Policy Briefs 5

Measuring and Monitoring Terrestrial Carbon as Part of "REDD+" MRV Systems

The State of the Science and Implications for Policy Makers

Discussion Draft Oct 2009

The Terrestrial Carbon Group Project

In partnership with UN-REDD PROGRAMME

The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries

One of the key unresolved issues in the United Nations negotiations on the inclusion of terrestrial carbon (the carbon stored in the terrestrial system including trees, other vegetation, soil, and peatlands) in the climate change solution is how to ensure that real, quantifiable and comparable carbon emission reductions and sequestration take place. To meet international requirements, countries and on-the-ground implementers will need appropriate carbon measurement and monitoring methods. This Policy Brief summarises important aspects of key methods, including their maturity, cost, and availability. It also describes how policy choices determine measurement and monitoring quality, and input and capacity requirements, and provides recommendations to progress to full terrestrial carbon accounting. This Policy Brief is an edited extract from a report commissioned in conjunction with the UN-REDD Programme. It is part of a larger project led by the Terrestrial Carbon Group with its partners that will, by working with developing and developed countries and supporting institutions, produce a roadmap for filling gaps in the science of terrestrial carbon measurement, monitoring, and management by 2013.

1 The Need to Measure and Monitor Terrestrial Carbon (inc Forest Carbon)

Improved management of the world's terrestrial carbon in agriculture, forestry, and other land use sectors, as described by the Intergovernmental Panel on Climate Change (IPCC), is a necessary part of the global effort to avoid dangerous climate change. It is expected that governments will agree in Copenhagen in December 2009 to create new incentives for maintaining existing terrestrial carbon and creating new terrestrial carbon.

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The objective of the Terrestrial Carbon Group is for terrestrial carbon (including trees, soil, and peat) to be effectively included in the international response to climate change.

The UN-REDD Programme is a collaboration between FAO, UNDP and UNEP that supports countries to develop capacity to reduce emissions from deforestation and forest degradation (REDD) and to implement a future REDD mechanism in a post-2012 climate regime.

The Terrestrial Carbon Group Project is publishing a series of Policy Briefs to inform the United Nations negotiations on how to include terrestrial carbon in developing nations in the overall climate change solution. We welcome your comments.

For other Policy Briefs, please visit our website:

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As with other components of the climate change solution, for countries to take advantage of incentives for terrestrial carbon management, national systems will be needed to document, report, and verify changes in carbon in a transparent, consistent, comparable, complete and accurate manner. These systems are widely known by the acronym "MRV", which is used variously (and confusingly) to mean "measurement, reporting, and verification" and "monitoring, reporting, and verification. In fact, both measurement (determining the amount of carbon in any given land area at any given time) and monitoring (observing changes in that amount over time) are required in an MRV system. Although reporting and verification are also important, this Policy Brief focuses on measurement and monitoring (M&M) as part of MRV, with emphasis on technical design considerations for national-level implementation.

While incentive mechanisms are as yet undecided, the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol provide context for national-level M&M of terrestrial carbon, complemented by detailed guidance that has been accepted by the international technical community. The UNFCCC is expected to provide further detail and guidance for designing national M&M systems within MRV systems, which will be influenced by decisions under the UNFCCC on the scope and scale (ie, the land use classes included in the agreement, and whether activities are reported at the project / sub-national or national level) of a terrestrial carbon incentive system.

The technical community has developed and tested a variety of M&M methods (and in some cases, whole systems) for terrestrial carbon, and experience has been gained in both developing and developed countries through project-scale carbon management activities and national greenhouse gas inventories. The term "methods" is used in this Policy Brief to include a wide range of tools and approaches such as field protocols, satellites, open-access databases, and models. These are described in more detail in the following sections.

Section 2 outlines the basic methods for measuring and monitoring terrestrial carbon. Section 3 outlines key design considerations for countries as they establish a national M&M system. Section 4 addresses common implementation challenges. Section 5 provides conclusions about areas for further work and issues for policy-makers.

(For more in-depth information, please see *Measuring and Monitoring Terrestrial Carbon: The State of the Science and Implications for Policy Makers*, available at www.terrestrialcarbon.org)

2 How to Measure and Monitor Terrestrial Carbon (inc Forest Carbon)

There is a suite of proven methods, specific to different land cover types (the type of vegetative material covering a site, eg, forest, row crops, etc), that can be used to measure stocks (measurement) and monitor changes in stocks (ie, monitoring) of terrestrial carbon, including (see Table 2 for further detail):

- Field measurements: in-situ data collection
- Remote sensing: techniques using optical, RADAR or LIDAR sensors mounted on aircraft or space-borne platforms
- Models: can be empirical (ie, based on observations) or process-based (ie, based on known relationships)

Total terrestrial carbon stock is a function of the areal extent and carbon density of each land use class (ie, categorisation of the area according to use such as an area managed for timber production) in an area of interest. Basic information requirements include:

