Roadmap for Terrestrial Carbon Science

Research Needs for Carbon Management in Agriculture, Forestry and Other Land Uses

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The Terrestrial Carbon Group

www.terrestrialcarbon.org

PARTNERS AND PARTICIPANTS

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The Terrestrial Carbon Group is an international group of recognized specialists from science, economics and public policy, working together to catalyze the inclusion of terrestrial carbon in the international response to climate change. A major objective is to create an effective, viable approach for carbon accounting that could be used for the broader inclusion of terrestrial carbon, including REDD, in the UNFCCC. The Terrestrial Carbon Group project is housed as the H. John Heinz III Center for Science, Economics and the Environment, a non-profit, nonpartisan organisation dedicated to improving the scientific and economic foundation for environmental policy.

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Improved terrestrial carbon management offers tremendous potential for climate change mitigation and, in many cases, there are associated co-benefits such as increased productivity, resilience, and biodiversity. It is expected that governments will agree to incentives for improved management of some forms of terrestrial carbon in developing countries, including maintaining existing carbon and creating new carbon.

Across a wide range of geographic scales and land classes, there is a need for a coherent, integrated information base for effective land management practices that produce real increases in sequestration together with real reductions in GHG emissions from terrestrial sources, and transparent, consistent, and comparable quantification of changes in carbon stocks.

Maximizing terrestrial carbon sequestration while minimizing emissions, then documenting and rewarding outcomes requires the ability to deliver the following functions: (1) Estimating the total biophysical and feasible carbon mitigation potential (through avoided emissions and sequestration) for all lands; (2) Measuring and monitoring terrestrial carbon for different land classes at multiple scales (including aggregated global estimates); (3) Setting reference emission and sequestration levels and complying with standards. Six general research categories encompass the scientific and technical foundation needed to deliver these functions:

1. Process-level understanding of carbon dynamics and mitigation potential
2. Scientific research base for alternative management practices
3. Feasible accounting tools for all lands and carbon pools (including all GHGs)
4. Components of a tiered global information system
5. Pathways to establishing national accounting systems that reflect country circumstances
6. Harmonization of reporting guidance across scales and sectors

This report assesses the scientific and technical advancements needed to support land-based mitigation. It identifies priority research needs that must be addressed, globally and in specific regions, and recommends technical investments and actions needed to accelerate avoided emissions and sequestration of terrestrial carbon.

What we already know

Much is already known and considerable capacity and expertise is available. Researchers have developed a solid understanding of the factors and processes controlling terrestrial carbon and can make general predictions for the effects of changing environmental conditions on carbon dynamics. A wide range of land management practices have been shown to effectively maintain and enhance terrestrial carbon. Well-tested tools and methods are available for field measurement and remote sensing and these can be combined with conversion equations and models to quantify terrestrial carbon.

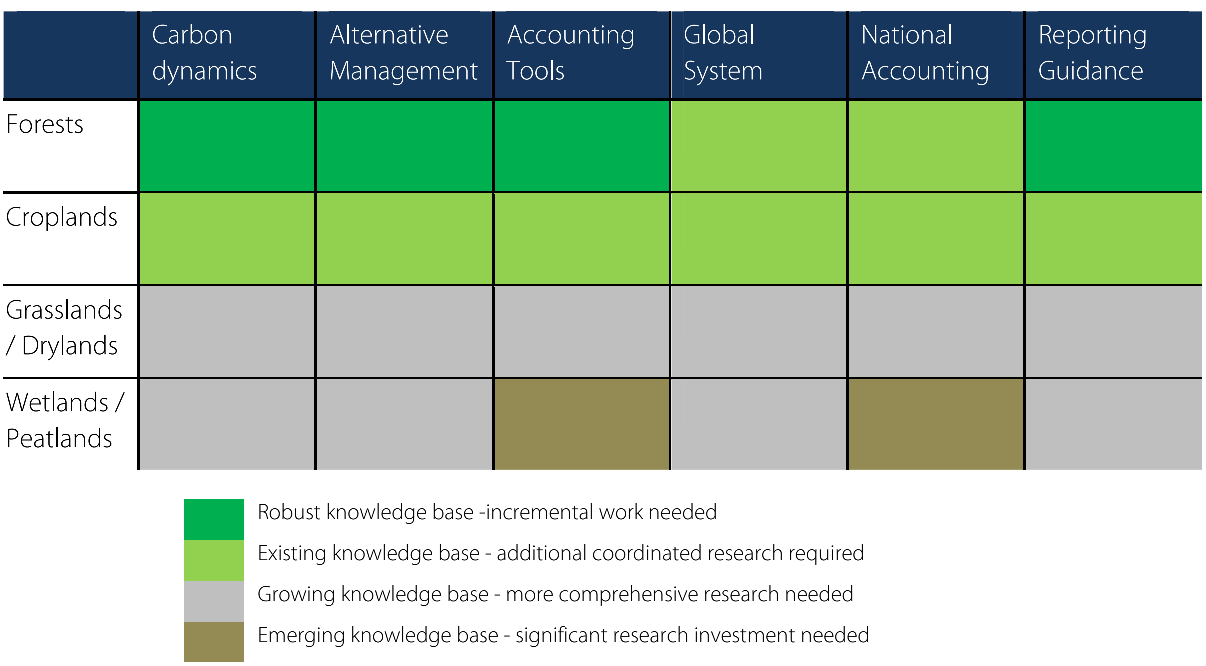
National carbon accounting systems can draw on international guidance, available tools and methods, and existing data systems to estimate mitigation potential for major land classes and actual emissions and sequestration. Important building blocks for national carbon accounting systems include national reports, commercial and academic assessments, and global databases among other existing resources. Multilateral agencies, research institutions, and others are working on data improvement, integration, and accessibility. The scope and clarity of reporting guidance from IPCC and the voluntary markets are improving with experience and scientific advancement.

Research needs

Research and information synthesis for carbon management techniques have not been equally distributed across carbon pools, land use types, and regions of the world. Richer process-level understanding is needed across all land classes for historical, current, and potential emissions and sequestration as well as for drivers of land use conversion and degradation. There is a relative scarcity of information for drylands, wetlands and peatlands and non-biomass carbon pools.

