

[5] IPCC Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types." Available at http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation_contents.html.

degradation when the length of fallow is shortened. Arguably, this degradation occurs in an agricultural system, rather than a forested one. Guidance is provided on SC in Annex B.

3.0 ESTIMATING THE SIGNIFICANCE OF FOREST DEGRADATION

In this guidance document, significance of degradation will follow the FCPF definition, that degradation emissions are significant and must be accounted when they are more than 10% of total emissions from the forest sector. In addition, it is useful to establish a threshold for the inclusion of individual activities. It is recommended here that emissions from any individual activity that accounts for at least 3% of total annual emissions should be included[6]. A quantitative tool has been developed to assist in determining whether degradation emissions are significant and should be included in a REDD+ program. The tool, described further below, will provide assistance to users in establishing a first-order estimate of historic emissions resulting from the forest degradation. These estimates can then be compared to other potential sources of emissions (e.g., from deforestation) within the jurisdiction to facilitate decisions on which activities to measure and monitor, as well as what REDD+ interventions could be used to decrease emissions.

REDD+ Web-based Decision Support Toolbox

Winrock International and the World Bank have developed an interactive, web-based tool designed to assist countries in understanding the key decisions required for REDD+ programs to ensure that they achieve emission reductions and removals cost-effectively[7]. The tool will assist users in: deciding which activities to include in a REDD+ program, understanding how these decisions impact outcomes, and providing a first order estimate of emissions from different activities, including degradation. The tool provides a starting point for countries or jurisdictions who are just beginning to develop a REDD+ program, as well as those expanding an existing program.

The REDD+ Decision Support Toolbox can be found here: http://redd-dst.ags.io/accounts/login/.

Preliminary emission estimates from this tool for the four lower Mekong countries and Papua New Guinea are provided in Annex A.

Decision points:

- Are emissions from degradation significant (>10% of total forest sector emissions) in your country or jurisdiction? See Annex A for first order estimates of deforestation and degradation emissions from the four lower Mekong countries and Papua New Guinea in which USAID LEAF is providing suppport to measure forest degradation.
- If emissions do not meet the above criteria, are there specific conditions within the area of interest that justify including forest degradation in REDD+?

[6] Note that for activities contributing emissions lower than 10%, a lower certainty Tier 1 method is acceptable, see section 6.0.

[7] This tool has been developed with assistance from the World Bank Forest Carbon Partnership Facility (FCPF).

- Which degrading activities occur and what is their significance? Which activities will be accounted?

4.0 ACCOUNTING APPROACHES

There are two accounting approaches, activity-based and land-based (IPCC 2000)[8]. Activity-based accounting considers specific human activities leading to forest degradation, and estimates emissions separately for each activity. Land-based accounting estimates the change in carbon stocks in a specified area of land, regardless of activities occurring. Each approach has advantages and disadvantages.

Land-based accounting provides complete accounting of all changes in carbon stocks, including deforestation, forest degradation, and enhancement across the identified area of forest, irrespective of activity. The total change in carbon stocks is determined for the relevant time period; total emissions or removals are the sum of all stock changes over all applicable land area, net of adjustments. A substantial amount of field data and imagery are required for land-based accounting, resulting in high costs. Moreover, land-based accounting is likely to have high uncertainty in the resulting emissions estimates as the coarseness of methods across entire forest areas will miss some types of degradation and some specific locations where forest degradation occurred.

Activity-based accounting is focused on identified activities, with methods targeted to those activities. Total emissions or removals are calculated by summing across all applicable activities. Activity-based accounting may provide higher certainty for individual activities, while increasing cost-effectiveness by focusing on the activities of most impact. It may also allow for better identification of actions that could reduce emissions from degradation, as the causes of emissions are known. However, there is the potential to count a given area of land more than once if it is subject to multiple activities, resulting in double-counting and inaccurate accounting.

Implications to consider for both land- and activity-based accounting (IPCC 2000) are described in Table 1.

Table 1. Implications for use of Land- and Activity-based accounting approaches.

Land-Based Accounting	***Activity-Based Accounting***
A method for **full** accounting of all land-based emissions from deforestation, degradation, enhancement.	Emissions can be combined across activities, but only accounts for included activities.
Statistical sampling of large areas (e.g., a regional forest or agricultural area) at two points in time could capture net effect of emissions and sinks, eliminating need to track separate activities on individual forest patches or agricultural	Where more than one activity occurs on a particular piece of land, carbon impacts of different activities may be difficult to verify.

[8] A quantitative comparison of these two accounting methods is being undertaken under the USAID Vietnam Forests and Deltas project. The results of this comparison will be made available when final.

fields.	
Provides option for measuring and monitoring deforestation, degradation, and enhancement together, but creates difficulty in distinguishing between effects of these activities.	Inherently distinguishes between activities.
Requires large amounts of data that are expensive to collect if they do not already exist from a national forest inventory or similar.	Will form the most cost effective approach as the completeness and complexity of accounting approaches can be associated with the significance of emission sources.
Does not easily allow measurement of non-CO_2 emissions.	Can be used to estimate non-CO_2 emissions.
Statistical sampling methods for different pools are well-established. Cost varies with required degree of precision and frequency of measurement. Methods can be transparent and results verifiable.	Methods can be transparent, but verification of seasonal activities may be difficult or impossible at a later time.
Measurement resolution will likely miss many localized small-scale impacts.	Small scale impacts can be included by activity if deemed significant.
May simplify tracking net emissions and removals from place to place or year to year.	Requires development of emission or removal factors for each activity in each region. Some factors may need to be tied to specific land uses or soil types under some conditions.

Examples: Activity-based and Land-based accounting

Activity-based accounting: Guyana has limited biomass data across the country (outside of timber concessions), and prior to implementing activities under a REDD+ program, did not have reliable data on land use change, requiring data collection for any estimates of carbon emissions. Two primary activities result in the majority of forest degradation in the country – mining and selective logging, both of which are limited to certain areas in Guyana and have reliable activity data. Given this scenario, it has been relatively cost-effective and dependable for Guyana to pursue an activity-based approach for estimating emissions from degradation, focusing fieldwork on areas that are most impacted by logging and mining. One drawback is that it has been difficult to determine emissions from forms of degradation for which activity data are not easily attainable, such as the extent of degradation in areas adjacent to infrastructure.

Land-based accounting: Vietnam has a national forest inventory that has gathered extensive data on forest biomass across multiple forest types throughout the country. There are also data on forest cover change, including degradation of forest timber stocks that have been collected for at least the last 20 years and will be collected into the future. However, there is limited understanding in the country regarding where and what specific activities have led to degradation. Vietnam has chosen to implement a land-based approach to estimate emissions from degradation, at a jurisdictional scale. Given the extensive inventory data available in Vietnam, this approach is relatively straightforward to implement, and has not required additional fieldwork. However, it is not easily identified which specific activities have led to degradation in various places, and it is also possible that the effects of degradation are over- or under-estimated, depending on the accuracy of land classification. Vietnam's approach is land-based in that the focus is on the land cover at different points in time – forest, degraded forest, or non-forest, each further separated into specific classes. The calculations used to estimate emissions rely on remote sensing (area moving from one land class to another) and carbon stocks in each land class (often imprecise because of too few sample plots in a given land class).

This guidance document will focus on activity-based accounting. Activity-based accounting is expected to be the accounting approach of the large majority of countries, with land-based only selected by countries which have the resources, motivation, and cost recovery for the inventory needed as part of land-based accounting.