- Estimation of the areal extent of significant land use classes and monitoring of land use change within and between various classes. Data can be obtained by field methods, but it is usually more efficient to use remote sensing approaches. Remote sensing has been used to record land use and land cover change for several decades and can also be efficiently used to track changes in the relative distribution of land use classes over time.
- Carbon density measurements and monitoring of changes to carbon density within major land use classes. This commonly requires a combination of direct field measurements coupled with models, which range in complexity from conversion equations (equations that describe the ratios of different objects to each other such as the above-ground portion of a plant to its root volume) to full process models.[1] Remote sensing can be used to estimate carbon density either directly – based on quantifiable relationships between above ground biomass (ABG, which is the living biomass existing above the soil) and spectral responses – or indirectly – based on classification techniques developed through research pairing field measurements with sensor measurements.[2] Detecting carbon density changes due to degradation and intensification or agricultural changes requires on more accurate field-level information, requiring either higher-resolution remote sensing data or data collected from more comprehensive field studies.

Data resulting from field measurements or from interpreted remote-sensing images can be combined with other types of information (eg, information on land management such as timing, quantity and type of fertilizer application) and fed into models (descriptions of complex relationships or processes) to estimate current carbon stocks as well as changes.

3 Design Considerations for M&M Systems

To access incentives for terrestrial carbon management (whether through carbon offset markets or performance-based funds), countries will need national-scale M&M systems for terrestrial carbon. These systems will need to align with existing and evolving international guidance and provide data that is relevant to the scope of international agreements, the scale of project / sub-national implementation activities, and the stage of the country's M&M (and MRV) system implementation. These considerations will inform the type and quality of information that M&M systems can deliver, and the input and capacity requirements to operate them.

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[1] Conversion equations, including allometric equations, are themselves based on field measurements and are only available for certain countries, land cover types and plant species. In this report, we refer to the term "allometric equation" as a more specialized form of conversion equation, providing a mathematical comparison of how characteristics of different organisms of the same species compare, and also between organisms in different species. For more information see: Avery and Burkhart. Forest Measurements. Copyright 2002 by McGraw-Hill Companies Inc. New York.

[2] WMO, UNESCO, UNEP, ICSU, FAO, 2008. GTOS 67, ECV T12: Biomass, Assessment of the status of the development of standards for the Terrestrial Essential Climate Variables (Draft Version 8). Avitabile, V., Marchesini L.B., Balzter, H., Bernoux M., Bombelli A., Hall R., Henry M., Law B.E., Manlay R., Marklund L.G. and Shimabukuro Y.E. (contributing authors), Sessa, R. (coordinator). Italy.

Discussion of terrestrial carbon accounting commonly elicits concerns about additionality, leakage, and permanence.[3] These concerns can be addressed by implementation of robust MRV systems that use well-tested M&M methods to produce transparent, consistent, comparable, complete and accurate information on changes to terrestrial carbon stocks. Although M&M methods exist, some are more developed than others, and the optimal combination will need to suit country circumstances. As described in Section 4, and in Table 2, each type of M&M method has specific capacities and limitations.

3.1 International Guidance

Under a global agreement on incentives for terrestrial carbon maintenance and sequestration, national-level M&M systems will need to produce and report information that is verifiable and comparable with information from other nations and consistent over time. Since 1996, all Annex I UNFCCC signatories are required to report anthropogenic greenhouse gas (GHG) emissions by sources and removals by sinks and are strongly encouraged to follow widely-accepted IPCC guidance in order to achieve the required quality and comparability.[4] (See Appendix I for details.) This has, however, been confounded by a lack of agreement on key definitions and categories used to compare land areas (including an agreement on the term "forest"). Non-Annex I countries are required to submit periodic National Communication reports.[5]

In addition to the IPCC guidance, acceptable methodologies for sub-national afforestation and reforestation activities are reviewed and approved by the Kyoto Protocol's Clean Development Mechanism (CDM) Executive Board under the UNFCCC, guided by technical panels and working groups. Methodologies specify which carbon pools require M&M under which types of activities, the types of information required and how net carbon emissions can be calculated. The UNFCCC has also provided some guidance on definitions (eg, on the national forest definition[6], but this describes a range rather than a single value and as a consequence comparison is difficult).

The IPCC identifies three reporting tiers ranging from spatially coarse activity data and default values (Tier 1) to the application of country-defined emission factors and, typically, higher-resolution activity data, and specialised land use categories[7] (Tier 2) to M&M systems tailored to national circumstances, repeated over time, driven by high-resolution activity data and disaggregated at sub-national to fine

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[3] This Policy Brief does not go into detail on these issues, which are well covered in other papers including Terrestrial Carbon Group. 2008. How to include terrestrial carbon in developing nations in the overall climate change solution; and Terrestrial Carbon Group Project. 2009. Policy Brief Number 2 "Tools for Setting Reference Emission Levels: A review of existing tools that can be used to set a benchmark for rewarding reduced emissions and increased sequestration of greenhouse gasses in the terrestrial system", both available at www.terrestrialcarbon.org.