There are significant differences in guidance for reporting emissions and sequestration across scales and sectors and streamlined processes are needed for approving consistent definitions, standards, and methodologies. There is considerable variety among countries in their ability to measure and monitor all types of terrestrial carbon. While some have sophisticated measurement and monitoring capacity, in general, non-Annex I countries have limited data-gathering capacity and access to reliable existing datasets and conversion equations. Overall, there is inadequate consistency in data-gathering methods and resulting datasets across scales and sectors.

The foundation for land-based mitigation and robust monitoring and reporting varies across major land classes. (See Table 3 for full version.)



In seeking to advance the scientific and technical foundation for land-based mitigation, adequate resources, expanded capacity, and clear incentives and mandates are needed to capitalize on the following opportunities:

- Rich scientific knowledge and field experience, available measurement tools and databases, and existing reports and international guidance provide a solid foundation for current and future work.
- Development of cost-effective, easy to use tools and methods and spatially-resolved, accurate data-gathering is needed to expand focus to all land classes (including complex landscapes), regions, and carbon pools.
- Diverse local, national, and regional circumstances can be accommodated by developing a regionally-relevant mix of management practices, measurement approaches, conversion equations, and models as well as planning for changing regional climatic conditions.
- Efforts to improve convergence and consistency can produce synthesized scientific knowledge, harmonized reporting guidelines and methodologies, compatible terminology, definitions, and classifications, and integrative modeling.
- Expanding and building regional and global networks can provide needed linkages across field research and technological advancements and facilitate access to tools, databases, technical support, infrastructure, and extension services.

Action and innovation

To translate policy frameworks and financial incentives into improved land management and significant climate change mitigation, action and innovation will be needed by international agencies, national governments, land managers, financiers, and project implementers and auditors. While there are some well-coordinated, multi-organization initiatives producing integrated responses to priority topics, structured frameworks are needed to link together the array of idiosyncratic projects and programs housed in various research institutions, private companies, and national and international agencies.

Continued and expanded leadership by research institutions and multilateral agencies can promote translational research that builds on existing knowledge and infrastructure, improves accuracy while developing experience, and informs policy and practice. An essential step will be estimating costs and capacity needs associated with research initiatives and generating the necessary financial and technical support. Linkages among developed and developing countries and across the public and private sectors will be critical to filling research gaps through coordinated, multi-lateral, multi-scale cooperation.

TERMS

Additionality	Requirement commonly imposed on carbon projects. It is established when there is a positive difference between the emissions that occur in the baseline scenario, and the emissions that occur in the proposed project.
Afforestation	Planting of new forests on lands that historically have not contained forests.
Auditing	An accounting of greenhouse gases and carbon stocks for an entity, firm, or region / country.
Baseline	The scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases that would occur in the absence of the proposed project activity.
Biophysical	Factors that originate or are related to biological function within given environmental constraints like temperature or moisture.
Carbon Density	Amount of carbon per land area.
Carbon dynamics	The movement of carbon in an ecosystem and processes determining the fate of carbon pools.
Carbon pools	Above-ground biomass, below-ground biomass, soil organic matter, litter, dead wood, and harvested wood products.
Community of Practice	A group of practitioners and experts with a common knowledge base and field of interest whose members share information and experience.
Deforestation	Conversion of forest to non-forest by cutting trees to less than 10-30 % cover and/or resulting in trees predominantly less than two to five meters in height (IPCC 2003).
Degradation	Negative effects on the ecological structure or function of a site resulting in reduced supply of products or services (eg, carbon storage, timber, biodiversity), usually as a result of overuse or poor management.
Disturbance	Natural or anthropogenic processes that alter environmental conditions and can lead to temporary or long-term changes in ecological structure or function.
Emission	The release of greenhouse gases and / or their precursors into the atmosphere over a specified area and period of time.
Field measurement	Measurement performed in situ; commonly converted into biomass and carbon estimates using conversion (allometric) equations or models.
Kyoto Protocol	Adopted in 1997 in Kyoto, Japan, at the Third Session of the Conference of the Parties to the UNFCCC, it contains legally binding commitments, in addition to those included in the UNFCCC. The Kyoto Protocol entered into force on 16 February 2005.
Leakage	Displacement of emissions from project area to outside project area as a result of project activity.
Measurement	The quantification of terrestrial carbon stocks.

Mitigation potential	The amount of climate change mitigation that could be achieved, but so far is not.
Monitoring	Periodic measurement of carbon stocks over time.
Reforestation	Planting of forests on lands that have previously contained forests but that have been converted to some other use.
Remote Sensing	Practice of acquiring and using data without coming into contact with the object of interest. Usually from satellites or aerial photography, such data is used to measure or infer land cover/use. May be used in combination with ground surveys to check the accuracy of interpretation.
Sequestration	The addition of a substance of concern to a reservoir. The uptake of carbon containing substances, in particular carbon dioxide, is often called (carbon) sequestration.
Tier 1, 2, 3	The IPCC uses a hierarchical tier method to estimate uncertainties and for classifying reporting systems; tiers range from 1 to 3, depending on quality of data used and approach taken.
Validation	The establishment of sound approach and foundation involving checking to ensure that the inventory has been compiled correctly in line with reporting instructions and guidelines. It checks the internal consistency of the inventory. The legal use of validation is to give an official confirmation or approval of an act or product.
Voluntary carbon market	All carbon offset trades that are not required by regulation.

ACRONYMS

AFOLU	Agriculture, Forestry and Other Land Use
Annex I	Refers to industrialized countries (have emission reduction commitments if signatory to Kyoto Protocol)
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
COP	Conference of the Parties
EFDB	Emissions Factor Data Base
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GHG	Greenhouse Gas(es)
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection And Ranging (optical remote sensing technology)
MRV	Monitoring, Reporting, and Verification
NFI	National Forest Inventory
Non-Annex I	Developing countries (no quantitative emission reduction commitments under the Kyoto Protocol)
REDD	Reducing emissions from deforestation and degradation (with emphasis on

	developing countries)
REDD+	Reducing emissions from deforestation and degradation including conservation, sustainable management of forests and enhancement of forest carbon stocks
REL	Reference Emission Level
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

LAND CLASS TERMINOLOGY

The terminology for describing different types of lands can vary across sectors and communities of practice. Both land cover and land use are important and in this document we use these terms to refer to their specific meaning. However, we also use the more general term "land classes" to refer to four broad categories that do not have hard distinctions and encompass a range of land cover or land use classes: Forests, Croplands, Grasslands / drylands, and Wetlands / peatlands.

