Analysing REDD+

Challenges and choices

Editor Arild Angelsen

Co-editors Maria Brockhaus
William D. Sunderlin
Louis V. Verchot

Editorial assistant Therese Dokken

Language editing, project management and layout Green Ink Ltd

Printed in Indonesia
ISBN: 978-602-8693-80-6

Angelsen, A., Brockhaus, M., Sunderlin, W.D. and Verchot, L.V. (eds) 2012 Analysing REDD+: Challenges and choices. CIFOR, Bogor, Indonesia.

Photo credits:
Cover © Cyril Ruoso/Minden Pictures
Parts: 1. Habtemariam Kassa, 2. Manuel Boissière, 3. Douglas Sheil
Chapters: 1. and 10. Yayan Indriatmoko, 2. Neil Palmer/CIAT, 3. and 12. Yves Laumonier, 4. Brian Belcher, 5. Tony Cunningham, 6. and 16. Agung Prasetyo, 7. Michael Padmanaba, 8. Anne M. Larson, 9. Amy Duchelle, 11. Meyrisia Lidwina, 13. Jolien Schure, 14. César Sabogal, 15. Ryan Woo, 17. Edith Abilogo, 18. Ramadian Bachtiar

Designed by CIFOR's Multimedia Team, Information Services Group
Language editing, project management and layout by Green Ink Ltd (www.greenink.co.uk)

CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia

T +62 (251) 8622-622
F +62 (251) 8622-100
E cifor@cgiar.org

cifor.org
ForestsClimateChange.org

Center for International Forestry Research
CIFOR advances human wellbeing, environmental conservation and equity by conducting research to inform policies and practices that affect forests in developing countries. CIFOR is a CGIAR Consortium Research Center. CIFOR's headquarters are in Bogor, Indonesia and it also has offices in Asia, Africa and South America.

Chapter 15

Emissions factors
Converting land use change to CO_2 estimates

Louis V. Verchot, Kamalakumari Anitha, Erika Romijn, Martin Herold and Kristell Hergoualc'h

- The lack of country and region specific data poses a serious limitation to converting area estimates of deforestation and forest degradation to carbon stock change estimates for most tropical countries. Thus we cannot make accurate and precise estimates of emissions and removals in national REDD+ programmes and REDD+ demonstration activities.
- Progress on building the institutional capacity of countries to conduct forest inventories and other measurements for improving greenhouse gas inventories in forestry and other land use sectors has been slow in most non-Annex I countries.
- The above constraints can be overcome if coordinated, targeted investments are made and productive partnerships are developed between the technical services in REDD+ host countries, intergovernmental agencies and advanced research institutes in developed countries during the readiness phase.

15.1 Introduction

The ability to measure performance is a prerequisite for implementing any results-based mechanism and, in the context of REDD+, accurately measuring emissions reductions is part of this challenge (see Chapter 13). Many groups are working to develop measurement systems for supporting the implementation of REDD+ in countries lacking the technical capacities to accurately assess emissions from deforestation and degradation. Countries need to measure two types of parameters to assess emissions. 'Activity data' is the jargon used in monitoring, reporting and verification (MRV) circles to describe data on the magnitude of human activity resulting in emissions or removals. For REDD+, these data usually refer to the areas occupied by management systems, deforestation or degradation but they could also refer to other things, such as amounts of inputs, i.e. fertiliser. To estimate the carbon stock changes and other greenhouse gas emissions resulting from land use and land use changes, including those in forest areas with increasing biomass, countries require so-called 'emission/removal factors' (for simplicity, we will shorten this to emission factor [EF]). These factors represent the emissions or removals in all relevant carbon pools and of all relevant greenhouse gases (GHGs) per unit of activity. For example, if an average forest loses 200 tonnes of carbon per hectare when it is cut down and deforestation in a particular year is 2,000 hectares, a country could estimate its deforestation emissions by combining these two types of data. Subsequent land uses also have carbon stocks and GHG emissions (e.g. nitrous oxide from fertiliser or methane from livestock) and these must be taken into account when estimating the effects or the foregone effects of land use and land use change (for reference emissions, see Chapter 16).

A number of initiatives involve improving remote sensing technologies to detect deforestation, reforestation and forest degradation. Several efforts have focused on improving systems for national and international measurement and monitoring of deforestation and forest degradation (Achard *et al.* 2002; Bucki *et al.* 2012). These efforts involve improved methods for quantifying deforested areas, detecting areas that have been degraded and monitoring areas that have been replanted, etc. Yet most of these approaches stumble over the problem of converting area estimates into emissions or removals values because of the lack of reliable emissions factors for the wide variety of ecosystems. Studies suggest that as much as 60% of the uncertainty of emissions estimates is due to poor knowledge of carbon stocks in forests and other land use systems (Houghton *et al.* 2000; Baccini *et al.* 2012).

For several reasons, it is important to improve our knowledge of carbon stocks and GHG fluxes associated with land use and land use change as part of the readiness phase of REDD+. Improved knowledge can help to better target interventions and improve implementation efficiency. It will also improve benefit sharing schemes by ensuring that activities do not lead to false claims of emissions reductions and will help in properly attributing credit for real reductions.