[4] UNFCCC website on Annex I Greenhouse Gas Inventories: http://unfccc.int/national_reports/annex_i_ghg_inventories/items/2715.php

[5] These vary significantly in quality due to lower reporting requirements. To date, 134 of 150 non-Annex I countries have submitted such reports, and of these only Mexico, South Korea and Uruguay have submitted a second report (See: http://unfccc.int/national_reports/items/1408.php)

[6] The UNFCCC Marrakesh Accords (UNFCCC COP 2002) define a forest as: ""...a minimum area of land of 0.05 to 1.0 ha with tree crown cover (or equivalent stocking level) of more than 10 to 30% with trees with the potential to reach a minimum height of 2 to 5 meters at maturity in situ. A forest may consist either of closed forest formations where trees of various stories and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10-30% or tree height of 2-5m are included under forest, as are areas are normally forming part of the forest area which are temporarily under stocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest..."

[7] IPCC Reporting Tier, as described in Chapter 3 in IPCC, 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry.* Available from: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html

grid scales (Tier 3). Tier 3 reporting is encouraged for land areas where carbon stocks are large and considered to be particularly vulnerable, while Tiers 1 or 2 may be acceptable for areas considered less significant, either in terms of estimated carbon quantities or vulnerability. For each land use type included, M&M systems may begin at lower reporting tiers and progress to higher tiers as experience is gained.

Existing methods can be combined in many different ways, depending on country circumstances, to meet international guidance. The ability to implement a national M&M system relies on in-country capacity, external support (in many cases), and access to adequate methods and data. A range of countries has successfully combined field measurements, remote sensing, and models to measure and monitor terrestrial carbon, particularly in above-ground biomass (ABG)[8].

3.2 Scope

At this stage in the UNFCCC negotiations, there is an active debate about what the scope of the international agreement should be. Major options include:

- RED (reduced emissions from deforestation)
- REDD (reduced emissions from deforestation and forest degradation)
- REDD+ (reduced emissions from deforestation and forest degradation plus conservation and sustainable forest management and enhancement of forest carbon stocks in developing countries)
- AFOLU (agriculture, forestry, and other land use)

There is growing consensus that the scope will be REDD+ immediately within a framework that leads as soon as technically possible to AFOLU. National M&M systems will need to reflect the outcome of the UNFCCC negotiations, and build in the ability and flexibility to adapt over time to a broader scope, and better methods and scientific information.

The IPCC identifies the following major terrestrial carbon pools: aboveground biomass (ABG), belowground biomass (BG), dead wood, litter, soil organic matter (SOM), and harvested wood products (HWP). Please see the Appendix for more detailed definitions. The relative importance of accurate measurement of different carbon pools varies across land cover types. In most forests, ABG is a major focus, while SOM and BG are important in all land cover types. The IPCC National Accounting Guidance recommends prioritising the M&M of the most significant national carbon pools, and those with the greatest potential to change.

As international incentives expand from forests to include other land cover types (ie, broader scope), national M&M systems will need to incorporate methods covering a broader range of pools, this is summarised in Table 1 below. While M&M methods exist for all major carbon pools, they are at varying levels of maturity for application at the national-scale.

[8] For example: Canada's CBM-CFS3 and Mexico's forest inventory (IPCC Tier 2).

Table 1. M&M considerations for different scopes (forms) of terrestrial carbon

	What is Covered?	M&M Considerations
RED	Deforestation (conversion of existing areas classified by the country as forests to new land cover)	Focus on carbon in the woody ABG pool, except for forests on peat soils Relies on quality of existing forest data, availability of historical images (eg, Landsat) and appropriate allometric equations and models, and access to medium-high resolution remote sensing imagery
REDD	Deforestation and degradation of existing forests	Similar to RED, but: ▪ Focus also on more subtle changes in carbon in the non-woody ABG pool ▪ Relies on more intensive field measurements and higher-resolution remote sensing imagery
REDD+	Deforestation, forest degradation, conservation, sustainable forest management and enhancement of forest carbon stocks in developing countries	Similar to REDD, but: ▪ Emphasis also on quality of information collection procedures in forest management ▪ May also expand focus to include carbon in BG, litter, dead wood, and HWP
AFOLU	Agriculture, Forestry, and Other Land Use	As above, but also: ▪ Focus expanded to include all pools and all greenhouse gases ▪ Relies on refined land use classification system, more comprehensive models, historical information on non-forest land use categories (ie, carbon density and area change), and additional land management information (eg, fertilizer application)

While data requirements for national M&M systems will depend on land cover types and carbon pools to be included, as well as approaches chosen for estimating areal extent and carbon density, it is likely that, in many countries, establishment of national M&M systems will begin with tracking changes in carbon levels associated with deforestation initially and increase capacity to collect information on forest degradation and changes in other land cover classes over time.