Land cover	refers to the material on any given area of the Earth's surface
Land use	refers to the human or natural activities occurring on a given area of land whether for commercial or subsistence purposes or for conservation / preservation (including combinations of these activities). The Intergovernmental Panel on Climate Change (IPCC) characterizes land use as land management activities (eg, grazing, farming, logging). A type of land use can occur in areas with different land cover – for example, grazing could occur in grasslands, croplands, or forests (IPCC, 2000)
Croplands	are areas where agricultural activities involving plants occur (including both annual and perennial crops).
Forests	refers to areas dominated by trees with single stems with at least 10% crown cover
Grasslands / drylands	Grasslands refers to a land cover type dominated by naturally growing herbaceous plants, particularly plants of the grass family. Drylands refers to a broad land category that includes most rangelands, deserts, semi-deserts and scrublands / shrublands
Wetlands / peatlands	include lands that are seasonally or permanently flooded by water resulting in anaerobic conditions that favor accumulation of biomass; in peatlands, accumulated biomass is peat. Peatlands are a subset of wetlands, but one that is of considerable importance in REDD / AFOLU discussion and therefore merits specific mention[1]

[1] "Peatland is, in contrast to what the term might suggest, no land use category like Forest land, Cropland, Grassland, or Wetland. It is a type of soil/substrate of which the properties are so dominant and conspicuous that the peat becomes eponymous for the landscape in which it occurs. So forest land, cropland, grassland, and wetland may all be peatland." (Barthelmes et al, 2009).

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Introduction

Improved management of the world's terrestrial carbon in agriculture, forestry, and other land use sectors (AFOLU) is a necessary part of the global effort to avoid dangerous climate change. There are a wide range of strategies for avoiding emissions and increasing sequestration of terrestrial carbon in forests, croplands, grasslands and drylands, and wetlands and peatlands – many of these strategies have co-benefits such as increased ecological productivity, resilience, and biodiversity.

It is expected that governments will agree to incentives for improved management of some forms of terrestrial carbon in developing countries, including maintaining existing carbon (eg, avoiding deforestation and forest degradation) and creating new carbon (eg, afforestation). Efforts in both the public and private sectors are building the foundation for incentives for improved carbon management under agriculture, forestry, and other land uses.

As new incentives for protecting and sequestering terrestrial carbon are agreed in international negotiations and created in both voluntary and compliance markets, a robust technical and scientific information base is needed to accompany actions that translate policy frameworks and financial incentives into improved land management. In aggregate, many types of terrestrial carbon mitigation projects in many regions and land classes around the world will achieve substantial net increase in the land sink for atmospheric carbon. Successful implementation through public and private sector action will:

> <u>Maximize terrestrial carbon sequestration under agriculture, forestry and other land uses</u>. Land managers will be able to quickly and cost-effectively estimate the carbon mitigation potential and socio-economic feasibility associated with alternative management practices and implement these practices, resulting in a net increase in carbon stored.
>
> <u>Document terrestrial carbon outcomes</u>. Implementers of terrestrial carbon emission reduction and sequestration activities will have tools and methods readily available to measure baseline carbon stocks and monitor changes in carbon over time. Governments will have established and have in operation national carbon accounting systems that use tools, methods, and statistical designs appropriate to country circumstances to produce national carbon accounts that can be aggregated into global accounting systems.
>
> <u>Reward improved terrestrial carbon management</u>. Implementers of terrestrial carbon emission reduction and sequestration activities are able to estimate reference levels to demonstrate additionality and account for leakage, and periodically report carbon outcomes to auditors and, if applicable, to financiers and offset credit purchasers. Auditors can in turn verify compliance of carbon mitigation activities to the agreed standards using approved methodologies and international guidance and recommended registration and, if applicable, offset credit insurance. Registries effectively track the performance of activities, including ownership of any economic incentives associated with meeting performance targets. This aggregated information is also available to be used to supplement national and international-scale estimates to assess the aggregate effect of activities in meeting national and / or international commitments.

This report assesses the scientific and technical advancements needed to achieve these goals. It identifies priority research needs that must be addressed, globally and in specific regions, to provide the quantitative basis for improved management of terrestrial carbon. It recommends technical investments and actions needed to accelerate avoided emissions and sequestration of terrestrial carbon and essential roles that researchers, practitioners, and institutions can play. The primary emphasis is on lands in developing countries where terrestrial carbon management represents a major component of cost-effective mitigation potential.

1 What Types of Technical and Scientific Information are Needed

Maximizing terrestrial carbon sequestration while minimizing emissions, then documenting and rewarding outcomes requires the ability to deliver the following functions:

- Estimate the total biophysical and feasible[1] carbon mitigation potential (through avoided emissions and sequestration) for all lands
- Measure and monitor terrestrial carbon (area and carbon density) for different land classes at multiple scales (and aggregate project-scale and national carbon accounting data to produce global estimates)
- Set reference emission and sequestration levels and comply with standards

1.1 Estimate the total biophysical and feasible carbon mitigation potential for all lands

All terrestrial carbon pools (and fluxes of all greenhouse gases from the terrestrial system) that interact with the atmosphere at timescales less than centuries, and all land classes, have an essential role to play in climate change mitigation. Land management practices can reduce the loss of carbon and other GHGs from ecosystems to the atmosphere and sequester atmospheric carbon in the land sink). Whether under a regulated or voluntary offset market, much of the activity that will deliver terrestrial carbon mitigation will occur at scales smaller than the national level (referred to here as “projects”).

These projects can range from very small areas parcelled together to large contiguous areas encompassing entire regions within a country. In order for project-scale activities to cumulatively generate carbon emissions reduction and sequestration at levels that make a meaningful contribution to global climate change mitigation, national landscape-scale planning is needed to design and optimize domestic policy incentives and to deliver supporting infrastructure.