The objective of this chapter is to look critically at constraints to MRV posed by the lack of emissions factors for important types of land use change and key carbon pools in tropical ecosystems. We will start with a brief overview of some important concepts underpinning the Intergovernmental Panel on Climate Change's (IPCC) greenhouse gas inventory methods and recommendations for good practices in this area. We will then look at the importance of emissions factors within this framework, examine the constraints in tropical ecosystems and some recent advances that are helping to reduce these constraints. Finally, we will discuss the roles of different stakeholders and analyse investment priorities for further reducing the challenges to MRV.

15.2 Introduction to the relationship between the IPCC, the UNFCCC and REDD+

The main efforts to develop methods for GHG inventories have been led by the National Greenhouse Gas Inventory Programme (NGGIP) of the IPCC, which issued a first set of guidelines for national GHG inventories in 1994. The guidelines were revised in 1996 (GL1996). They have provided a useful framework for the compilation of national estimates of emissions and removals in many sectors and still serve as the basis for national GHG inventories. However, there was a need for further guidance on how best to deal with uncertainties so that countries could produce inventories that were "accurate in the sense of being neither over nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable" (IPCC 2000). This led to the development of two supplementary reports on good practice to assist countries in "…the development of inventories that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and assurance, efficient in the use of the resources available to inventory agencies and in which uncertainties are gradually reduced as better information becomes available" (IPCC 2000; 2003). 'Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories' (GPG2000) was published in 2000 and provided updated guidelines for compiling inventories in several sectors, including agriculture (IPCC 2000). 'Good Practice Guidance for Land Use, Land Use Change and Forestry' (GPG-LULUCF) was published in 2003 (IPCC 2003). The 'Good Practice' reports did not replace the IPCC Guidelines but provided additional guidance or revisions, which complemented and were consistent with the guidelines.

In 2006, the IPCC issued a revision of the GL1996 that built on the GPG2000 and GPG-LULUCF. The revised guidelines (GL2006) recommend using consistent inventory methods for agriculture, forestry and other land uses to allow for more comprehensive inventories of emissions from most land use categories.

In a decision adopted by COP 15 in Copenhagen in 2009 (UNFCCC 2009b), the UNFCCC requested that countries wishing to participate in the REDD+ mechanism "use the most recent Intergovernmental Panel on Climate Change guidance and guidelines, as adopted or encouraged by the Conference of the Parties, as appropriate, as a basis for estimating anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks, forest carbon stocks and forest area changes." Thus, the GL1996 and the GPG-LULUCF provide the framework for current efforts in REDD+. However, decisions at COP17 in Durban in 2011 have set the UNFCCC on a path to adopt the 2006GL for use by 2015, so those guidelines can also be used.

The basic structure of the inventory procedures is organised around a simple equation:

$$Emission = A \bullet EF$$

This equation formalises what was said in the introduction about the types of data needed to develop an estimate of emissions. *A* represents activity data in the equation. The IPCC provides three possible approaches to obtaining activity data, which can be adapted to the needs of a particular inventory situation (see Chapter 14; IPCC 2006). The *EF* in the equation represents emission factors. These factors are often based on a sample of measurement data that can be averaged to yield a representative rate of emissions for a given activity associated with land use change (e.g. conversion of forestland to grassland) or with land remaining in a land use category (e.g. rehabilitated forestland).

In most cases, inventories cover five carbon pools: aboveground biomass, belowground biomass, deadwood, litter and soil organic matter. The IPCC uses the concept of key categories to determine the level of rigour that needs to be applied to estimating both activity data and emissions factors (IPCC 2000). A key source/sink category is an activity and/or carbon pool that has a significant influence on the estimate of GHGs with respect to the absolute level trend, or uncertainty in emissions and removals. A key category receives priority treatment in GHG inventory. In the aggregate, non-key sources and sinks comprise less than 10% of the uncertainty of an inventory or less than 5% of the total emissions. Detailed methods need to be used for estimating emissions and removals for key categories. Key category analysis is required to determine the following:

- Which land use and management activities are significant
- Which land use or livestock subcategories are significant
- Which emissions or removals from various carbon pools are significant

- Which non-CO_2 gases and from which categories are significant
- Which approach (see the description of tiers below) is required for reporting.

IPCC also identifies three 'tiers' for reporting. Tiers represent the methodological complexity required to estimate the emissions and removals from a category, based on its influence on a country's total inventory, data availability and national circumstances. The IPCC recommends that inventory compilers apply either Tier 2 or 3 methods to key categories of land activities that account for major sources of uncertainty or emissions and use Tier 1 methods for non-key categories (Figure 15.1).

Tier 1 is the simplest approach and is applicable to non-key categories where country or region specific emissions factors are missing. The compilers of inventories should use specific activity data for a country or region but they can use global default values with unknown uncertainty for the emissions factors. Tier 1 methods allow compilers to produce a complete inventory and avoid investing in data collection for activity categories that account for only a small portion of the total emissions or removals or that account for only a small proportion of the uncertainty. The estimation of uncertainties by source category at Tier 1 is done using statistical error propagation equations.