Decision points:

- Which accounting method will be used?
  - Activity-based
  - Land-based (if so, separate guidance is necessary)

5.0 DATA NEEDS

Regardless of the type of degradation, there is a general process to measure and monitor the impacts of degradation. This process would be integrated into the National Forest Monitoring System, although some aspects differ based on differing activities and resulting data requirements. The general framework is shown in Figure 1 and defined in more detail in the Framework Document (Brown et al. 2013).

To measure emissions, two components are needed – Activity Data (AD) and Emission Factors (EF). AD refers to the extent of degradation and EF refers to the emissions / removals per unit activity. Activity Data are often expressed as an area of change such as hectares of land degraded, but they can also be comprised of other data such as volume of timber or fuelwood harvested. Data on carbon stock change are used to estimate emissions per unit of activity and develop EFs. Emission factors must correspond to AD, so they are expressed as tons of CO_2 per unit of activity, i.e. per hectare or per cubic meter.

Just as with the potential recovery of forest after deforestation, the recovery of forests after degradation is impossible to accurately know. Recovery will depend on the damage of the degrading activity to the forest structure, vitality, and fertility, as well as the probability of ongoing anthropogenic activity either maintaining or furthering the degradation or leading to deforestation. As such, methods should account the emissions from forest degradation of all activities which significantly reduce the carbon stocks of an area of forest but do attempt to include potential recovery of stocks post degradation.

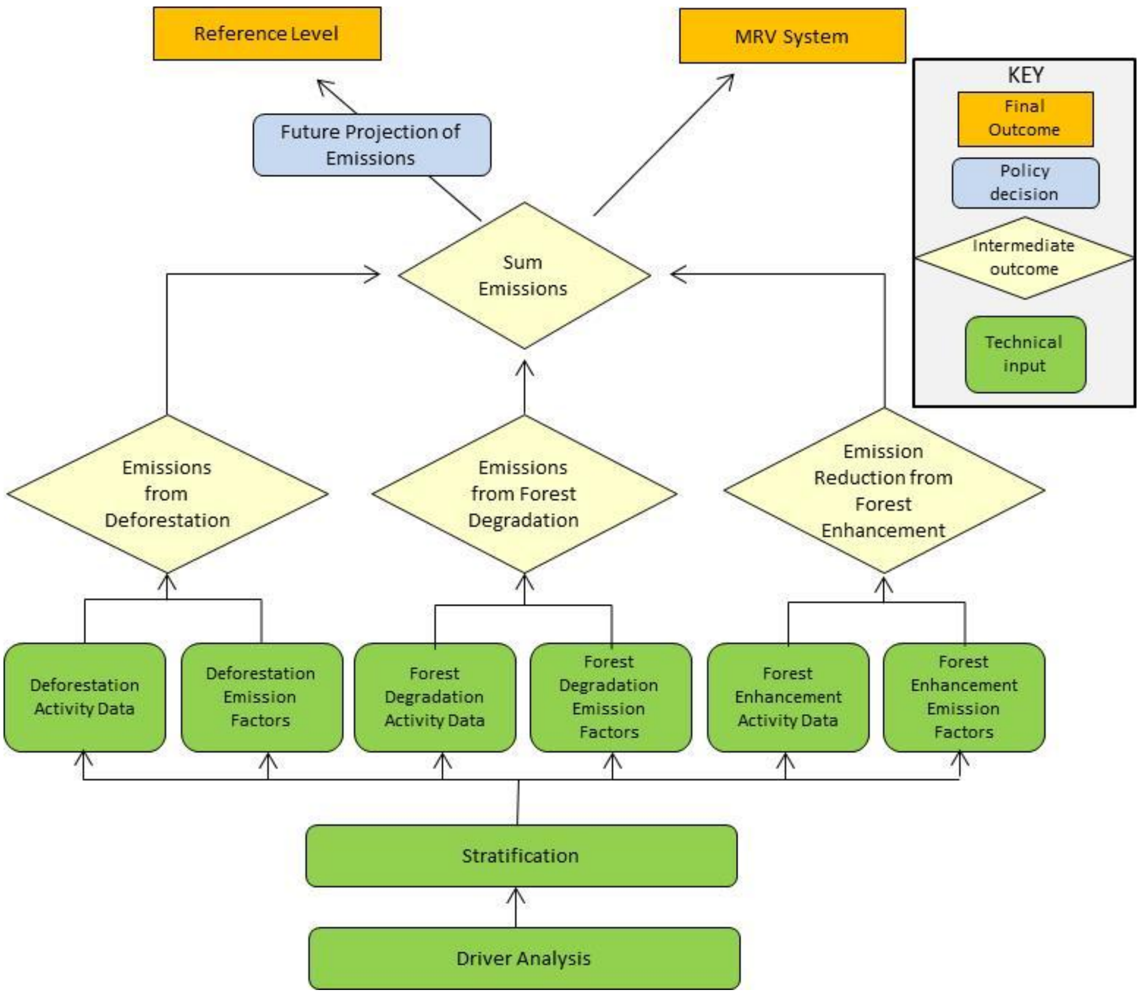

Figure 1. Framework for a National Forest Monitoring System to provide key inputs into the historical emissions for Reference Level Development and the Measuring, Reporting, and Verification System

Emission factors for degradation can be developed using either the gain-loss or stock-difference method. Using the gain-loss method, changes in carbon stocks are calculated by estimating gains in carbon based on typical growth rates and losses from activities such as harvesting for timber and fuelwood. With the stock-difference method, changes in carbon stocks are calculated as the difference in estimated carbon stocks pre and post degradation. Gain-loss is often easier to use for estimating degradation emissions, although both methods are viable. Key decisions required for developing degradation emission factors are the same as those required for a REDD+ National Forest Monitoring System (NFMS) and are described in the Framework Document (Brown et al. 2013).

There are multiple ways to develop Activity Data for land area and area change. It can be preferable to obtain such data using remote sensing. For degradation to be detected on satellite imagery, however, it needs to occur at a scale that causes a visible change in the canopy. In general, the pixel resolution and temporal frequency of medium resolution sensors such as Landsat are insufficient to capture degradation completely (Table 2)[9]. The detection accuracy of higher resolution 5-meter imagery is still only around 80%, which points to the potential limitations of detection using only existing space-borne optical sensors (Manley et al. 2013). Area data can also be estimated based on ground surveys. If other relevant data are available, they can sometimes provide more accurate estimates of change. This includes volume and type of timber harvested, mill efficiency, and amount of fuelwood harvested for heating or cooking. These data may be more difficult to acquire if they do not already exist, and while they may be more accurate than remotely sensed activity data, they are contingent upon complete accounting and record-keeping.

Table 2. General detection capabilities of satellite remote sensing methods for specific degradation activities (adapted and expanded from Manley et al. 2013).