National governments, multi-lateral institutions, international donors, private financiers, and others that work to identify the most significant land-based carbon mitigation opportunities at sub-national and national scales need to know the magnitude, location, and type of biophysical carbon mitigation potential associated with major land classes. This requires process-level understanding of the controlling factors for carbon and GHG emissions and sequestration – including the effects of geographic and temporal variability, biophysical limits, and natural disturbances – as well as estimates of historical and current emission and sequestration patterns.[2]

In addition to biophysical potential, there are other important technical and socio-economic factors that control the actual, or feasible, mitigation potential for any land area. Technical capacity for implementing alternative land management practices requires knowledge and access to suitable methods to estimate the mitigation potential, over time, of alternative management options in a project area and to assess the practicality of implementing new management practices.

1.2 Measure and monitor terrestrial carbon for different land classes at multiple scales

Under a global agreement on incentives for terrestrial carbon maintenance and sequestration, carbon accounting systems will be required at multiple scales:

- At the national level to demonstrate fulfilment of voluntary or compulsory national commitments. National-level carbon accounting systems will be expected to produce and report information that is verifiable, comparable with information from other nations, and consistent over time.

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[1] Feasibility will be influenced by nature of available incentives and costs associated with alternative management.

[2] Spatially-resolved understanding of ecological processes can enable landscape-scale planning that maximizes co-benefits such as biodiversity conservation (Stickler et al., 2009; Venter et al., 2009).

- At sub-national or project scales where much of the activity that will deliver carbon benefit will occur. 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.
- At the global scale, an integrated information framework is needed for ensuring that project- and national-scale accounting can be aggregated to produce estimates of impact on atmospheric GHG concentrations (ie, determine global net emissions / sequestration for terrestrial systems). In order to cross-check the accuracy of aggregated national data, global-scale projections of carbon emissions reduction and sequestration potential are needed.

Data requirements and selection of measurement methods will reflect the scale, scope, and stage of implementation of each carbon accounting system. At any scale, data collection and carbon estimation must use a consistent framework and comply with relevant standards and criteria.

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. National terrestrial carbon accounting systems require appropriately scaled-up technical tools and infrastructure for documenting changes in carbon over space and time. Resulting data systems must align with existing and evolving international guidance, as well as country circumstances, and be capable of integrating project-scale data.

Estimating terrestrial carbon stocks relies on measurement of the areal extent and carbon density of different land classes in an area of interest[3]. Once base measurements are in hand, on-going monitoring generates estimates of change in carbon stocks. Efficient monitoring of terrestrial carbon to produce information relevant to project implementation, landscape-scale planning, and national and international accounting will require valid statistical designs for estimating area, biomass, and carbon as well as conversions to other land cover and uses.

1.3 Set reference emission and sequestration levels and comply with standards

In order for terrestrial carbon management to be rewarded under incentives, carbon accounting systems need to document actual change from reference emission and sequestration levels (ie, additionality).[4] For example, a business-as-usual approach to setting a reference emission level assesses carbon at risk of emission and rewards management that protects at-risk carbon.

When carbon emissions are shifted to another location, within or beyond national borders, as a result of carbon project activity, the carbon benefit of the project is diminished. Appropriately developed reference emission levels at project and national scales are important tools to address domestic leakage.[5]

The scale, type, and quality of information required to develop reference levels will depend on the standard-setting body under which a project seeks to be rewarded, as well as any specific criteria set by the organisation providing the funding for the activity (eg, governments or private financiers) and / or the government of the country in which the project takes place. General information needs include land cover, local environmental conditions (eg, soil types, climate, hydrology, fire regime), biological conditions (eg, species composition, growth rates), historical and current land use, and socio-economic factors for the region (eg, population, food and fuel demand, infrastructure, commodity prices,

[3] Carbon density is influenced by a number of factors including current and historical management practices..

[4] See Terrestrial Carbon Group Project *Policy Brief Numbers 2 and 3* (www.terrestrialcarbon.org).

[5] Maximizing participation of countries in international agreements and incentive systems can improve international leakage (Murray, 2008).

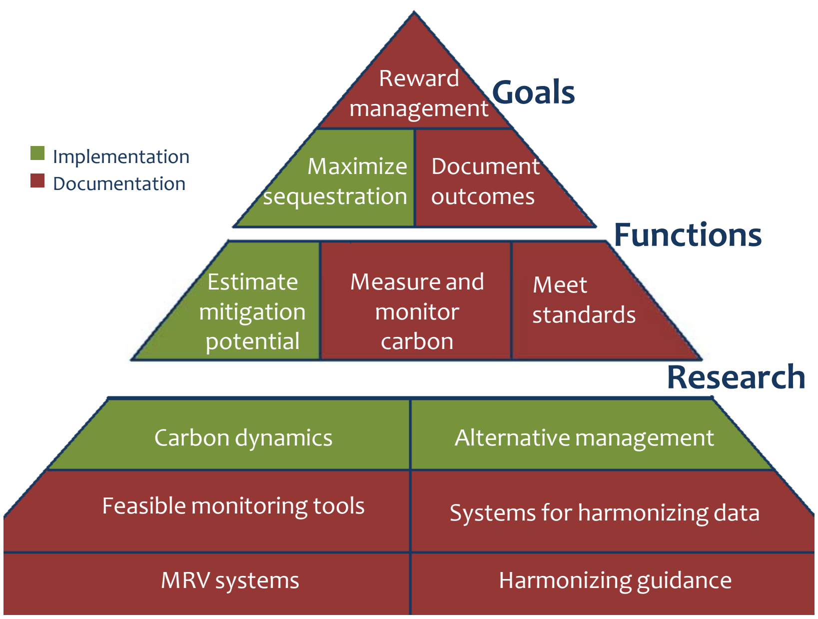
governance). These data can be integrated using modelling tools to project future emissions or sequestration in the absence of an incentivized change in land management.

To be rewarded for carbon projects in the regulated or voluntary market, compliance is required with approved standards and methodologies. Standard-setting bodies specify methodologies and technical information requirements for different types of projects and independent auditors verify that project implementation meets methodology criteria before recommending registration and credit issuance.