3.3 Scale

In the international agreement on including terrestrial carbon in the climate change solution, it is likely that M&M systems will be required at the national level for accounting purposes and to demonstrate fulfilment of voluntary or compulsory national commitments. In addition, M&M activities have occurred and will continue to occur at smaller scales because much of the activity that will deliver the carbon benefit will occur at sub-national or project scales.

Implementation of carbon emission reduction and sequestration activities can and does occur at a wide range of scales. For project-scale implementation of terrestrial carbon management (whether under international agreements or voluntary carbon markets), detailed and location-specific information must be collected to predict, measure, and document the carbon outcomes of changes in land management. Projects also need to collect information pertaining to the region and country in order to demonstrate additionality and to quantify and ameliorate leakage. Information about land cover and land management, as well as an understanding of where the largest potential lies for carbon sequestration and avoided emissions, is needed to enable projects to scale up to a meaningful contribution to global climate change mitigation and adaptation.[9] This assessment should include an analysis of the local socio-economic drivers of land use conversion and land management change (eg, population, urbanization, food and fuel demand, commodity markets) as well as local and sub-regional scales of activity that are necessary to achieve significant carbon sequestration outcomes.

National- and project-scale accounting will likely have different data requirements. Commonly, project accounting will be focussed on smaller areas and emphasize finer geographic scale of measurement and higher frequency of monitoring, while national accounting will be focussed on coarser geographic scale of measurement (but be comprehensive for major land cover types) and lower frequency of monitoring. Project-and national-scale accounting may also make use of different monitoring methods. For example, project-scale M&M might rely more heavily on field measurements to achieve greater accuracy and precision in carbon estimation, while national-scale M&M may rely to a greater extent on remote sensing approaches that can provide extensive coverage and detect changes in land cover types at the national level.

3.4 Stage of Country's National M&M (and Overall MRV) System Implementation

Data requirements and selection of measurement methods will reflect the stage of implementation of each national M&M (and overall MRV) system. Data collection and carbon estimation will be needed for:

- Establishing baselines and parameters for assessing additionality, including setting reference emission levels and reference sequestration levels. This stage will involve refining or developing base maps of major land cover types and estimating current carbon stocks as well as projecting "business as usual" carbon emissions against which to measure emission reductions or sequestration (see Terrestrial Carbon Group Project Policy Brief Numbers 1, 2 and 3[10]).
- On-going monitoring of carbon stocks, estimation of change in carbon from baselines and / or reference levels, and reporting, including the transformation of data into a consistent format that meets agreed requirements and the verification / validation of data.

A range of developing and developed countries has experience using various combinations of field measurements, remote sensing, and models to measure carbon or ABG stocks and / or monitor changes. For example, they may already be used for commercial activities, to meet existing national policy objectives, and to carry out carbon project activities under the Kyoto Protocol or the voluntary market. Although tested and applied in a few countries, more advanced combinations of these methods have yet to be as widely implemented for measuring and monitoring emissions and sequestrations from non-forest land use classes and forest carbon pools other than ABG.

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[9] In addition, some participants in the debate have suggested the need for carbon accounting for the aggregate of participating nations, particularly to ensure that international leakage is adequately addressed.

[10] Terrestrial Carbon Group Project Policy Brief Number 1 "Distribution of Terrestrial Carbon Across Developing Countries: Forest and Non-Forest; Vegetation and Soil"; Terrestrial Carbon Group Project. 2009. Policy Brief Number 2 "Tools for Setting Reference Emission Levels: A review of existing tools that can be used to set a benchmark for rewarding reduced emissions and increased sequestration of greenhouse gasses in the terrestrial system"; and Terrestrial Carbon Group Project Policy Brief Number 3 "Estimating Tropical Forest Carbon at Risk of Emission from Deforestation Globally: Applying the Terrestrial Carbon Group Reference Emission Level Approach", all available at www.terrestrialcarbon.org

Existing data produced through public and private data-gathering programs can provide a useful foundation of experience and infrastructure for expanded M&M systems. Typical existing information sources include:

- National / regional maps and descriptions (eg, forest inventories, soil maps)
- Satellite images (historical and recent)
- Information from local weather agencies
- Environmental records (eg, fire data) and historical management records
- Allometric equations and expansion/conversion factors for local species
- Timber surveys, agricultural yield statistics and annual agricultural census data
- Socio-economic surveys

Typical information challenges include:

- Lack of agreement on key definitions (eg forest definition and how to classify lands)
- Lack of historical and project-scale information (eg, satellite images, vegetation cover, soil maps, management)
- Lack of information on local drivers of land use change
- Dispersed and incomparable information
- Inconsistency between the types of measurement and monitoring methods used
- High information requirements because of numerous and detailed, complex project methodologies

A different mix of public and private sources of funding may be needed for different stages of national M&M implementation. This will be influenced by the outcome of international negotiations (eg, incentive schemes) and national implementation strategies (eg, decentralization of activities). Baseline and reference level establishment will require refining field methods (including the design of sampling schemes for data collection), cross-checking interpretation of remote sensing data with other types of images and data collected using field measurements, and building national technical and institutional capacity. This will likely require significant technology transfer (from both developed and developing countries) and international financial support, while financial flows from carbon offset markets may support on-going data collection.