Type	Method	**Commercial/ non-commercial selective timber harvesting** DBH ≥ 45 cm	**Commercial/ non-commercial pole/fuelwood harvesting** DBH 5-44 cm	**Fire** Continuous fire area ≥ 10 ha (allowing for spatial complexity)
Optical	**Low resolution remote sensing (e.g. MODIS)**	Limited detectability of multiple crowns removed in close proximity	Not possible	Detectable at size if considered not part of shifting cultivation
	Medium resolution remote sensing (e.g. LandSat)	Detectability of multiple crowns removed in close proximity. 10-20% canopy disturbance	May be detectable, if multiple stems harvested in close proximity. Not possible if overstory canopy is undisturbed	Detectable
	High resolution remote sensing (e.g. RapidEye)	5m individual tree crown detectable.	Detectable only if overstory canopy is disturbed.	Detectable
Light Detection and Ranging (LIDAR)		Detectable if point density is high enough (e.g. >20 points per crown or	Detectable if point density is high (e.g. >20 points per crown or gap). Most accurate if	Most accurate if overstory is sparse or disturbed, but not as effective as optical,

[9] There are now mechanisms being developed to detect in-pixel changes in spectral resolution as a result of a canopy change. See the work of the Carnegie Institution for Science (http://claslite.carnegiescience.edu/en/) and the work of Applied Geosolutions (http://www.appliedgeosolutions.com/)

	gap)	overstory is sparse or disturbed.	use in conjunction with optical
High resolution synthetic-aperture radar (SAR)[10]	Detectable, especially with longer wavelengths (30-100cm)	Detectable if overstory disturbed. May be detectable when canopy is intact, but needs appropriate pairing of SAR wavelength to mean harvested DBH. Requires extensive calibration and ground verification.	Detectable if overstory is significantly affected, use in conjunction with optical

6.0 METHODS TO MEASURE AND MONITOR DEGRADATION

Once it has been determined that one or more forms of forest degradation cause significant emissions (see section 3.0), then the next step is to decide on how the measuring and monitoring of emissions will be accomplished.

In general, the methods used should be based on the significance of emissions from each activity. The IPCC describes three Tiers for estimating emissions, based on increasing levels of data complexity. For activities that result in 2-10% of emissions, global default values or Tier 1 methods can be considered appropriate. For activities that result in 11-20% of emissions higher level methods such as region or country specific Tier 2 data and methods should be used. For any activities that contribute more than 20% of total emissions, Tier 3 methods based on repeated inventories and spatially explicit activity data should be used to estimate emissions.

The type of monitoring that should be conducted depends on the significance of emissions from the degrading activity:

- Emissions from **timber harvesting** are often significant and can be measured with low uncertainty using Tier 3 methods or, where less significant, Tier 2 or Tier 1 variants
- Emissions from **fire** are often significant and can be measured with low uncertainty using Tier 3 methods, or where less significant, Tier 2 or Tier 1 variants

[10] There are several SAR wavelengths that have very different capabilities (e.g. C Band, L Band, X Band). The shorter wavelengths scatter off canopy tops, and the longer ones can penetrate the canopy and include the boles and the subsoil.

- Emissions from **fuelwood collection** generally have low significance and are very challenging to measure with low uncertainty. They are most cost effectively measured using regional or country-specific defaults/methods (Tier 2 or combined Tier 1 & 2).
- Emissions from less common activities such as grazing generally have low significance and are likely most appropriately measured using Tier 1 methods.

This section describes individual methods for measuring and monitoring forest degradation from the above activities[11], along with their requirements, the advantages and disadvantages of each, and references to the sources that provide more complete guidance.

For each activity included, there are a set of ***decision points*** that must be address:

- What is the likely significance of emissions and what Tier should be used for estimates?
- What relevant data currently exist and are they reliable and verifiable?
- What additional data are needed?
- Are there capacity and resources to collect additional required data? If not, can capacity be increased or will it be necessary to pursue alternative approaches such as hiring external consultants?
- How frequently will degradation be monitored?

6.1 Timber Harvesting

Selective timber harvesting can degrade forest carbon stocks, especially in humid tropical forests (Pearson et al 2014). Biomass is lost during harvesting operations from a number of sources: felling of the timber trees; incidental damage to trees surrounding the felled trees; and built infrastructure such as skid trails, log decks, and roads. Timber harvesting can be legal or illegal.

Legal timber harvesting is easier to measure and monitor, as harvest plans and volume data are often available. If data are available, illegal timber harvesting can be estimated, although the certainty of the emissions estimates will likely be lower given the nature of such logging and the relative reliability of data. When activity data for logging are based on government statistics or mill reporting, it is critical to consider how reliable the data are, whether they are regulated, and if they can be verified.

Pearson et al (2014) developed a complete accounting method for estimating emission factors from selective logging, including all sources of emissions. The method uses the IPCC gain-loss approach, and the total emission factor is the sum of these three sources of emissions, expressed as units of carbon per cubic meter of timber extracted:

$$\mathbf{TEF = ELE + LDF + LIF}$$

Where:

TEF = total emission factor resulting from timber harvest (t C m^{-3})

[11] Methods for measuring emissions from **shifting cultivation** are discussed in Annex B.

ELE = extracted log emissions (t C m^{-3}extracted)

LDF = logging damage factor—dead biomass carbon left behind in gap from felled tree and incidental damage (t C m^{-3}extracted)

LIF = logging infrastructure factor—dead biomass carbon caused by construction of infrastructure (t C m^{-3})

The total emission factor can then be multiplied by activity data derived from timber harvesting statistics, typically expressed as volume over-bark harvested in cubic meters, to estimate total emissions from logging operations. Alternately, activity data can be based on area logged, in which case emission factors must be developed as tons of carbon per hectare. This method is likely to be less accurate as it can be difficult to identify all logging areas using remote sensing (Indufor 2013).

The data needed to estimate emissions from timber harvesting are given in Table 3. Both Tier 2 and Tier 3 would require original data collection in the REDD+ country. The difference would be in the completeness of data collection, with a Tier 2 being just a limited sampling of timber harvesting sites to develop national factors and Tier 3 being more finely stratified by area and by harvesting practices within the country. Walker et al (2015) provides a description of the fieldwork required for the development of Tier 3 emission factors specific to a jurisdiction.

Table 3. Requirements and sources of data needed to estimate emissions from timber harvesting

Type of data	Specific data needs	Sources for Tier 1 data	Sources for Tier 2 & 3 data	References
Activity Data	Timber extraction data (volume per hectare or total volume) on an annual basis	FAO Global Forest Resources Assessment	Government statistics, timber concession reporting, mill reporting	Pearson et al 2014
	Area of logged forest per year	Limited availability in FAO Global Forest Resources Assessment (often total area of produciton forests only)	Government statistics, timber concession reporting, remote sensing data	GOFC-GOLD 2014; Souza et al 2013; Shimabukuro et al. 2014
	Area of logging roads, skid trails, logging decks	Not available	Government statistics, timber concession reporting, high resolution remote sensing data	Pearson et al 2014; Brown et al. 2011

Emission Factors	Measurements of logged trees (ELE)	Pearson et al (2014)	Pearson et al (2014) correlation; Fieldwork/REDD+ NFMS	Pearson et al 2014; Walker et al 2015
	Extent of incidental damage (LDF)	Pearson et al (2014)	Pearson et al (2014) correlation; Fieldwork/REDD+ NFMS	Pearson et al 2014; Walker et al 2015
	Extent of infrastructure (LIF)	Pearson et al (2014)	Fieldwork/REDD+ NFMS	Pearson et al 2014; Walker et al 2015

6.2 Human-Induced Fire

The impact of fire on forests is complex - fires can be ground fires where smaller trees and understory are burned, or intense stand-replacing fires where the post-burn area may or may not recover at all. In the case of human-induced fires intended to clear land for agriculture or other uses, the result is deforestation, and should be captured as such. However, these fires sometimes escape into the surrounding forests, resulting in degradation rather than a change in land cover. Most fires in tropical forests are human-induced (GOFC-GOLD 2014), and should be accounted under a REDD+ scheme.

Fires result in emissions of three main gases: carbon dioxide, methane, and nitrous oxide. All three gases should be accounted in estimating emissions from fire, with methane and nitrous oxide converted to carbon dioxide equivalent.

Fires are generally detectable by satellite imagery, even those that result in degradation rather than deforestation. Monitoring fire annually or biannually may be necessary, as regrowth can quickly eliminate evidence of smaller fires in remotely sensed imagery[12].