Tier 2 methods follow a similar framework as Tier 1. Country or region specific activity data are used but emissions and removals are estimated using country or region specific emissions factors. Higher temporal and spatial resolution

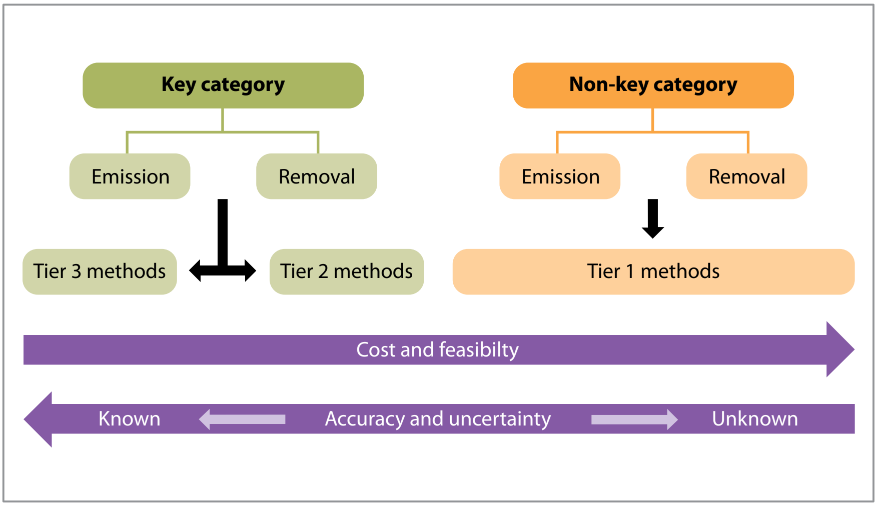

Figure 15.1 Relationships between key categories and the tier levels for inventory compilation and accuracy vs. cost tradeoffs (Adapted from Maniatis and Mollicone 2010)

and more disaggregated activity data are typically used in Tier 2 methods, in association with specific emissions factors for appropriate climatologic or geological subregions and specialised land use or livestock categories.

Tier 3 methods require spatially explicit and high resolution data on land cover dynamics. Tier 3 uses higher order methods, including models and inventory measurement systems, which are repeated over time. Land areas where a land use change occurs can usually be tracked over time, at least statistically. Most models include climate-related variation in aspects such as growth, senescence and mortality and thus allow for estimates with annual variability. Models should undergo quality checks and validation. Tier 3 produces high quality output in terms of precision and accuracy as the bias is reduced and the complexity of the system is well represented. The major constraints to implementing Tier 3 methods are the cost and effort involved in the production of quality datasets and site specific measurements.

15.3 IPCC methods for developing EFs

The IPCC has two approaches to developing emissions factors for the inventory equations. Carbon stock changes in any pool can be estimated using an approach called the Gain–Loss method, which can be applied to all carbon gains or losses (IPCC 2006). Gains are attributed either to growth or to transfers of carbon from another pool (e.g. the transfer of carbon from an aboveground biomass carbon pool to a dead organic matter pool due to harvest). Losses are attributed to transfers of carbon from one pool to another or to emissions due to decay, harvest, burning, etc. In this system, it is important to account for transfers, since any transfer from one pool to another is a loss from the donor pool and an equal gain to the receiving pool. Consequently, CO_2 removals are transfers from the atmosphere to a carbon pool (usually biomass); CO_2 emissions are transfers from a carbon pool to the atmosphere.

The second approach is called the Stock–Difference method, which is applied where carbon stocks in relevant pools are measured at two points in time to assess carbon stock changes. Generally, carbon stock changes are estimated on a per hectare basis and the value is then multiplied by the total area in each stratum (activity data) to obtain the total stock change estimate for the pool. On occasion, activity data may be in the form of country totals (e.g. m^3 of harvested wood), in which case the stock change estimates for the aboveground biomass pool are calculated directly from the activity data, after applying appropriate factors to convert to units of carbon mass. When using the Stock–Difference method for a specific land use category, it is important to ensure that the area of land in that category at times t_1 and t_2 is identical to avoid confounding stock change estimates with area changes. Table 15.1

presents examples of how Tier 1 default factors can be derived using IPCC default values for aboveground biomass.

The Gain–Loss method lends itself to ecological modelling approaches using coefficients of stocks and flows derived from empirical research. This approach will smooth out interannual variability to a greater extent than the Stock–Difference method. Both methods are valid and should provide comparable results over time but each is more appropriate for certain pools. For example, a Stock–Difference approach based on forest inventories is the most practical way to estimate changes in aboveground biomass carbon (Brown 2002; Qureshi *et al.* 2012). For other pools, for example, the soil and organic matter carbon pool in peat soils (see Box 15.1), the Gain–Loss Method is more practical. Figure 15.2 summarises the steps involved in generating emissions factors using both methods. To apply either approach, it is necessary to first develop a meaningful stratification of the landscape and determine which activities and pools require higher tier accounting and which can be addressed using Tier 1 methods. Data must then be collected and compiled in such a way that they provide a representative estimate of the ecosystem and management system in question.

15.4 The current state of EFs and opportunities for improvement

15.4.1 MRV capacity and EFs

As part of CIFOR's Global Comparative Study (GCS) on REDD+ (see Appendix), we carried out an analysis of MRV capacity in 99 tropical non-Annex I countries. The study scored each country on several types of capacity (e.g. remote sensing, forest inventory, carbon stock assessment) and national engagement (e.g. completeness of national reporting, engagement in UNFCCC REDD+ technical negotiations). The study then scored the REDD+ challenges (e.g. fire incidence, presence of peat soils, high carbon densities) and remote sensing challenges (e.g. high cloud cover, mountainous terrain) in the countries. Gaps were then calculated using the difference between the scores for challenges and capacities and the countries were grouped into categories based on the magnitudes of their scores.