1.4 Summary

Improved terrestrial carbon management offers tremendous potential for climate change mitigation and, in many cases, there are associated co-benefits such as increased productivity, resilience, and biodiversity. Implementation of terrestrial carbon emission reduction and sequestration activities can and does occur at a wide range of geographic scales and land classes. Across these scales and land classes, there is a need for a coherent, integrated information base for effective land management practices that produce real increases in sequestration together with real reductions in GHG emissions from terrestrial sources, and, transparent, consistent, and comparable quantification of changes in carbon stocks.

Figure 1. Goals, required functions, and priority research areas for implementing and documenting improved management of the world's terrestrial carbon.



2 What Are the Major Research Needs

As incentive systems for improved terrestrial carbon management evolve through international negotiations and voluntary markets, there are significant opportunities to advance the scientific and technical foundation for estimating mitigation potential, multi-scale monitoring, and achieving high-quality reporting and verification. While much is known and considerable capacity and expertise is available, knowledge and technology gaps remain that must be addressed, globally and in specific regions.

The following sections provide, for six general categories, an overview of current scientific and technical capacity, priority research needs, and recommended strategies for meeting these needs. These categories include:

1. Process-level understanding of carbon dynamics and mitigation potential
2. Scientific research base for alternative management practices
3. Feasible accounting tools for all lands and carbon pools (including all GHGs)
4. Components of a tiered global information system
5. Pathways to establishing national accounting systems that reflect country circumstances
6. Harmonization of reporting guidance across scales and sectors

Many researchers and institutions are already making major contributions in these areas (see Appendices for specific examples). Further progress in and integration across these six categories will enhance global capacity to deliver essential functions in support of maximizing net terrestrial carbon sequestration and documenting and rewarding outcomes.[6]

2.1 Process-level understanding of carbon dynamics and mitigation potential

2.1.1 What is already known?

In order to estimate mitigation potential[7] in terrestrial ecosystems, it is necessary to understand the major biophysical processes that control carbon dynamics (and GHG flux) in soils and biomass. The general processes that influence the way that carbon is taken up, stored, and released are well understood. Key controlling factors for carbon stocks and sequestration rates include local climatic conditions, land cover, land use, soil type, and topography (Trumbore, 1997).

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[6] For example, at Agriculture Day in Copenhagen (December 12, 2009), a key recommendation was that research and other advancements in agriculture, climate change mitigation, and carbon markets will produce more effective tools and systems if they are conducted in a coordinated way. (Venues suggested included development of the next IPCC Assessment Report and the agriculture work program under SBSTA). Similarly, discussion highlighted the importance of integrated research on natural resource management (eg, land use change and associated drivers; water management) informed by broad stakeholder engagement in setting the scientific research agenda (see http://www.agricultureday.org/exhibitions-and-events.html#3).

To meet the climate challenge, substantial additional financing and investment will be needed across the entire rural value chain. New investments must be handled transparently to ensure that adaptation and mitigation are not undermined by reduced support for global food security and rural development. In addition, new investment must be accessible to all stakeholders, including researchers and members of civil society, especially farmers and their associations. Specifically, the group urged climate negotiators to agree on the early establishment of an agricultural work program under the Subsidiary Body for Scientific and Technological Advice (SBSTA):

[7] A number of efforts have assessed the major mitigation opportunities in the land sector. For example, the IPCC points to increased sequestration of CO_2 as well as reduced emission of CH_4 and N_2O as the major mitigation opportunities in agricultural soils globally (IPCC, 2007).

Specific patterns will vary across different types of ecosystems and climate, disturbance,[8] and management regimes. The conditions and processes that control terrestrial carbon stocks and fluxes are spatially variable and there can be great heterogeneity at the scale of continents or within a forest stand or farm field. Also, while much remains to be understood about future climatic changes in specific regions of the world, changes in moisture regime and temperature conditions have the potential to alter growing seasons, plant water availability, insect populations, decomposition processes, and a number of other factors relevant to terrestrial carbon dynamics. In addition, increasing atmospheric CO_2 concentrations are likely to influence vegetation in a number of ways including growth rates, drought tolerance, and nitrogen demands (IPCC, 2007). Elevated atmospheric CO_2 will also influence net carbon accumulation by plants and in soils (Hungate et al, 2009).

2.1.2 What are the primary research needs?

There is room for richer process-level understanding for all land classes and all carbon pools, however there is a relative scarcity of information for grasslands, drylands, wetlands, and peatlands and for non-biomass carbon pools (eg, soil organic matter) in general. Improved knowledge can be used to predict carbon dynamics in a spatially-resolved way. An overarching question is how changing climate regimes will influence carbon dynamics in specific land classes and regions.

Of the major land classes, carbon dynamics in forests are relatively well-understood. There has been variability among global assessments of CO_2 emissions from deforestation and forest degradation (these studies have made use of different approaches) and, over time, estimates have been revised substantially based on new data and evolving methods (van der Werf et al, 2009). Ongoing research is likely to produce greater convergence in these global estimates in the near term.

In croplands, two important areas for further investigation of carbon dynamics are partitioning to soil carbon pools over decadal time periods and variation in carbon quantity and vulnerability with depth. Potential factors include soil type, climatic conditions, historic and contemporary land use, organic matter additions, erosion, and redeposition, as well as factors of soil quality (and associated capacity for productivity) such as soil structure, biological activity, plant available water capacity, and nutrient dynamics (Lal et al, 2004).

Biophysical processes in grasslands and drylands have received significant attention by the research community, but require additional regional- and global-scale synthesis of resulting knowledge. Efforts are needed at multiple scales to improve understanding of soil carbon (including inorganic carbon) dynamics, pools, and fluxes, as influenced by climate, land use, and management (Lal, 2001). Of particular importance is improving understanding of sequestration rates (Conant, 2009) and fire events and dynamics (White et al, 2000).