Emission factors for fire can be developed based on Eq. 2.27 in the IPCC 2006 Guidelines for National Greenhouse Gas Inventories (GL), Volume 2:

$$L_{fire} = M_B * C_f * G_{ef} * 10^{-3}$$

Where:

L_{fire} = amount of greenhouse gas emissions from fire, t $ha^{-1}$of each GHG ha^{-1} e.g., CO_2, CH_4, N_2O

M_B = biomass of fuel available for combustion, t ha^{-1}. This includes biomass in all selected pools, excluding belowground biomass as this it is unlikely to burn.

C_f = combustion factor (proportion of pre-fire biomass that burns; from Table 2.6 IPCC 2006 GL), dimensionless.

[12] Note that this does not mean that the effects of fire do not persist, merely that they may not be detectable from imagery for extended periods of time.

G_{ef} = emission ratio, g kg^{-1} dry matter burnt (from Table 2.5 IPCC 2006 GL) for each GHG as follows: 1580 for CO_2, 6.8 for CH_4, and 0.20 for N_2O

Emission estimates for each gas (L_{fire}) must be converted to carbon dioxide equivalents by multiplying by the appropriate 100 year global warming potential factor (34 for methane and 298 for nitrous oxide[13]).

The data needed to estimate emissions from human-induced fires are given in Table 4. For Tier 2, data from scientific literature specific to the region and/or country or original data collection will be needed to develop emission factors. For Tier 3 it is likely that fire scientists will have to be involved to develop detailed emissions modeling or calculations. Walker et al (2015) provides a description of the fieldwork required for the development of Tier 2 emission factors specific to a jurisdiction.

Table 4. Requirements and sources of data needed to estimate emissions from fire

Type of data	Specific data needs	Sources for Tier 1 data	Sources for Tier 2 & 3 data	References
Activity Data	Total area and location of fire	Global datasets	Medium to high resolution RS data, field surveys	GOFC-GOLD 2014; Souza et al 2013; Shimabukuro et al. 2014; Indufor 2013
Emission Factors	Biomass in all relevant pools (M_B)	Default values	NFI, REDD+ NFMS	Walker et al 2015; IPCC 2006
	Combustion factor and emission ratios (C_f & G_{ef})	Default values	Specific values if available	IPCC 2006

6.3 Fuelwood and Charcoal Collection

Woody biomass is collected for fuel or charcoal for both domestic and commercial use. The wood collected is generally either standing or lying dead wood (including residues from timber harvest), or individual live trees. A critical factor for fuelwood specifically is whether sufficient stocks are extracted to degrade the forest. Determining the answer to this question will often require modeling of supply of fuel. Bailis et al (2015) have developed a spatial supply and demand method to estimate greenhouse gas emissions related to the harvesting of wood for fuel use: Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM)[14]. The method uses available data on woodfuel demand, based on

[13] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang (2013) "Anthropogenic and Natural Radiative Forcing". In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Anthropogenic and Natural Radiative Forcing

[14] See http://www.wisdomprojects.net/global/.

national and sub-national studies, and separately maps subsistence demand, occurring in rural areas, and commercial demand, occurring in more densely populated areas. Aboveground woody biomass is mapped across the relevant landscape, and the mean annual increment is used to estimate the woodfuel supply. Supply and demand maps are combined to define a woodshed and determine the minimum quantity of non-renewable biomass required to meet existing demand. Greenhouse gas emissions are then estimated from two flows: combustion emissions and CO_2 sequestered by renewable portion of harvested woodfuel.

Drigo et al. (2014) conducted a subnational spatial analysis of fuelwood demand and supply potential for 86 tropical countries using the WISDOM method. The World Bank REDD+ Decision Support Toolbox uses this analysis to estimate emissions from fuelwood collection and use (Sidman et al 2014). Estimates of non-renewable biomass (NRB), the extracted biomass that causes degradation, are given along with location of consumption. The NRB from land cover change (LCC) by-products (deadwood remaining after deforestation) was calculated as well as some wood that is burned as fuelwood comes from deforestation rather than degradation. In an effort to avoid double-counting emissions, in the World Bank REDD+ Decision Support Toolbox, only the fuelwood demand that was satisfied by non-LCC by-products was considered to count only fuelwood collection that resulted in forest degradation.

The WISDOM method, with output as provided by the REDD+ DST is recommended for use because fuelwood collection is difficult to detect spatially and because its use comprises a relatively small proportion of degradation emissions. . The subnational jurisdiction values of Drigo et al. (2014) can be considered to be a Tier 2 approach. If a Tier 3 estimate of emissions is desired, a more detailed scientific investigation will be needed. One approach could follow the VCS REDD Methodological Module on the estimation of emissions from fuelwood extraction that can be followed[15]. This method relies on projected volume of fuelwood use, based on household and commercial surveys, and uses the following equation:

$$\Delta C_{BSL,degrad-FW/C} = \sum_{t=1}^{t*} \sum_{i=1}^{M} \left(\left(\frac{FS_{BSL,i,t} * D_{mn}}{0.9} * CF * \frac{44}{12} \right) + GHG_{BSL,E} \right)$$

Where:

$\Delta C_{BSL,degrad\text{-}FW/C}$	= Net greenhouse gas emissions in the baseline from degradation caused by fuelwood collection and charcoal making; t CO_2e
$FG_{BSL,i,t}$	= Average projected volume of fuelwood to be gathered in the project area in the baseline scenario in stratum *i* at time *t*; m^3
D_{mn} *l*	= Mean wood density of species harvested for fuelwood or charcoal production; t d.m. m^{-3}
CF	= Carbon fraction of dry matter; t C t d.m.$^{-1}$
$GHG_{BSL,E}$	= Greenhouse gas emissions as a result of degradation activities within the project boundary in the baseline; t CO_2e

[15] Approved VCS Module VMD0008, available at http://www.v-c-s.org/sites/v-c-s.org/files/VMD0008%20BL-DFW%20Fuelwood%20baseline.pdf.

i	= 1, 2, 3, …M strata	
t	= 1, 2, 3, … t^* years elapsed since the projected start of the REDD project activity	

The data needed to estimate emissions from fuelwood collection are given in Table 5.

Table 5. Requirements and sources of data needed to estimate emissions from fuelwood

Type of data	Specific data needs	Sources for Tier 1 data	Sources for Tier 2 & 3 data	References
Activity Data	Total amount of fuelwood collected	Global datasets	WISDOM analysis, field surveys, statistics	Bailis et al 2015; Drigo et al 2014; VCS VMD0008
Emission Factors	Biomass in all relevant pools	Default values	WISDOM analysis, NFI, REDD+ NFMS	

6.4 Overgrazing

Where grazing animals are allowed on forest land, they kill or damage young and regenerating trees both by browsing and by trampling. This leads to forest degradation because new seedlings do not survive and tree girdling leads to the ultimate mortality of larger trees. Ultimately intense grazing can slowly lead to deforestation, but degradation occurs as an intermediate step. Grazing of forests generally occurs on the forest fringes adjacent to grazing lands or may in some cases become more broadly possible once other activites (i.e., fire and logging) have reduced canopy cover allowing understory and grass growth. It is unlikely that degradation from grazing will result in a significant amount of greenhouse gas emissions, even if there is a significant impact to the understory (IPCC 2003). There are no commonly accepted methods of monitoring grazing, and any estimates are likely to have high uncertainty because it is difficult to accurately identify the appropriate area.

The data needed to estimate emissions from over grazing are given in Table 6.