The analysis showed that the majority of countries lack the capacity to implement a complete and accurate national monitoring system for measuring the performance of REDD+ implementation according to the IPCC guidelines, as will be required in Phase III when payments will be based on quantified emissions reductions (Romijn *et al.* 2012). Forty-nine countries had a very large capacity gap, while only four countries had a very small capacity gap. These latter countries already had good to very good

Box 15.1 Using the Gain–Loss method to improve the facility of estimating emissions factors for tropical peatlands

Indonesia is one of the greatest emitters of GHGs in the world, with about 80% of national emissions coming from land use and land use change. In insular Southeast Asia, deforestation rates in peat swamp forests are twice as high as in any other forest type (Miettinen *et al.* 2011). For this reason, quantifying GHG emissions from land use change in peatlands is critical. A major concern is the estimation of carbon loss from the peat. Recent estimates suggest that carbon loss associated with the conversion of peat swamp forest to oil palm plantation contributes more than 63% to total losses. Losses from the biomass amounted to 158 Mg C ha^{-1} whereas those from the peat reached 270 Mg C ha^{-1} over 25 years, which is the rotation period of an oil palm plantation (Hergoualc'h and Verchot 2011).

Peat loss may be assessed either by measuring changes in carbon stocks (the Stock–Difference approach) or changes in carbon flows (the Gain–Loss approach). An accurate assessment of soil carbon stock changes following land use change requires carbon stock measurements over the full depth of the peat profile, because changes occur at greater depths in drained soils; losses are not limited to the top 30 cm as they are in mineral soils. Indeed, the combined physical and chemical activities associated with drainage, peat subsidence and fires may make it hard to determine which soil layers should be compared before and after land use change. Nevertheless, it is clear that studying only the superficial layers of peat soils is not a valid approach to comparative studies of changes in peat carbon stocks associated with land use change. In addition, most peat formations in Southeast Asia are in the shape of a dome, hence the selection of representative and consistent locations within the dome before and after land use change is necessary to avoid erroneous emissions or removals estimates. Developing an adequate sampling scheme is especially challenging, given the lack of maps locating the position of peat domes in many landscapes, limited accessibility (pristine peatlands are often remote and difficult to reach) and authorisation constraints.

Given the problems cited above, a better approach for assessing peat carbon loss after land use change is the Gain–Loss method. This approach requires knowledge of the main carbon inputs (litterfall and root mortality) and the main outputs (soil heterotrophic respiration rates, loss associated with fires, methanogenesis, leaching, runoff and erosion). These flows are easier to estimate accurately and without bias than are changes in stocks. Soil respiration may be a useful indicator of peat carbon loss. However, the heterotrophic component must be estimated and losses have to be balanced against gains in order to evaluate how much carbon the peat is losing or sequestering. The balance between gains and losses before and after land use change must be compared in order to assess emissions and removals associated with land use change.

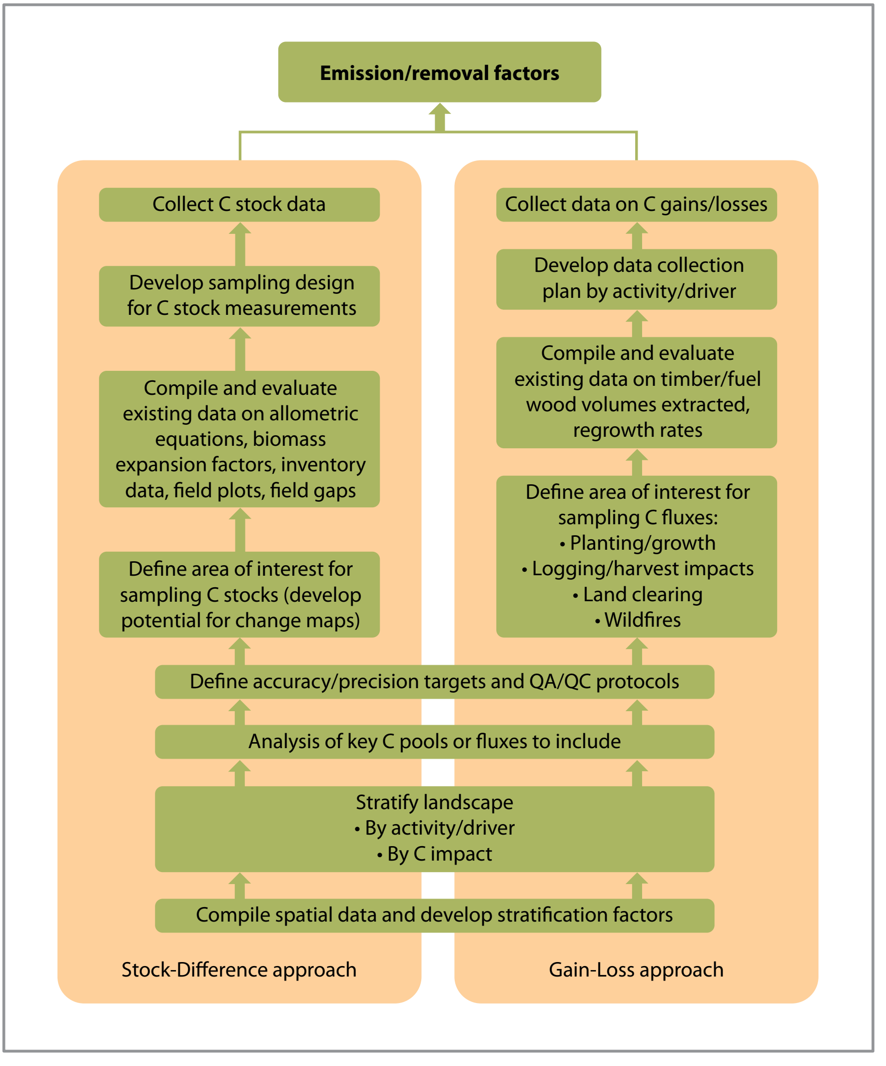

Figure 15.2 Steps involved in the estimation of emission factors (Adapted from Meridian Institute 2011a)