Technical work to understand biophysical processes and mitigation potential in wetlands and peatlands has been robust in some regions, but additional process-level knowledge is needed. Of particular importance is improved understanding of the full range of greenhouse gas emissions and key controlling factors.[9] As a particularly carbon-rich subset of wetlands, peatlands merit further attention for key aspects of carbon dynamics including depth, density, and decomposition maturity in peatland ecosystems around the world. Additional work is needed to characterize key processes in peatlands such as lateral dimensions of subsidence and the relationship between drainage depth, subsidence rate, and CO_2 emissions (Hooijer et al, 2006). Overall, improved understanding of geographic and temporal variability, biophysical limits, natural disturbances, and confounding factors is needed (Canadell and Raupauch, 2008; McNamara et al, 2008). For example, interactive effects such as changes in soil physical properties and associated disturbance risks such as fire or insect infestation can dramatically alter terrestrial carbon (FAO, 2001).

[8] "Terrestrial carbon dynamics are characterized by long periods of small rates of carbon uptake, interrupted by short periods of rapid and large carbon releases during disturbances or harvest (IPCC, 2007)."

[9] Emissions can result from a wide variety of conditions such as N_2O emissions triggered by water-logging of semi-tropical systems in rainy seasons. Similarly, in some systems CH_4 emissions may be inversely linked to productivity if carbon is diverted to plant growth.

At the global scale, more work has been done to estimate biophysical mitigation potential in forests and croplands. However, dryland, wetland, and peatland ecosystems are recognized to offer significant mitigation potential (Joosten and Couwenberg, 2009; Alterra, 2008) and further quantitative work at appropriate geographic scales is needed (Zhao et al, 2009).

There are many different approaches for estimating mitigation potential for major land classes (see Appendix 1). The scope (ie, land classes; carbon alone or all GHGs), geography (eg, global, regional), timeframe (eg, annual rate, specific future date), units (eg, mass per unit area, CO_2 equivalents), and other parameters (eg, fixed carbon price), are variable across these estimation approaches. More work is needed to characterize the relative magnitude of mitigation opportunities within major land classes globally, such as the potential contribution of major mitigation strategies such as grazing management or peatland rewetting.

2.1.3 What can be done to meet research needs?

There are major opportunities for improving process-level understanding of carbon dynamics and mitigation potential. (See Appendix 2.)

New research in understudied regions and land classes. The research community can build on existing understanding of carbon dynamics and disturbance processes by implementing basic research (eg, field studies) in understudied regions and land classes to ensure that estimated mitigation potentials are calibrated to a more accurate understanding of biophysical processes, geographic and temporal variability, and regional conditions for the full range of land classes and regions.

Whole landscape research strategies. Commonly, research efforts are, and will continue to be, organized around major land classes: forests, croplands, grasslands and drylands, and wetlands and peatlands. Within these communities of practice, there is a wealth of expertise available to be more fully harnessed in answering outstanding questions about biophysical processes, carbon dynamics, and mitigation potential. However, there is emerging awareness of the need for a more complete and integrated characterization of ecological landscapes. While some large land areas can be described homogeneously (eg, contiguous unmanaged forests, extensive grasslands), land cover and land use in many regions are quite heterogeneous, making land classification difficult in many places. A number of research investments offer promise for increasing our ability to accurately predict and monitor changes in carbon across whole landscapes. Establishment of networks of permanent benchmark field sites for ongoing monitoring of soil carbon and related properties[10] could improve the consistency of research and estimation efforts (Paustian et al, 2006) and enable comparison of improved management outcomes with baseline measurements (FAO, 2009).

Synthesizing findings from existing research base. Research and information synthesis have not been equally distributed across land classes, carbon pools, or regions of the world. Establishing platforms for sharing research-scale findings (eg, open source databases) can enlarge the pool of information available for meta-analysis of the controlling factors for carbon emission and sequestration and global-scale estimation of mitigation potential. Increased availability of resources for synthesis activities (eg, bridging local-scale studies to develop landscape-scale information) can improve process-level understanding of carbon dynamics for a larger set of land classes and regions.

Improving estimation of biophysical sequestration potential. To develop the capability to cross-check avoided emissions and sequestration estimates at national and sub-national scales, robust global-scale estimates will be needed. Efforts to harmonize estimates of land-based mitigation potential across scales and land use types could facilitate better understanding and coordination.[11] The

[10] For example, expansion of long term ecological research networks across the Americas to a broader range of ecosystems, countries, and continents (Greenland et al, 2003; Hobbie et al, 2003).

[11] The objective of global consistency should be pursued with equal attention to the diversity of local conditions and engagement of local and national involvement in sequestration potential estimation.

ability to produce global-scale estimates for major land classes and the full scope of the land sector will require harmonized definitions of land classes, carbon pools included in analysis, timeframes of analysis, and common units (see Section 2.6).

Integrating research activity. A number of existing institutional and cooperative initiatives are already directed to addressing priority research needs. It is important to expand on efforts to integrate research across scientific disciplines (eg, geology, hydrology, climatology, plant biology, chemistry) to better understand major drivers of land conversion and degradation (Lal, 2004). Multilateral and national agencies, professional societies, and individual researchers and research institutions can all contribute to research integration networks, platforms, and activities.

2.2 Scientific research base for alternative management practices

2.2.1 What is already known?

To achieve land-based mitigation at the scale required, a synthesized, accessible, geographically-relevant scientific research base for incentivizing and implementing shifts to alternative land management is necessary for all types of lands (including heterogeneous landscapes) and land managers (including smallholders, indigenous communities, and others who own and manage land.

A wide range of land management practices have been shown to be effective at maintaining and enhancing terrestrial carbon and contributing to mitigation (IPCC, 2007).[12] In many regions, significant research has been conducted for management of forests, croplands, grasslands, and drylands (FAO, 2001). An emerging body of work documents management practices for maintaining and enhancing carbon and reducing overall GHG emissions in peatlands (Kaat and Joosten, 2008). Increases in agricultural productivity in existing croplands may also contribute to reductions in conversion of forests and other 'natural' lands to croplands.[13]

Some of the major management practices for achieving terrestrial mitigation include (Canadell and Raupach, 2008; IPCC, 2007; Stickler, 2009; Trumper et al, 2008; Conant et al, 2001; Joosten and Couwenberg, 2009; DB Climate Change Advisors, 2009):

Forests: Reduced deforestation; afforestation; reforestation; forest management to increase biomass productivity and carbon density; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; improved fire management.