Table 6. Requirements and sources of data needed to estimate emissions from overgrazing

Type of data	Specific data needs	Sources for Tier 1 data	Sources for Tier 2 & 3 data	Source of data or methods
Activity Data	Total area and location of overgrazing	Default values, literature	Government statistics, field surveys	GOFC-GOLD 2014; IPCC 2006; Hosonuma et al 2012
Emission Factors	Carbon stocks by area/forest type, before and after grazing	Default values	NFI, REDD+ NFMS	IPCC 2006; Walker et al 2014

6.5 Other forms of degradation

Where **land use change** occurs but the loss of canopy cover does not reach the threshold necessary for an area to be defined as non-forest then technically degradation rather than deforestation has occurred. This could happen where trees are left around fields, or through settlement. Emissions from land use change can be estimated based on emission factors derived from the difference between carbon stocks at time one and time two. Area change can be estimated using remote sensing if change is visible from imagery, or from field data if not. The certainty of emission estimates is based on the accuracy and precision of the carbon stock and area change data.

The impacts of pollution can reduce forest health and lead to lower forest biomass, with emissions resulting from tree mortality. This might occur where there are tailings from mines or run-off or air pollution from industry. Emissions resulting from **forest pollution** can be estimated similar to those from land use/land cover change, based on carbon stocks at time one and time two and area impacted by pollution.

7.0 FRAMEWORK FOR DEGRADATION MEASUREMENT AND MONITORING PLAN

If degradation is significant enough to be accounted (see Section 2), it needs to be included in a REDD+ Measurement and Monitoring Plan. The outline below provides an overview of the items that such a plan must address for forest degradation. It is intended to assist countries and jurisdictions in collating information identified and addressing the decisions outlined in this document. It assumes that the overall Forest Measurement and Monitoring Plan will include basic information such as the area of interest and the definition of a forest. Some of the information listed below will be addressed for deforestation, but may differ somewhat for degradation, in which case it should be addressed separately.

1. Agreed degradation definition for area of interest
2. Assessment of current conditions
    - Location of degradation
    - Types of degradation
        - Assessment of type, location and significance of degradation, based on first order greenhouse gas estimate associated with identified degrading activities
    - First order assessment of emissions from each type of degradation
        - Based on existing data or World Bank REDD+ DST
        - Estimate significance of each type of degradation
3. Monitoring design
    - Land-based or Activity-based approach
        - If land-based, degradation will be included with all emissions, rather than by activity, as described here
    - Monitoring objectives

        - Precision target for each type of degradation (Tier 1, 2, or 3)
        - Justification for inclusion/exclusion of each degrading activities
    - Available data relevant to significant types of degradation
        - Vegetation classifications and maps
        - National forest inventories
        - Degradation activities/socio-economic data
        - Remote sensing products
        - Biomass equations/emissions factors
    - Gap assessment
        - Need for additional data
        - Costs for additional data collection
    - Institutional capacity for additional data collection
    - Monitoring systems
        - Default or global datasets
        - Emission factors – field inventory
        - Activity data – statistical information (e.g. volume harvested)
        - Activity data – remote sensing change detection
4. Data analyses
    - Emission factors/field data analysis
    - Activity data/RS imagery/statistical information
    - Total emissions
    - Uncertainty
    - Predictive modeling, if applicable
5. Implementation plan
    - Responsible parties
    - Schedule and cost estimate
        - Test through pilot interventions and/or full implementation?
        - Personnel and equipment
        - Data acquisition
        - Data analysis
        - Reporting
    - Integration with implementation of deforestation measurement and monitoring

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ANNEX A: EMISSION ESTIMATES BY PROVINCE

The tables below provide **first order** emission estimate by province for the Lower Mekong countries, Papua New Guinea, and Malaysia, and are drawn from the Winrock-developed FCPF REDD+ Decision Support Toolbox (Sidman et al 2014, http://redd-dst.ags.io)[16]. The DST is composed of a series of four modules that cover the design of the technical elements of a REDD+ program:

1. REDD+ Design
2. Reference Levels
3. National Forest Monitoring
4. Reporting and Verification

The modules guide users through a series of decisions related to the construction of a REDD+ Program and provide pragmatic support based on current REDD+ standards and guidelines as defined by the United Nations Framework Convention on Climate Change (UNFCCC), the World Bank Forest Carbon Partnership Facility (FCPF), and the Verified Carbon Standard (VCS). Using global datasets and scientifically sound methods, the REDD+ Decision Support Tool offers location-specific first-order estimates of emissions from deforestation, degradation, and potential C removals/sequestration based on available land. In addition, the DST builds a customized basic REDD+ Reference Level that reflects user input and selection of C pools.

The tool allows REDD+ stakeholders to understand how different decisions fit together at a high level, while providing guidance in sufficient detail to build internal capacity and operationalize essential components of a REDD+ program. In particular, for countries that have expressed interest in the Forest Carbon Partnership Facility (FCPF) Carbon Fund, the tool presents a structured approach that helps country stakeholders formulate clear and coherent ideas for their emission reduction programs.

Below is a first-order analysis of publicly available data that provides an estimate of emissions or removals from each REDD+ activity in the lower Mekong countries and Papua New Guinea within the approximate period of 2000-2010. It is important to note that these data are based on global data sets meant only to provide first order estimates for countries and jurisdictions to decide which activities to include in their REDD+ programs and therefore, which activities (e.g. logging, fuelwood etc.) will require more accurate and precise emission estimates.

[16] Because Malaysia is not an FCPF country it is not included in the DST and estimates were calculated separately, using the same methods.

Cambodia								
Province	Deforestation[17]		Timber[18]		Fuelwood[19]		Fire[20]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Bântéay Méanchey	432,248	62%	3,901	1%	54,797	8%	209,605	30%
Batdâmbâng	6,554,571	76%	44,254	1%	62,887	1%	1,926,707	22%
Kâmpóng Cham	2,694,254	90%	19,938	1%	90,160	3%	202,459	7%
Kâmpóng Chhnang	364,908	39%	12,351	1%	21,870	2%	534,305	57%
Kâmpóng Spœ	1,781,383	54%	19,014	1%	53,106	2%	1,430,197	44%
Kâmpóng Thum	6,281,781	91%	60,408	1%	35,719	1%	553,103	8%
Kâmpôt	1,317,703	88%	16,243	1%	38,689	3%	125,898	8%
Kândal	24,233	11%	5,183	2%	183,850	83%	7,284	3%
Kaôh Kong	4,313,873	82%	96,990	2%	4,039	0%	816,135	16%
Kep	8,732	73%	240	2%	2,481	21%	572	5%
Krâchéh	6,590,201	77%	65,057	1%	5,253	0%	1,881,307	22%
Krong Pailin	2,056,974	83%	6,256	0%	62	0%	421,559	17%
Krong Preah Sihanouk	763,316	92%	7,666	1%	19,954	2%	34,437	4%
Môndól Kiri	1,175,743	20%	76,165	1%	2,651	0%	4,661,536	79%
Otdar Mean Chey	2,041,278	95%	17,413	1%	1,868	0%	94,860	4%
Phnom Penh	327	0%	105	0%	308,513	100%	422	0%
Pouthisat	2,680,026	55%	71,372	1%	41,985	1%	2,060,721	42%
Preah Vihéar	2,014,980	58%	85,754	2%	6,695	0%	1,357,258	39%

[17] All deforestation emissions are calculated based on Hansen, et al. 2013. and Saatchi, et al. 2011

[18] All emission estimates relate to timber are based on FAO Data and Timothy R H Pearson et al 2014 methods

[19] All emission estimates related to fuel wood are based on R. Drigo. 2014. Elaboration of the pan-tropical analysis of NRB harvesting (Tier 1 data, version 01 April 2014) produced by the Yale-UNAM GACC Project" Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and Beyond" for the Global Alliance for Clean Cookstoves (GACC). Ref: Drigo R., R. Bailis, O. Masera, and A Ghilardi. May 2014. Yale-UNAM NRM Project: Tier 1: Final Report.