capacities for measuring forest area change and for performing a national forest inventory on growing stock and forest biomass. In the countries with very large capacity gaps, problems stemmed from limited engagement in the UNFCCC REDD+ process, lack of experience in the application of the IPCC guidelines and lack of access to appropriate data for Tier 2 inventories (Hardcastle *et al.* 2008; Herold 2009). The study documented where capacity is inadequate at technical, political and institutional levels to allow a complete and accurate estimation of forest area change and associated carbon stock changes and showed that the REDD+ mechanism is creating requirements that are beyond the experience of many national technical services.

Table 15.1 Examples of Tier 1 emissions factors for biomass (aboveground and belowground) associated with the conversion of forest to grassland in Africa, calculated by means of the Stock–Difference method and using default values for carbon pools (IPCC 2006)

	Forest				Grassland/pasture			
	Aboveground biomass *	Belowground biomass†	C density‡	Carbon stocks in biomass pool	Total above- and belowground biomass§	C density	Carbon stocks in biomass pool	Emissions factor for biomass¶
	Mg d.m. ha^{-1}		Mg C Mg $d.m.^{-1}$	Mg ha^{-1}	Mg d.m. ha^{-1}	Mg C Mg $d.m.^{-1}$	Mg ha^{-1}	Mg ha^{-1}
Tropical rainforest	310	115	0.46	195	16	0.47	8	188
Tropical moist deciduous forest	260	52	0.46	144	16	0.47	8	136
Tropical dry forest	120	34	0.46	71	9	0.47	4	67
Tropical shrubland	70	28	0.46	45	9	0.47	4	41

Note: 1 Mg = 1 tonne, d.m. = dry matter.
* Values for African forests from Table 4.7 of GL2006
† Based on ratio of belowground biomass to aboveground biomass from Table 4.4 of GL2006
‡ C densities from Table 4.3 of GL2006
§ Values for grasslands from Table 6.4 of GL2006
¶ Difference between the total C stocks in above- and belowground biomass of each system

This capacity gap was also obvious during two recent global Forest Resources Assessments (FRA) (FAO 2006; 2010) conducted by the Food and Agriculture Organization (FAO 2007; Mollicone *et al.* 2007). Marklund and Schoene (2006) analysed country submissions to the 2005 FRA and found the quality and reliability of data to be highly variable. Most countries lack good forest inventory data and rely on conversion factors and default values to estimate carbon stocks. Of the countries that do have inventory data, most have measurements at only one point in time. Of the 229 countries and territories that reported to the 2005 FRA, only 143 reported on carbon in the biomass pool and only 50 reported on carbon in litter and soil pools. Thirty-four countries provided no carbon stock data. There were small improvements in the 2010 FRA (see Box 15.2).

In another GCS study, CIFOR surveyed 17 REDD+ demonstration sites across Latin America (7), Africa (7) and Southeast Asia (3). Fifty-three percent of the projects were found to use site specific or country specific allometric equations for assessing aboveground biomass, as would be required for a Tier 2 approach Forty-seven percent of the projects use generalised equations for the whole tropics. The other carbon pools are usually less important in these projects, but can still represent a significant portion of net emissions. Not surprisingly, capacity to inventory these pools was even lower. Only 24% of the project teams were familiar with methods for estimating belowground biomass. In the case of dead wood carbon measurements, 41% of the teams were familiar with the methods. For litter and soil carbon pools, most of the respondents plan to use either the values set by the IPCC or to neglect these pools. Most of the projects that were surveyed did not have sufficient information to deal with carbon estimation in various pools. An exception was a project in Brazil, which used site specific allometric equations to estimate aboveground biomass coefficients (Higuchi *et al.* 1982; Silva 2007), belowground biomass and dead wood (Silva 2007). Litter was estimated using Tier 1 default values. The project will not inventory the soil carbon pool.

Finally, the development of MRV methods for REDD+ projects focuses mostly on remote sensing and ground inventories by professional foresters (GOFC-GOLD 2010). These are expensive and may be of limited effectiveness in following actual developments on the ground at the necessary scale to inform project implementation. There is growing experience with community-based MRV (see Box 15.3) to address the lack of involvement of the people living or depending on land where REDD+ schemes are being carried out. Practical approaches are being developed and tested for engaging local people effectively in monitoring (Skutsch 2010).