Croplands: Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated / drained organic and peat soils and degraded lands; improved rice cultivation practices and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertilizer application practices to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.

Grasslands / Drylands: Improved grazing land management to increase soil carbon storage; restoration of degraded lands; maintaining or enhancing vegetation; erosion control; application of soil fertilization and amendments; afforestation and woodland regeneration; improved livestock and manure management to reduce CH_4 emissions.

Wetlands / Peatlands: conserving peat carbon stocks; maintaining / restoring net carbon sequestration; rewetting; water and fire management; substituting use of peatland fossil fuel by renewable sources

[12] Application of practices commonly associated with sustainable land management may generate co-benefits such as greater resilience to shifts or increasing variability in climatic conditions (Stickler et al, 2009).

[13] In addition to changes in on-site management practices, other strategies for terrestrial carbon mitigation include expanding the designation and enforcement of protected forest areas, eliminating agricultural products produced on deforested land from supply chains, and encouraging low-deforestation livelihoods have been shown to contribute to avoided deforestation in Brazil (Nepstad et al, 2009).

In many locations around the world, these practices and others have been adapted to provide practical, context-specific options for alternative management.

The effectiveness of alternative management practices will vary by local conditions[14] and the feasibility of their implementation will be influenced by socio-economic factors. In order to know the location and type of carbon mitigation potential in an area of interest, estimates of historical and current emission and sequestration patterns as well as projected outcomes associated with alternative management are needed. In order to evaluate the actual, or feasible, mitigation potential, it is important to understand relevant drivers of land use conversion and degradation (eg, local infrastructure, global commodity prices) and available capacity for implementation of alternative land management practices (eg, knowledge of and access to suitable methods). Also, adjustments in land management practices in response to variability are critical for coping with climate change (Easterling and Apps, 2005).

2.2.2 What are the primary research needs?

While forest carbon is well understood for many regions of the world, further characterization of forest areas in the tropics and sub-tropics with high mitigation potential (as well as high vulnerability to disturbance) is needed. Data on forest carbon in mixed landscapes and forest fire regimes are not complete (Matthews et al, 2000). A key remaining challenge is more effective and coherent tracking of changes in some regions. In addition, further work is needed to refine estimates of historical, current, and potential carbon emissions and sequestration in forests. Increasingly nuanced understanding of the net carbon benefits of individual and combined forest management practices and their suitability for local conditions will contribute to optimized land management (Nabuurs et al, 2008).

Cropland management for carbon conservation has received substantial research investment in a number of countries, producing a solid knowledge base for a broad range of management practices. However, it is widely acknowledged that application of these practices must be adapted to local conditions, requiring field trials in regions that have been underrepresented to date. There are important temporal dimensions to identifying optimal cropping patterns in specific places and the short- and long-term potential of various practices (eg, boosting annual yield, resilience to climate variability over multiple years) will influence cropping decisions by land managers. In addition, two important areas for general research advancement for croplands include residence times for various soil carbon pools and exchange of greenhouse gases between soil and the atmosphere under different land management practices (Lal, 2004).

Existing research in grassland and dryland systems has show that carbon sequestration rates may be relatively slow (Conant, 2009) and further work is needed to understand the factors that contribute to higher productivity and carbon sequestration. The most pressing technical barrier to improved carbon management is the relative scarcity of information about grassland and dryland ecosystems around the world (Farage et al, 2007). For example, the extent of land degradation and conversion in drylands is poorly documented and there are limited and divergent quantitative estimates of dryland carbon sequestration potential and the impact of land use changes and desertification (Trumper et al, 2008). Key opportunities for improving the knowledge base for carbon management in grasslands include investigating the extent of carbon sequestration in grasslands (including the associated level of variation and uncertainty) and quantifying sequestration responses to land management practices in specific grazed ecosystems (FAO, 2009).

Recent work has identified general responses of GHG fluxes in wetlands and peatlands to water level management, for example, rewetting to particular depths can optimize for CO_2, CH_4, and N_2O emissions (Joosten and Couwenberg, 2009). Application of alternative management practices in wetlands and peatlands may produce very different outcomes for carbon sequestration and net GHG

[14] Spatial heterogeneity of the conditions and processes that control terrestrial carbon levels also influences the effectiveness terrestrial carbon mitigation practices at the scale of major regions. For example, reforestation in tropical regions is likely to promote cloud formation and reflect additional sunlight, while reforestation in boreal regions is likely to reduce albedo and negate carbon sequestration benefits (Canadell and Raupach, 2008).

fluxes (in many cases, the latter may be of greater significance), depending on local climatic conditions and other factors (Li et al, 2004). To improve the knowledge base for mitigation in peatlands, refined understanding of GHG emissions under current or alternative management is needed (Couwenberg, 2009). Further work is needed to expand geographic coverage of data on peat extent and peat depth and to understand the nature and extent of conversion, draining, and degradation of peatlands (Hooijer et al, 2006).

Globally, spatially-resolved information for land cover, carbon density, and other biophysical factors are available, although resolution and accuracy vary by region and variables of interest. In many countries, activity data needed for estimating historical and current emissions and sequestration (eg, cropping, livestock management, productivity) are not spatially-explicit.

2.2.3 What can be done to meet research needs?

Researchers have been working to understand outcomes associated with land management practices for many years and for many purposes. Historically, attention has focused on enhancing agricultural and forest productivity as well as environmental conservation, and it is only more recently that there has been increasing interest in land management for the explicit purpose of carbon sequestration and GHG mitigation. There are a number of opportunities for focusing efforts in this area (see Appendix 3 for further details).

Identifying areas of high terrestrial mitigation potential. In developing a more comprehensive, spatially-resolved understanding of current carbon stocks, carbon emissions and sequestration, and mitigation potential, it will be particularly important to enrich the data and knowledge base in specific regions of the world, at relevant scales.

Identifying understudied regions. In order to prioritize areas for new field trials and other research to understand the outcomes of alternative management practices on carbon and GHGs, it will be important to assess which regions have been underrepresented to date.