[20] All emission estimates related to fire are based on http://www.globalfiredata.org/

Cambodia

Province	Deforestation[17]		Timber[18]		Fuelwood[19]		Fire[20]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Prey Vêng	20,045	14%	433	0%	116,142	83%	3,180	2%
Rôtânôkiri	4,505,594	54%	78,434	1%	2,864	0%	3,828,089	45%
Siemréab	4,587,523	87%	52,390	1%	93,544	2%	549,089	10%
Stœng Trêng	3,293,739	50%	81,395	1%	825	0%	3,264,014	49%
Svay Rieng	99,000	60%	1,012	1%	61,686	37%	3,047	2%
Takêv	8,762	11%	593	1%	67,553	84%	3,551	4%

Laos

Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Attapu	3,563,272	80%	127,241	3%	477	0%	740,526	17%
Bokeo	2,553,424	77%	95,275	3%	572	0%	658,836	20%
Bolikhamxai	7,524,164	82%	219,651	2%	10,049	0%	1,414,377	15%
Champasak	2,875,259	72%	155,532	4%	78,753	2%	908,658	23%
Houaphan	6,688,686	62%	246,129	2%	1,113	0%	3,882,449	36%
Khammouan	4,328,333	91%	216,071	5%	55,361	1%	175,136	4%
Louang Namtha	5,574,660	80%	141,822	2%	1,181	0%	1,226,137	18%
Louangphrabang	5,143,808	46%	285,469	3%	77,367	1%	5,682,004	51%
Oudômxai	3,646,530	60%	168,158	3%	2	0%	2,229,932	37%
Phôngsali	3,187,731	63%	222,345	4%	2	0%	1,636,774	32%
Saravan	1,945,001	91%	116,684	5%	1,940	0%	66,419	3%
Savannakhét	4,229,295	90%	200,773	4%	63,972	1%	187,123	4%
Vientiane	3,586,896	48%	155,429	2%	67,227	1%	3,667,529	49%

Laos								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Vientiane [prefecture]	912,496	54%	25,225	1%	475,708	28%	277,539	16%
Xaignabouri	3,096,352	32%	203,631	2%	33,651	0%	6,209,471	65%
Xaisômboun	1,877,947	46%	108,462	3%	132	0%	2,075,501	51%
Xékong	3,096,148	90%	119,459	3%	117	0%	206,230	6%
Xiangkhoang	3,147,805	54%	166,700	3%	27,335	0%	2,437,030	42%

Malaysia								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Johor	28,025,721	84%	5,464,693	16%	0	0%	46,910	0%
Kedah	5,725,103	71%	2,332,756	29%	0	0%	4,881	0%
Kelantan	13,116,141	76%	4,110,351	24%	0	0%	56,304	0%
Melaka	684,399	63%	393,868	37%	0	0%	688	0%
Negeri Sembilan	7,800,960	80%	1,919,480	20%	0	0%	4,838	0%
Pahang	48,758,227	81%	11,187,380	19%	0	0%	155,069	0%
Perak	21,590,272	77%	6,500,426	23%	0	0%	40,947	0%
Perlis	79,331	45%	98,020	55%	0	0%	173	0%
Paulau Pinang	215,717	56%	167,582	44%	0	0%	0	0%
Sabah	55,843,007	70%	22,745,660	28%	0	0%	1,496,535	2%
Sarawak	225,395,575	84%	39,397,020	15%	0	0%	2,443,077	1%
Selangor	10,948,579	84%	1,983,216	15%	0	0%	27,671	0%
Trengganu	8,829,005	70%	3,776,888	30%	0	0%	26,129	0%

Papua New Guinea								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Central	1,498,336	50%	712,692	24%	374,374	12%	420,811	14%
Chimbu	305,895	57%	150,952	28%	51,231	10%	28,657	5%
East New Britain	3,272,359	83%	399,490	10%	58,117	1%	189,586	5%
East Sepik	2,862,091	69%	1,020,439	25%	814	0%	272,633	7%
Eastern Highlands	564,808	58%	250,485	26%	120,096	12%	45,625	5%
Enga	638,005	66%	290,429	30%	8,389	1%	33,998	4%
Gulf	1,882,430	67%	893,200	32%	215	0%	41,270	1%
Madang	4,387,875	78%	723,487	13%	34,324	1%	503,837	9%
Manus	321,547	85%	54,588	14%	1,954	1%	-	0%
Milne Bay	2,985,806	87%	345,401	10%	429	0%	89,344	3%
Morobe	3,049,097	68%	798,866	18%	372,081	8%	252,784	6%
New Ireland	1,366,984	83%	248,540	15%	30,842	2%	2,880	0%
North Solomons	2,303,142	90%	242,881	10%	7,755	0%	2,124	0%
Northern	3,052,835	75%	576,184	14%	41,928	1%	382,058	9%
Sandaun	3,114,183	74%	917,806	22%	71,148	2%	82,104	2%
Southern Highlands	1,019,360	56%	653,988	36%	6,219	0%	125,537	7%
West New Britain	6,014,216	78%	525,679	7%	29,526	0%	1,097,288	14%
Western	4,226,666	29%	2,427,021	16%	383	0%	8,174,833	55%
Western Highlands	754,278	68%	221,802	20%	109,753	10%	26,634	2%

Thailand								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Amnat Charoen	600,896	100%	383	0%	72	0%	278	0%
Ang Thong	519	6%	33	0%	1,144	13%	7,023	81%
Bangkok Metropolis	1,671	1%	53	0%	127,589	98%	474	0%
Buri Ram	44,144	91%	723	1%	1,476	3%	2,090	4%
Chachoengsao	129,353	81%	844	1%	1,778	1%	28,535	18%
Chai Nat	14,215	54%	86	0%	416	2%	11,494	44%
Chaiyaphum	43,802	33%	2,946	2%	138	0%	87,878	65%
Chanthaburi	890,638	84%	3,527	0%	-	0%	170,874	16%
Chiang Mai	1,721,842	25%	15,311	0%	13,669	0%	5,236,183	75%
Chiang Rai	992,082	57%	5,208	0%	3,491	0%	754,389	43%
Chon Buri	253,845	95%	725	0%	6,837	3%	6,668	2%
Chumphon	2,042,558	78%	4,381	0%	1,151	0%	570,807	22%
Kalasin	76,419	97%	444	1%	798	1%	1,101	1%
Kamphaeng Phet	188,075	34%	1,837	0%	246	0%	358,980	65%
Kanchanaburi	1,207,441	29%	9,837	0%	1,344	0%	2,920,194	71%
Khon Kaen	14,095	29%	734	1%	5,982	12%	28,413	58%
Krabi	3,969,405	97%	3,691	0%	145	0%	137,705	3%
Lampang	995,745	73%	8,172	1%	2,125	0%	359,782	26%
Lamphun	381,430	60%	2,352	0%	948	0%	248,056	39%
Loei	224,010	16%	3,558	0%	-	0%	1,135,637	83%
Lop Buri	9,237	27%	374	1%	1,172	3%	23,994	69%
Mae Hong Son	1,031,651	10%	10,745	0%	-	0%	9,043,549	90%
Maha Sarakham	1,265	42%	25	1%	1,322	44%	391	13%
Mukdahan	612,377	99%	1,263	0%	535	0%	1,667	0%
Nakhon Nayok	27,279	69%	675	2%	814	2%	10,962	28%