4 Implementation at the National Scale

Existing data and well-accepted methods can be combined to carry out national-scale terrestrial carbon accounting, particularly for the woody ABG pool.[11] After an initial national M&M system has been constructed, capacity for gathering information on other carbon pools can be added, supported by adaptation of existing methods (eg, allometric equations, models) to new geographic regions. If desired, a national M&M system can enable the collection of other important information (eg, on biodiversity and socioeconomic conditions), and be used to improve national planning.

[11] This is evidenced by the development of such systems in several non-Annex I countries including Brazil, Indonesia, Papua New Guinea and Guyana.

4.1 Method-Specific Implementation Issues

Field measurements form the base of a country's national communication under the UNFCCC. These methods are well-tested in many different locations, and measurements can be collected by people with minimal training. Only basic equipment is required, for example, access to rudimentary laboratory equipment (eg, oven and scales) is necessary at the national or provincial level. Comparability of data from various field-based measurements can be jeopardized by differences in data collection process (sampling design). Less commonly, lack of agreement on data collection and assessment methods (eg, for soil bulk density) can reduce data comparability.

The availability and applicability of allometric equations, which are used to interpret data collected in the field, can also be a limitation. These equations are developed and well-tested for most commercial tree species, but may be entirely lacking for others. Most of these equations have been developed for areas that have a history of commercial plantations, and may therefore not be as representative of other regions with different conditions. African species, in particular, are poorly represented in this regard. This issue has been temporarily overcome by the use of the conservative default equations posted on the IPCC's EFDB[12], but these require updating and refinement.

Interpretation and standardization can also be an issue for remote sensing methods. Well-established, freely-available coarse and medium resolution images are critical for many national and sub-national land use activities, eg, planning field sampling strategies and establishing CDM-project eligibility. However, data collection and interpretation are based on land cover classification techniques that are not standardized. Some less-developed countries may also lack staff with the technical skills to interpret the images. This issue is compounded in countries or regions with poor field-based measurements to validate the images.

Model inputs can either be default values or site-specific information, or a combination of the two, and may come from a variety of sources, including field measurements and remote sensing. Several Annex I countries have high-quality models that yield accurate information on carbon stocks and flows, eg, the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)[13] and the Australian National Carbon Accounting System (NCAS) and Tool (NCAT).[14] Models that integrate information from a variety of information sources are also used in non-Annex I contexts, for example in Brazil, Mexico and Indonesia.[15] Models can, with some adaptation and validation using field measurements, be adapted to other countries or regions.[16]

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[12] Information on the IPCC Emission Factor Database can be found at: http://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[13] Information about CBM-CFS3 can be found at: http://carbon.cfs.nrcan.gc.ca/CBM-CFS3_e.html

[14] For more information on the Australian National Carbon Accounting System (NCAS) and the National Carbon Accounting Tool (NCAT), see: http://www.climatechange.gov.au/ncas/about.html

[15] For an overview of some of the current models and information sources used please refer to the June 2009 SBSTA paper: "Information on experiences and views on needs for technical and institutional capacity-building and cooperation", Submissions from Parties. Available from http://unfccc.int/resource/docs/2009/sbsta/eng/misc02.pdf and from http://unfccc.int/resource/docs/2009/sbsta/eng/misc02a01.pdf (Brazil, Mexico, Nepal)

[16] For example, NCAS is being adapted to the Republic of Indonesia under the Indonesia-Australia Forest Carbon Partnership (http://www.climatechange.gov.au/international/publications/pubs/indonesia-australia.pdf).