15.4.2 EFs for biomass carbon pools

To implement the Stock–Difference or the Gain–Loss methods, inventory compilers need data on forest and non-forest ecosystems to be able to produce

Box 15.2 Evidence of progress between FRA 2005 and FRA 2010

Between the 2005 and 2010 reporting periods for the FAO Forest Resources Assessment (FRA), some modest improvements can be seen in monitoring capacity. Figure 15.3 shows the changes in capacity to report on carbon in different pools. Most of the improvements occurred in African countries, where overall monitoring capacity was not well developed in 2005. Progress is usually associated with the fact that these countries reported on two carbon pools in 2010 (aboveground biomass and soil) instead of only one (aboveground biomass). However, they are still reporting at Tier 1 level, using IPCC default values. Remote sensing capacity and the use of time series data for monitoring changes in forest areas barely increased between 2005 and 2010. Forest inventory capacity also showed little improvement over this period. A decrease in monitoring capacity can be found in a few countries, in some cases due to an internal political situation.

The apparent lack of significant improvement in monitoring capacity between FRA 2005 and 2010 reporting suggests that efforts by REDD+ to build capacity have not yet had much impact on national reporting. The international community needs to commit greater human and financial resources to addressing capacity gaps in order to change this situation.

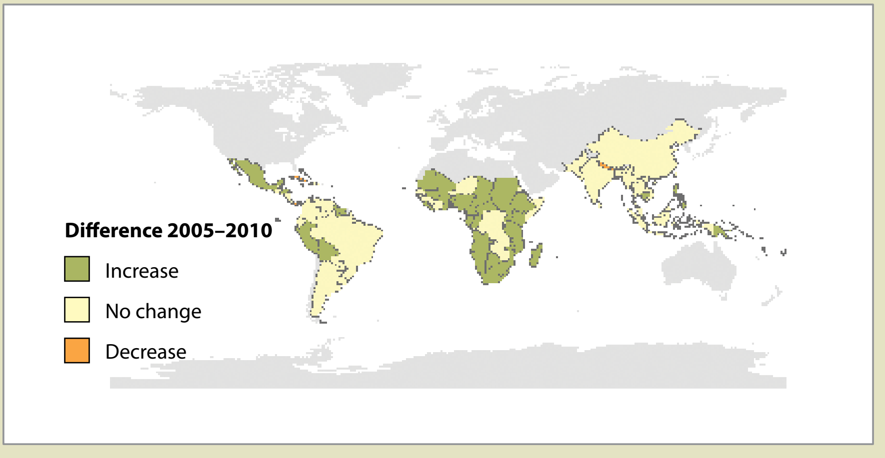

Figure 15.3 Change in capacity for 99 tropical non-Annex I countries based on the difference between FAO/FRA 2005 and 2010 reporting on the five different forest carbon pools

Source: Romijn *et al*. (2012)

Box 15.3 From global to local in REDD+ MRV: Linking community and government approaches

Finn Danielsen, Neil D. Burgess and Martin Enghoff

In recent years, a number of manuals have been developed to guide local data collection on forest biomass (Verplanke and Zahabu 2009; Subedi *et al.* 2010; An *et al.* 2011; UN-REDD Programme 2011b; Walker *et al.* 2011). Studies have shown that local people can reliably collect data on aboveground biomass and forest use and can meet the requirements at higher reporting tiers of the IPCC (Danielsen *et al.* 2011).

Community involvement in REDD+ MRV is particularly useful in forest areas that are under some form of community regime, where resource rights are recognised by the government and where there is local interest in managing the forest area. Involving communities helps link national REDD+ implementation to local decision making and forest management (Danielsen *et al.* 2010). Moreover, it reduces the risk that REDD+ will undermine local forest tenure. It also helps to promote the transparency and accountability of REDD+ initiatives and contributes to equitable governance and benefit sharing.

The question arises as to how to successfully integrate community monitoring of REDD+ effectiveness with the monitoring undertaken by national REDD+ implementing institutions. In the past, most community forest monitoring initiatives have been localised (Fry 2011). There are no examples of community schemes that have been scaled up to the national level.

To effectively link community and state monitoring for REDD+, community monitoring needs to be embedded in a scheme that feeds data into national MRV initiatives. The national REDD+ programme should also ensure that the communities are compensated for their labour. The involvement of communities in REDD+ MRV must be supported by national policies to ensure that sufficient funds and staff are set aside for the development of the community monitoring component in the national REDD+ programme.

In most countries, community-based organisations already have experience in community forest monitoring. These organisations, or other institutions representing communities, should be encouraged to take a central role in the design, development and piloting of the community monitoring component of the national REDD+ programme. It is advisable to start small, see what works and then expand as experiences accumulate (Herold and Skutsch 2011).

At the national level, there is a need for a minimum standard for community forest monitoring so that the same approach is used at all sites throughout

continued on next page

Box 15.3 continued

the country. The standard should specify the format of the raw data (measurements of tree girth, wood density) and auxiliary supporting information (location, date). Any additional requirements for data on forest resources status and forest governance developments should also be specified. The standard should describe how and when the data should be transmitted from the community-based organisations to the government. It should also prescribe how to collect, verify, check, process and analyse the data (Pratihast and Herold 2011). Quality checking requires comparing random spot checks with data sets from other sources. The national REDD+ programme should inform the community-based organisations and communities about signs of displacement of carbon emissions from forest loss and degradation in neighbouring forest areas.