Thailand								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Nakhon Pathom	5,291	26%	196	1%	8,430	42%	6,317	31%
Nakhon Phanom	578,876	94%	814	0%	926	0%	34,876	6%
Nakhon Ratchasima	208,456	87%	2,695	1%	11,581	5%	17,064	7%
Nakhon Sawan	102,514	37%	734	0%	1,302	0%	169,867	62%
Nakhon Si Thammarat	4,379,412	99%	6,095	0%	5,482	0%	28,086	1%
Nan	2,294,670	49%	8,894	0%	711	0%	2,359,069	51%
Narathiwat	3,443,914	100%	3,550	0%	3,854	0%	5,260	0%
Nong Bua Lam Phu	12,190	7%	280	0%	-	0%	165,235	93%
Nong Khai	355,327	66%	725	0%	2,746	1%	175,606	33%
Nonthaburi	2,989	13%	46	0%	18,931	82%	1,036	5%
Pathum Thani	3,246	18%	58	0%	8,883	49%	5,954	33%
Pattani	312,621	98%	921	0%	4,743	1%	1,871	1%
Phangnga	2,659,239	100%	3,205	0%	-	0%	172	0%
Phatthalung	977,120	100%	1,729	0%	563	0%	186	0%
Phayao	696,244	81%	3,120	0%	288	0%	159,331	19%
Phetchabun	116,224	35%	3,733	1%	398	0%	211,883	64%
Phetchaburi	361,591	83%	3,043	1%	1,645	0%	69,759	16%
Phichit	8,749	51%	72	0%	31	0%	8,365	49%
Phitsanulok	300,116	60%	3,896	1%	1,392	0%	195,723	39%
Phra Nakhon Si Ayutthaya	2,916	7%	83	0%	7,209	18%	29,982	75%
Phrae	924,050	90%	4,409	0%	2,789	0%	98,946	10%
Phuket	245,224	99%	325	0%	3,329	1%	-	0%
Prachin Buri	58,803	55%	1,507	1%	413	0%	45,441	43%
Prachuap Khiri Khan	784,871	84%	2,984	0%	1,131	0%	145,472	16%
Ranong	1,279,695	93%	2,562	0%	407	0%	93,125	7%

Thailand								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Ratchaburi	347,805	73%	1,438	0%	5,218	1%	122,022	26%
Rayong	574,951	99%	1,318	0%	2,933	1%	4,374	1%
Roi Et	123,010	98%	222	0%	2,110	2%	582	0%
Sa Kaeo	70,404	38%	1,328	1%	721	0%	114,331	61%
Sakon Nakhon	244,669	88%	1,237	0%	204	0%	32,096	12%
Samut Prakan	1,108	5%	34	0%	20,075	93%	265	1%
Samut Sakhon	5,445	44%	169	1%	6,233	50%	558	5%
Samut Songkhram	3,145	44%	187	3%	2,343	33%	1,413	20%
Saraburi	69,526	82%	754	1%	2,996	4%	11,946	14%
Satun	1,264,074	100%	1,978	0%	117	0%	198	0%
Si Sa Ket	152,918	81%	995	1%	1,778	1%	32,181	17%
Sing Buri	291	4%	19	0%	1,155	17%	5,367	79%
Songkhla	3,466,972	100%	4,417	0%	9,198	0%	2,320	0%
Sukhothai	743,072	86%	1,986	0%	-	0%	120,244	14%
Suphan Buri	53,000	54%	674	1%	4,015	4%	41,135	42%
Surat Thani	8,264,970	99%	9,887	0%	3,680	0%	109,144	1%
Surin	62,229	79%	627	1%	1,755	2%	14,164	18%
Tak	1,236,751	23%	11,618	0%	471	0%	4,031,282	76%
Trang	3,871,535	100%	3,631	0%	4,440	0%	452	0%
Trat	537,357	78%	1,616	0%	-	0%	149,549	22%
Ubon Ratchathani	1,108,826	95%	2,418	0%	6,131	1%	49,065	4%
Udon Thani	112,836	35%	889	0%	5,764	2%	204,814	63%
Uthai Thani	138,954	25%	3,011	1%	-	0%	411,381	74%
Uttaradit	651,779	70%	4,421	0%	686	0%	272,984	29%
Yala	1,915,648	99%	3,699	0%	2,712	0%	6,136	0%

Thailand								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Yasothon	244,812	99%	221	0%	583	0%	522	0%

Vietnam								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
An Giang	9,882	6%	59,383	34%	97,581	56%	8,596	5%
Ba Ria - VTau|Ba Ria-Vung Tau	231,684	68%	78,400	23%	29,759	9%	2,480	1%
Bac Giang	566,963	72%	165,268	21%	57,431	7%	1,375	0%
Bac Kan|Bac Can	596,415	53%	534,578	47%	-	0%	1,851	0%
Bac Lieu	2,768	8%	10,289	29%	22,150	62%	295	1%
Bac Ninh	158	0%	337	1%	52,340	99%	-	0%
Ben Tre	763	1%	50,131	48%	51,014	48%	3,397	3%
Binh Dinh	1,879,319	78%	477,057	20%	44,596	2%	5,724	0%
Binh Duong	804,009	84%	133,945	14%	20,130	2%	2,412	0%
Binh Phuoc	2,537,818	73%	513,227	15%	-	0%	414,576	12%
Binh Thuan	2,498,641	76%	375,138	11%	28,133	1%	384,519	12%
Ca Mau	395,145	76%	109,419	21%	14,192	3%	1,187	0%
Can Tho	2,412	3%	15,228	21%	48,578	68%	5,591	8%
Cao Bang	375,053	38%	618,888	62%	-	0%	3,473	0%
Da Nang City|Da Nang	382,188	77%	79,480	16%	34,976	7%	22	0%
Dac Nong	3,331,837	57%	759,435	13%	5,218	0%	1,720,803	30%
Dak Lak|Dac Lac	4,470,740	81%	560,726	10%	-	0%	490,427	9%

Vietnam								
	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
Province	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Dien Bien	1,871,316	47%	814,530	21%	2,323	0%	1,269,747	32%
Dong Nai	706,866	64%	347,956	31%	48,957	4%	5,115	0%
Dong Thap	11,287	8%	51,902	37%	55,204	39%	22,303	16%
Gia Lai	6,616,099	75%	1,155,582	13%	-	0%	1,060,379	12%
Ha Giang	614,996	49%	626,786	50%	-	0%	6,187	0%
Ha Nam	8,196	14%	7,953	14%	41,573	72%	11	0%
Ha Noi City|Hanoi	6,946	4%	2,819	2%	172,014	95%	-	0%
Ha Tay	30,045	17%	18,699	10%	129,263	72%	2,479	1%
Ha Tinh	1,794,902	79%	434,172	19%	45,804	2%	9,404	0%
Hai Duong	14,489	11%	8,617	7%	103,323	82%	24	0%
Hai Phong City|Haiphong	16,087	11%	21,003	14%	114,019	75%	-	0%
Hau Giang	4,230	5%	41,228	50%	35,913	44%	565	1%
Ho Chi Minh City|Ho Chi Minh	21,716	5%	57,916	14%	343,184	81%	162	0%
Hoa Binh	553,969	53%	372,680	36%	6,508	1%	104,462	10%
Hung Yen	115	0%	178	0%	62,341	100%	-	0%
Khanh Hoa	992,941	70%	365,088	26%	37,378	3%	32,338	2%
Kien Giang	221,580	58%	120,604	32%	35,631	9%	1,605	0%
Kon Tum	4,048,774	82%	765,903	15%	834	0%	144,480	3%
Lai Chau	484,061	27%	747,032	41%	-	0%	574,846	32%
Lam Dong	3,124,416	74%	941,555	22%	19,179	0%	158,013	4%
Lang Son	933,604	55%	766,135	45%	-	0%	4,402	0%
Lao Cai	531,158	51%	440,373	42%	-	0%	70,248	7%
Long An	41,656	25%	93,138	55%	22,898	13%	12,327	7%
Nam Dinh	570	0%	4,022	3%	128,476	96%	106	0%