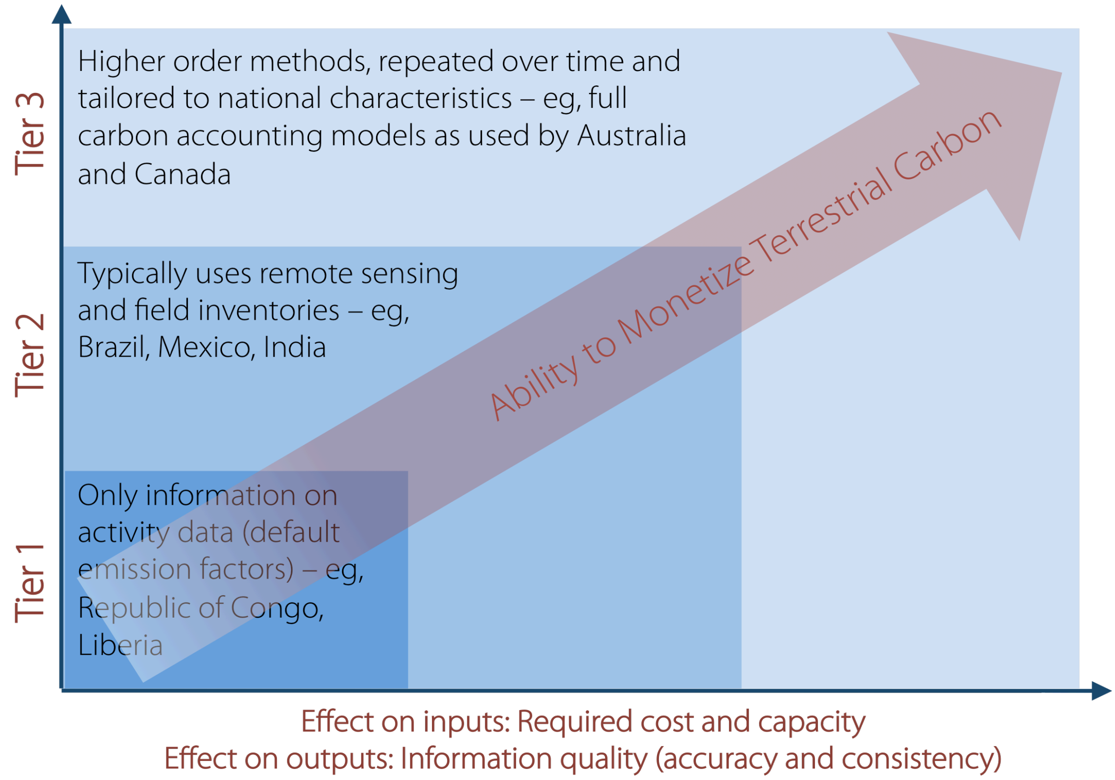
Table 2. Capacities and limitations of the key categories of methods for measuring and monitoring terrestrial carbon

	What Can it Do?	Capacities	Limitations
Field Measurements and Observations	Carbon density, areal extent, change over time if measured more than once	▪ Precise for measured variables, ▪ Low technology requirements ▪ Can be inexpensive depending on labour cost	▪ Costs proportional to area and labour requirements, ▪ Limited to measurable variables, ▪ Can be slow and may not provide results that are consistent over a large area ▪ Accuracy may depend on conversion values applied
Remote Sensing	Areal extent, volume and change over time if measured more than once.	▪ May be cost-effective, ▪ Supports field work performance, ▪ Transparent interpretation methodologies, ▪ Can be routinely collected, if available, ▪ Globally consistent, ▪ Accurate for area estimation	▪ Some forms of sensor may not be suitable for tropical forests or available for all regions, ▪ Can be technically demanding / expensive to interpret results ▪ Not suitable for estimating stocks.
Models	Combine information to derive carbon volumes	▪ Framework for integrating various types of data	▪ Dependent on quality of input data.

4.2 Cost and Capacity Issues

The combination of M&M methods used will determine cost and capacity requirements. Not only is this affected by the IPCC guidance and internationally agreed rules (eg, on reporting frequency, scope of the agreement, definitions etc.) but also by a country's environmental and socio-economic characteristics. For example, a country with low labour costs may wish to gather more field measurements, whereas a country with remote and inaccessible regions may wish to rely more heavily on LIDAR and / or RADAR remote sensing. The implications of the various combinations are described by Figure 1 below.

Figure 1. Overview and examples of the effects of achieving higher quality estimates



In addition to the on-going capacity and costs of the M&M system described in Figure 1 above, countries with weak or non-existing M&M system will incur "readiness" costs. These costs are dependent on the international agreement (eg, incentives for reporting at higher tiers), country characteristics, and quality of pre-existing data and infrastructure[17]. MRV cost estimates (the bulk of which are for the M&M aspects of MRV) have found considerable heterogeneity among countries with regard to the level of funding required to implement national scale accounting for RED and REDD.[18] There have been no published cost estimates for national implementation of REDD+ or AFOLU.

Table 3 below sets out the UNFCCC Secretariat's analysis of the range of national system start-up costs based on the World Bank's Readiness Plan Idea Notes (R-PINs), discussions with developing countries undertaking activities to carry out REDD and independent estimates. The annual maintenance costs for a national REDD programme is approximated to be $720,000 to US$1,900,000 per year. This annual figure includes $200,000 to $950,000 for sampling (ie, field measurements), $120,000 to $240,000 for data costs (ie, data acquisition) and $400,000 to $800,000 for analysis of remote sensing data (in US$ based on 2008 prices).[19]

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[17] These cost factors are described in detail in: UNFCCC, 2009. Technical Paper: "Cost of implementing methodologies and monitoring systems relating to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and greenhouse gas emissions from changes in forest cover, and the enhancement of forest carbon stocks". Reference: FCCC/TP/2009/1. 31 May 2009. Available from: http://unfccc.int/resource/docs/2009/tp/01.pdf

[18] LTS International (2008). "Capability and cost assessment of the major forest nations to measure and monitor their forest carbon, for Office of Climate Change." UK.