It is important to allow government staff the time to provide feedback to the communities, in terms of questions about their data, and help them to solve any land management issues that may arise. There will be a need for regular community visits by national REDD+ staff. Where possible, it would be helpful to involve government staff with experience in participatory rural appraisal techniques and in holding dialogues with community members.

emissions factors for net changes associated with land use or land use change. In the case of agricultural and grassland ecosystems with little to no woody vegetation, estimating biomass is not technically difficult. Most agronomic studies carried out by agricultural universities and research institutions around the world measure total productivity, not just harvest. So developing default biomass values for most cropping systems will require a literature search, although this may be complicated in many non-Annex I countries by the fact that these data are often found in grey literature and may not be readily available internationally. Biomass and productivity are also measured for managed pasture systems and in many cases for indigenous rangelands. For the biomass carbon pools, the technical challenge is estimating biomass of woody vegetation.

One of the main limitations to improving emissions factors is the lack of appropriate biomass equations for converting plot scale measurements collected in a traditional forest inventory into biomass estimates and, subsequently, into carbon numbers (IPCC 2006). The most common biomass equations – allometric equations – use easily measured dimensions of trees, like diameter and height, to predict biomass. A review of 850 allometric equations in sub-Saharan African countries revealed that less than 1% of the tree species in the region have country-specific models and less than 2% of the equations account for root biomass (Henry *et al.* 2011). Additionally, seven tree species accounted for 20% of the available equations (all equations are available in the open access database of Carboafrica: www.carboafrica.net). Thus, for many species, we must rely on equations that are not specific to the species being sampled and that have not been validated. The review also questioned the quality of the available equations, since most of them gave values that regularly fell outside expected ranges. The authors concluded that no countries in sub-Saharan Africa have enough nationally appropriate biomass models to use in assessing forest carbon stocks and their variation under the IPCC Tier 2 or Tier 3 approaches. For example, Cameroon has around 600 forest trees species, of which 20 species have specific allometric models. Generalised or averaged models must be used for the other species and their bias is unknown.

The most common approach to inventorying very diverse tropical forests is to use general equations, which are based on measurements of a variety of tree species from different ecosystems across the tropics. A simple geometrical argument suggests that the total aboveground biomass of a tree should be proportional to the product of the trunk basal area and the total height of the tree, which provides an estimation of a volume. This volume, multiplied by the specific gravity, allows an estimation of the mass per unit volume (Chave *et al.* 2005). Several pantropical equations exist and are widely used (Brown *et al.* 1989; Brown and Lugo 1992; Brown *et al.* 1997; Fearnside 1997; Chave *et al.* 2005). However, the predictive power of these models can only be determined if they are validated using tree biomass data obtained directly from destructive harvest experiments, which is rarely done (Crow 1978; Cunia 1987; Brown *et al.* 1989; Chave *et al.* 2001; Houghton *et al.* 2001). Ketterings *et al.* (2001) proposed a method of non-destructive sampling for 'tuning' the biomass equations to a site using the relationship between specific gravity, diameter or basal area and height. This approach holds promise but requires much more work before it can become a practical tool for inventory. Recently, Picard *et al.* (2012) proposed a Bayesian model averaging approach to combine different biomass models and improve allometric biomass estimates. This approach is appropriate when there are several models available for an area and one cannot *a priori* judge which model is the best to use.

We conclude the discussion of aboveground biomass with a final word on the allometric nature of these equations. In most ecosystems, it is relatively easy to measure the diameters of trees. Foresters use a standard measure of diameter at breast height, which is at 1.3 m above the surface of the soil. There are various recommendations for measuring irregular trees (e.g. forked trees, trees with buttresses, etc.) or trees on slopes, but these are beyond the scope of this chapter. In dense tropical forests, measuring the height of trees accurately is difficult. While height generally increases the accuracy of biomass equations, most equations in humid tropical forest situations forego this measurement and rely solely on diameter or diameter and wood density. In the survey of African biomass equations cited above, only 15% used height (Henry *et al.* 2011).

As noted above, belowground biomass is not well represented in allometric equations. Most inventory approaches use the Stock–Difference approach, wherein belowground biomass is estimated through so called root:shoot ratios, which use the relationship between belowground and aboveground biomass (IPCC 2003; 2006). The survey of a small number of REDD+ demonstration projects indicated that both allometric equations and root:shoot ratio data were insufficient for carbon estimation at all levels: local, regional and national. With few exceptions, most of the projects surveyed plan to use the generalised equations found in Cairns *et al.* (1997) and Mokany *et al.* (2006). Some projects plan to use IPCC Tier 1 default values.

Mokany *et al.* (2006) reviewed a large number of published root:shoot ratio values and suggested that quality is also an issue for this measure. Excavating root systems properly is difficult and needs to be undertaken by trained individuals; sometimes even scientists do not get it right. Out of 786 root:shoot values collected, 63% had to be discarded, either because the values were unverifiable or because the methods used to generate them were inadequate. Among those retained, only 20 observations were from tropical forest ecosystems. Other tropical systems were equally poorly sampled. Despite this serious limitation, the authors validated several relationships that were known from smaller scale ecological studies and found that root:shoot ratios varied with some predictability and can be useful for inventory purposes while more data are gathered. For example, the root:shoot ratio decreases as precipitation increases in forest and woodland ecosystems, although the relationship is subject to wide variation. In all ecosystems, the root:shoot ratio also decreases as shoot biomass increases. While this behaviour is expected for mathematical reasons, it can be used to set priorities for data collection.