Vietnam								
Province	Deforestation[15]		Timber[16]		Fuelwood[17]		Fire[18]	
	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total	Emissions (tCO2/yr)	% of total
Nghe An	2,615,018	56%	1,409,237	30%	96,703	2%	556,713	12%
Ninh Binh	37,116	33%	32,630	29%	43,929	39%	74	0%
Ninh Thuan	421,653	63%	181,520	27%	21,507	3%	42,905	6%
Phu Tho	379,667	59%	193,692	30%	33,638	5%	34,843	5%
Phu Yen	1,480,675	80%	332,467	18%	19,364	1%	14,872	1%
Quang Binh	1,182,294	60%	764,311	39%	16,168	1%	17,109	1%
Quang Nam	3,019,082	73%	1,034,361	25%	45,624	1%	61,676	1%
Quang Ngai	2,296,376	84%	421,200	15%	30,259	1%	2,298	0%
Quang Ninh	1,471,799	75%	455,908	23%	22,370	1%	20,119	1%
Quang Tri	1,955,517	82%	406,872	17%	12,558	1%	15,051	1%
Soc Trang	6,149	7%	30,809	37%	45,668	55%	896	1%
Son La	3,837,716	54%	1,125,159	16%	1,177	0%	2,174,099	30%
Tay Ninh	139,235	48%	111,387	38%	10,967	4%	30,921	11%
Thai Binh	668	1%	3,514	3%	118,861	97%	33	0%
Thai Nguyen	504,105	65%	250,004	32%	22,554	3%	-	0%
Thanh Hoa	1,377,725	53%	799,282	31%	146,287	6%	268,852	10%
Thua Thien - Hue	979,053	67%	427,837	29%	40,432	3%	4,321	0%
Tien Giang	2,993	2%	51,717	37%	76,760	55%	8,878	6%
Tra Vinh	8,791	13%	21,872	31%	38,403	55%	1,020	1%
Tuyen Quang	1,360,023	72%	515,261	27%	-	0%	1,163	0%
Vinh Long	2,074	2%	26,002	29%	55,754	62%	6,532	7%
Vinh Phuc	51,689	38%	28,314	21%	55,631	41%	8	0%
Yen Bai	896,416	55%	585,085	36%	1,005	0%	157,087	10%

ANNEX B: SHIFTING CULTIVATION

Shifting cultivation, or swidden agriculture, is an agricultural system where land is cleared of forest and cultivated temporarily until its productivity diminishes. The land is then left fallow to regenerate for a period of time until it is cultivated again. The length of the fallow and cultivation periods will vary according to cultivation practices, soil fertility, market opportunity, population growth, and possibly relevant policies. Kiyono et al (2011) make the distinction that pioneer shifting cultivation is deforestation, while rotational shifting cultivation is steady state. When the fallow period is shortened for shifting cultivation, carbon stocks are degraded, yet arguably this is occurring on agricultural land rather than forest land (though in some countries land in the Shifting Cultivation cycle is considered forest land).

When the forest is initially cleared for cultivation, the area impacted will be easy to detect through remote sensing if it is of sufficient size for the chosen resolution (Table B1). In subsequent re-clearings, however, it may be more difficult to identify the area accurately, especially if the fallow period is short.

Table B1. General detection capabilities of remote sensing methods for specific degradation activities (adapted and expanded from Manley et al. 2013).

Type	Method	Swidden agriculture/shifting cultivation Confirmed by village surveys/activity data
Optical	**Low resolution remote sensing (e.g. MODIS)**	5 ha field, needs to occur biannually or annually (of limited use as typical clearing is < 5 ha)
	Medium resolution remote sensing (e.g. LandSat)	1-2 ha field, needs to occur biannually or annually
	High resolution remote sensing (e.g. RapidEye)	Very detectable, needs to occur biannually or annually
Light Detection and Ranging (LIDAR)		Very detectable, needs to occur biannually or annually
High resolution synthetic-aperture radar (SAR)[21]		Very detectable, needs to occur biannually or annually

The **activity data** required for shifting cultivation includes the location and area of land under cultivation and the length of cycles of cultivation and fallow. Low resolution remote sensing imagery cannot detect change at a scale smaller than 5 hectares and is therefore not appropriate for shifting cultivation. Medium resolution imagery can detect change at a scale of 1-2 hectares, and would need to be analyzed

[21] There are several SAR wavelengths that have very different capabilities (e.g. C Band, L Band, X Band). The shorter wavelengths scatter off canopy tops, and the longer ones can penetrate all the way down to boles and into the subsoil.

biannually or annually. Medium resolution imagery can be used to identify areas of cultivation and monitor them annually for changes in length of fallow if remote sensing data are available for long enough periods of time. It may also be possible to determine cycle lengths using high resolution remote sensing data in the future when data over a longer time frame are available, but a more likely option is to conduct surveys of farmers practicing shifting cultivation supported by literature reviews and other data sources. Any remote sensing data should be verified through ground truthing and/or field surveys. Likewise, it may be possible to verify surveys using RS data.

Developing **emission factors** requires data on forest carbon stocks in all chosen pools, as well as carbon stocks of cultivated lands and fallow lands. It is important to note that for first time clearing the land cover will change from forest to agriculture, but subsequent fallow periods are unlikely to return to pre-clearing forest conditions. Therefore, the carbon stocks during fallow will be different from forest carbon stocks. Carbon stocks for all three of these conditions can be obtained through field inventory or use of default data. Emission factors can be developed in a number of ways:

- Time-weighted (and possibly area-weighted) average of carbon stocks for area under cultivation, applied once to the area converted from forest to shifting cultivation
- Emission factor for conversion from forest to agriculture, with subsequent application of growth rate to determine annual carbon stocks during fallow period. At next cultivation period, emission factor will be based on change from fallow to cultivated land.
- Identification of change in carbon stocks between each land use. Requires activity data for each change, which may be cost-prohibitive or even unattainable.

The data needed to estimate emissions from shifting cultivation are given in Table B2.

Table B2. Requirements and sources of data needed to estimate emissions from shifting cultivation

Type of data	Specific data needs	Sources for Tier 1 data	Sources for Tier 2 & 3 data	References
Activity Data	Area of land under cultivation	Local records, interviews	Remote sensing (medium or high resolution), ground truthing	GOFC-GOLD 2014; Souza et al 2013; Indufor 2013
Emission Factors	Live tree carbon stocks by forest type	Default values	Field inventory	Walker 2014; IPCC 2006
	Carbon stocks for other forest pools, by forest type	Default values	Field inventory	Walker 2013; GOFC-GOLD 2014; IPCC 2006
	Carbon stocks for fallow period/agriculture	Default values	Field inventory	Walker 2013; GOFC-GOLD 2014; IPCC 2006

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