[19] Assumes a 2008 average GBP to US$ exchange rate of 2.0. Estimates from: LTS International (2008): "Capability and cost assessment of the major forest nations to measure and monitor their forest carbon, for Office of Climate Change." UK.

Table 3. Estimated costs of implementing REDD (in thousands of US dollars)[20]

Major Components of Readiness	Estimate[21]	Country[22]	R-PIN[23]	Average[24]
REDD management	440-490	130-430	550-1,115	525
Develop REDD Strategy	500	200-410	400-690	450
Consultations	420	380-440	350-182	365
Environment & social impacts assessments	50	50	50	50
REDD implementation framework	250-500	300-350	150-500	341
Develop reference scenario	500	200-400	300-1,200	516
Design MRV system	1,000-1,300	1,000-1,560	250-940	1,008
TOTAL (without annual measurement, reporting and verification costs)	3,160-3,760	2,2640-3,640	2,050-4,627	3,255

Information on project-level activity costs are not readily available as many RED, REDD, REDD+, or AFOLU projects are not mature and some are developed by private companies that are unwilling to disclose commercially sensitive information. It would be valuable to better understand the trade-offs between accuracy and M&M costs and rewards associated with different system design options (scope and scale). An overview of the expected trade-offs between various approaches is provided by Figure 2 below.

[20] Reproduced from: UNFCCC, "Cost of implementing methodologies and monitoring systems relating to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and greenhouse gas emissions from changes in forest cover, and the enhancement of forest carbon stocks". Technical Paper FCCC/TP/2009/1. 31 May 2009.

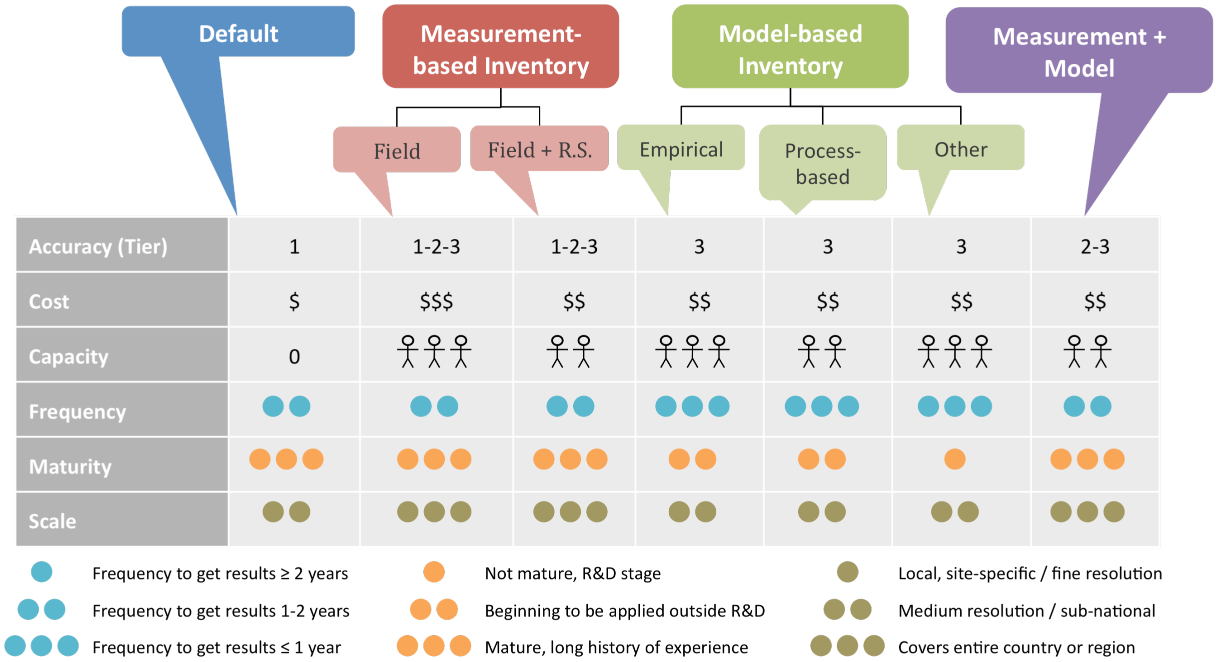
[21] Bottom up estimate by the World Bank based on the tasks that need to be performed.

[22] Estimates by the World Bank based on staff mission to several tropical developing countries and R-PINs submitted by countries.

[23] Estimates submitted in the R-PINs, including one or two countries of different tropical regions.

[24] The average estimate reflects cost estimates for small/medium-sized countries. *Source:* World Bank Forest Carbon Partnership Facility presentation at the second Participants Committee, Gamboa 2009. Data up to October 2008.