15.4.3 EFs for other carbon pools and GHG fluxes

Approaches have been developed for inventorying the changes in other carbon pools. However, data for local, regional and inventories are largely lacking. Palace *et al.* (2012) reviewed a total of 49 studies on deadwood in tropical forests. Many of these studies used a percentage of total fallen deadwood to estimate standing deadwood. Standing and fallen deadwood were both measured in 21 studies, with a ratio of standing to total deadwood, ranging from 6% in a disturbed forest to 98% at a heavily disturbed site. In undisturbed forests, standing to fallen deadwood stocks ranged from 11% to 76%. The authors found that in dry tropical forests (2.5–118.6 Mg d.m. ha^{-1}), the percentage of fallen deadwood tended to be smaller than in moist tropical forests (1.0–178.8 Mg d.m. ha^{-1}). The proportion of deadwood to total aboveground mass can be surprisingly high: 18 to 25%, even in unmanaged forests. The GOFC-GOLD sourcebook (GOFC-GOLD 2008) indicates that deadwood can make up to about 7% of total carbon stock; understory vegetation and litter values are usually less than 3% of total carbon stock. In our survey of REDD+ demonstration projects, some were found to use well defined methods for measuring carbon in deadwood, based on approaches developed by several authors (Heath and Chojnacky 1995; IPCC 2003; Pearson *et al.* 2005; Zanne *et al.* 2009). Two projects in Tanzania do not plan to measure deadwood because the local community uses it as fuelwood. Most projects do not intend to measure litter carbon.

Finally, fire related emissions are an important concern for which data and methods are still not well developed. For example, fire releases large amounts of CO_2, but is also a major source of non-CO_2 GHG emissions, such as CO, CH_4, N_2O, NO_x. For the IPCC equations, the mass of fuel that actually burns is the critical factor for estimating non-CO_2 emissions. Yet country and ecosystem specific factors for these emissions do not exist in most cases. The combustion of the individual fuel elements proceeds through a sequence of stages: ignition, flaming and glowing and pyrolysis (smouldering), glowing and pyrolysis, glowing and extinction. Each of these stages involves different chemical processes, which result in different emissions (Yokelson *et al.* 1997).

A comprehensive review of the emission factors for fires was conducted by Andreae and Merlet (2001). The authors concluded that there were adequate data for emissions factors from tropical savannas, but that there were not sufficient data for most other major ecosystems to generate robust emissions factors for the different gases. The effect of species composition in the fuel mix is also largely unstudied, despite potentially having an important impact on emissions. For example, emissions of NO_x and N_2O from fire can vary as a function of the N content of the fuel. Species with high N concentrations, like some legumes, would be expected to have higher emissions of these gases.

15.5 The way forward

The first conclusion that can be drawn from the above analysis is that while adequate information exists for Tier 1 GHG inventories, for most tropical systems there are inadequate data available for developing higher tier approaches. Fortunately, more data are available for estimating emissions from large carbon pools like aboveground biomass, but for the most part these data were collected for specific purposes and are not representative of an ecosystem over large scales. Thus, we cannot estimate their bias. Other pools, like belowground biomass or soil carbon, contribute significantly to total ecosystem carbon stocks, but are less well characterised. Whereas the stated goal for REDD+ is quantified emissions reductions in a performance-based scheme, we are far from being able to make better than order-of-magnitude estimates of emissions from sources and removals by sinks with adequate certainty in national REDD+ programmes. We know about precision because most syntheses calculate standard errors. We also know that the data used to generate equations and emissions factors are not globally representative and thus we have no idea of the bias in these estimates.

The second conclusion is that progress over the past decade has been slow, both with respect to the generation of new data to support better GHG inventories and the capacity of countries to implement higher tier inventories in the forestry sector. There are several MRV capacity building efforts underway as part of REDD+ readiness activities, but their impact was not evident in the 2010 FRA. There are signs that the scientific community is responding to policy needs for better data to enable more accurate and precise inventories and a number of new and important syntheses have been published. Nevertheless, efforts at the moment are piecemeal and uncoordinated.

There have been several multilateral and bilateral partnerships between developed countries and MRV institutions in early action REDD+ countries. The UN-REDD Programme and its partners are working with a number of countries to establish transparent MRV systems. The Australian partnership in Indonesia is just one example of bilateral cooperation. These partnerships have largely concentrated on land use assessment and land use change detection; the issue of limitations due to emissions factors is only beginning to be discussed.

Most developing countries have forestry research institutes and university faculties of forestry. The Cancún agreements settled on a three-phase approach to REDD+ and, as part of the capacity building in Phases 1 and 2, trained personnel will need to be mobilised to contribute necessary data and knowledge to facilitate higher tier inventories. During Phase 1, inventories will have to be implemented with a hybrid of Tier 1 and Tier 2 approaches for activities that meet the key category criteria. Investments and coordinated efforts will be needed to overcome the constraints to GHG inventories of limited emissions factors. As more data are gathered, fewer Tier 1 estimates will have to be made in key categories. A great deal of progress can be made over the next ten years if coordinated, targeted investments are made in capacity building and mobilisation. In the meantime, partnerships between research institutes and university faculties working on forestry, agriculture and other land management systems in REDD+ host countries, intergovernmental agencies with technical capacities (e.g. GEO, UNEP, CGIAR) and advanced research institutes in developed countries should be established to enable coordination, complementary technical skills and capacity building. South–south cooperation and the building of regional technical networks should be fostered as well.