Figure 2. Overview and examples of the effects of achieving higher quality estimates (ie, reporting tiers)



5 Conclusions: What is Possible Today and what are the Priorities for Policy Makers

It is technically possible to measure and monitor all types of terrestrial carbon using existing M&M methods and systems. Both field measurements and remote sensing are required for efficient systems. At the national-scale, existing methods and systems are particularly good for the woody ABG pool. It is difficult to cost-efficiently scale existing methods and systems to the national-scale for other terrestrial carbon pools. In other words, at the national scale, it is possible to cost-efficiently measure and monitor carbon emissions and sequestration from deforestation, afforestation and reforestation, but difficult for some types of forest degradation and non-forest land uses.

A number of developed and developing countries have, or are building, national M&M systems (including – among developing countries – Brazil, Guyana, India, Indonesia, Mexico, and Papua New Guinea). However, most developing countries have limited data-gathering capacity and limited access to reliable existing datasets and conversion equations. The quality of outputs from existing national-scale M&M systems ranges significantly due to differences in capacity, available historical information, and available M&M methods.

To expand M&M capacity beyond deforestation to better include degradation, more intensive field measurements and higher-resolution remote sensing imagery collected at appropriate temporal scales are necessary. To expand capacity to include agriculture and other land uses, it will be necessary to apply more refined land use classification systems, develop more well-tested and comprehensive models (in particular, ones that include methane and nitrous oxide), acquire and refine historical information on non-forest land use categories (carbon density and area change), and improve land management information systems (eg, on fertilizer application).

5.1 Recommendations for the International Community

The international community, including developed and developing nations, can contribute to expanded national-level capacity for terrestrial carbon accounting by:

- Expanding the range of species- and ecosystem-specific allometric equations, and improving and sharing credible databases of equations, such as the IPCC's Emissions Factor Database (EFDB)
- Enhancing and harmonizing guidance for terrestrial carbon accounting, including through increased clarity and consistency of definitions, land cover and land use classifications, best practice standards, methodologies, and technologies
- Ensuring the integration and continuity of widely used coarse and medium-resolution remote sensing data and free access to the most commonly used types of remote sensing data (eg, Landsat), and committing to long-term investments in new platforms that provide access to more cost-efficient and transparent data gathering (eg, LIDAR)
- Sharing and adapting existing models
- Training developing country experts in data interpretation
- Increasing coordination and sharing of terrestrial carbon measurement and monitoring experience (including from pilot projects and the voluntary market), costs and data resources, including through a common data archive

5.2 Recommendations for Developing Nation Governments

Developing nations, with technical and financial assistance from developed nations, can continue to take concrete steps towards establishing national M&M systems (within overall MRV systems) by:

- Surveying existing data systems (eg, national or sub-national surveys, commercial or research-scale data-gathering) and designing M&M systems that are relevant to country circumstances
- Establishing or expanding the infrastructure and expertise to collect (through remote-sensing using satellites and through on-the-ground surveying) and analyse terrestrial carbon data
- Agreeing regionally-appropriate, yet internationally comparable, methods to determine how much carbon is stored in a particular type of landscape and what happens to that carbon under different land uses
- Creating and auditing national terrestrial carbon inventories
- Establishing or expanding credible and transparent systems and institutions to: measure terrestrial carbon; certify, verify and audit project- and national-level outcomes; monitor changes over space and time; produce national terrestrial carbon accounts; and coordinate with international institutions

Appendix: IPCC Guidance

The IPCC provides detailed, widely accepted guidance for acceptable methods for determining biomass (ABG and BG) and carbon content in the following documents:

- The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories[25]
- The IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000)[26]
- Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types (2003)[27]
- The Good Practice Guidance for Land Use, Land Use Change and Forestry (2003)[28] and
- The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 4: Agriculture, Forestry and Other Land Use)[29], which have yet to be agreed by all Parties

Carbon Pool Definitions (from IPCC 2006)[30]

Term	Definition
Above-ground biomass pool	"All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage"
Below-ground biomass pool	"All biomass of live roots. Fine roots of less than 2 mm diameter (the suggested minimum) are often excluded because these often cannot be distinguished empirically from soil organic matter."
Dead wood pool	"All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter."
Harvested Wood Products pool	"HWP includes all wood material (including bark) that leaves harvest sites."
Litter pool	"All non-living biomass with a size greater than the limit for soil organic matter (the suggested minimum is 2 mm) and less than the minimum diameter chosen for deadwood (for example 10 cm) lying dead and in various states of decomposition above or within the mineral organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the suggested minimum for below-ground biomass) are included whenever they cannot be empirically distinguished from the litter."
Soil Organic Matter pool	"Organic carbon in mineral soils to a specified depth chosen and applied consistently through a time series. Live and dead fine roots within the soil (of less than the suggested minimum for below-ground biomass) are included whenever they cannot be empirically distinguished from the soil organic matter."

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[25] Available from: http://www.ipcc-nggip.iges.or.jp/public/gl/invs4.html

[26] Available from: http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html

[27] Available from: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation_contents.html

[28] Available from: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html

[29] Available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

[30] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf

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