Investigating mitigation potential associated with alternative management practices. Identifying land management practices that maximize emissions reduction and sequestration in particular regions will require additional study of the net effects of different practices in a more comprehensive set of geographic areas. Research on the effectiveness of land management practices for mitigation involves a combination of data from field and remote sensor measurements and modelling to provide ex ante predictions and to characterize multi-year outcomes. A key limitation is availability of datasets that are representative of all relevant regions, so there is a need for global coordination and investment in data-gathering in under-represented countries and regions.

Expanding research to include alternative management for all land classes. While carbon offset projects have initially focused on avoided deforestation and afforestation / reforestation[15], there is significant emissions reduction and sequestration potential associated with application of alternative management practices in other land classes, including croplands, grasslands, and drylands (IPCC, 2007), which collectively cover extensive areas, as well as wetlands and peatlands which have high carbon density and potential GHG fluxes. Expanded research investment in these land classes can generate needed understanding of how shifts in land management can contribute to mitigation goals.

Operationalizing an integrated continuum view of landscapes. To strengthen capacity for managing complex landscapes, a more nuanced knowledge base for gradients of land management within land cover types is needed that reflects the reality of highly variable land management, ranging from complete land cover conversion (eg, large-scale deforestation) to fully protected areas (often within complex, fine-scale mosaics).

[15] While reforestation is generally accepted to result in increased aboveground biomass, Malmer et al (2009) point to the need for additional field studies and of longterm empirical data collection on the effects on soils.

Gathering and analyzing socio-economic data related to land use change drivers. Changes in carbon stocks and GHG fluxes can result from on-site activity as well off-site activities that alter drivers of land management and land use conversion. For example, peatland conversion and drainage has been driven by establishment of oil palm and timber plantations (Hooijer et al, 2006). Research on the feasibility of alternative management practices requires an understanding of key drivers of land use change as well as availability of relevant socio-economic data and modelling capability.

Fast-tracking scientific advancement to land managers. Larger investments in research and synthesis, combined with a commitment to expanding awareness, through effective extension activities,[16] and uptake, through incentives and appropriate infrastructure, will be key for mobilizing land managers to shift practices (and thereby, in many cases, generate a variety of co-benefits at parcel, watershed, and regional scales).

2.3 Feasible accounting tools for all lands and carbon pools (including all GHGs)

2.3.1 What is already known?

In order to document and reward implementation of improved terrestrial carbon management, appropriate measurement and monitoring methods are necessary to demonstrate that real, quantifiable, and comparable carbon emission reductions and sequestrations take place (Reid et al, 2004; Trumper et al, 2008). A suite of methods to measure and monitor terrestrial carbon exists, particularly for those carbon pools which have historically received most attention (ie, aboveground woody biomass in forests).[17] Field measurements, remote sensing, conversion equations, and models – the main categories of accounting tools – vary in their capacity, availability, cost, and scale of relevance (see Appendix 4). Spatial variability of the conditions and processes that control terrestrial carbon levels has important implications for efforts to measure or model carbon stocks and fluxes.

Total terrestrial carbon stock is a function of the areal extent and carbon density (stock per unit area) of each land class in an area of interest.[18] Basic information requirements include estimation of the areal extent of significant land classes and monitoring of land use change within and between various land classes as well as carbon density measurements and monitoring of changes to carbon density within major land classes

Data on the distribution and extent of land classes 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 cover change for several decades and can also be used to track changes to the relative distribution of land use classes over time.[19] Measuring carbon density of land classes requires a combination of direct field measurements (to estimate biomass) coupled with conversion equations and / or models. Conversion and expansion factors and equations, such as allometric equations, are themselves based on field measurements and are only available for certain countries, land classes, and plant species.

There are several approaches for using remote sensing to estimate carbon density and changes in carbon density. It can be estimated directly based on quantifiable relationships between biomass and spectral responses or it can be estimated indirectly based on classification techniques, indices, and regression equations or process models developed through research pairing field measurements with remote sensing reflectance measurements (WMO et al, 2008). Detecting carbon density changes due

[16] For example, extension services in rangelands can build on current pastoral networks of communication over long distances (Reid et al, 2004).

[17] See Terrestrial Carbon Group Project *Measuring and Monitoring Terrestrial Carbon: The State of the Science and Implications for Policy Makers* and also *Policy Brief 5* (www.terrestrialcarbon.org).

[18] Carbon density is influenced by many factors including current and historical land management.

[19] Note that the cost-effectiveness of remote sensing decreases for small areas of interest (eg, less than 300 ha). The relative cost of field measurement programs may increase in landscapes with high heterogeneity.

to degradation and intensification or agricultural changes requires more detailed data and data interpretation.

Results can be combined with other types of data (eg, information on land management) and fed into models to estimate current stocks as well as changes (van der Werf et al, 2009). Many well-accepted models exist and are used to integrate information from a variety of information sources. Typical inputs for models include information related to carbon stock estimates and activity data. Consistent with IPCC guidance, inputs can either be default values (Tier 1), country-specific information (Tier 3), or a combination of the two (Tier 2).

There is considerable experience with field methods to quantify biomass, in particular above-ground biomass in tropical, temperate, and boreal regions. Many biomass measurement and monitoring methods are widely accepted and commonly used, and often require only basic technical capacity. The primary challenge is usually ensuring high-quality, transparent data collection and interpretation methods that are consistent over time.

More recently, public and private research organizations have been working to develop tools and methods for quantifying terrestrial carbon using field methods, remote sensing, and models in combination. While these tools and methods have been more widely tested and calibrated in Annex I countries, many of them have been applied in other areas of the world (eg, South Africa, India, China, Mexico, Brazil, Indonesia).

2.3.2 What are the primary research needs?

Field measurements are essential for producing data to build, calibrate, and update inventories, maps, models, and other necessary types of information. One of the most important directions for investment and activity is application of existing tools and methods to fill data gaps for underrepresented land classes and regions. Advancements in field measurement capabilities are also usefully focused on improved and new tools and methods for minimizing labor, time, and costs associated with extensive field surveys. Also, field measurements will be critical to producing regionally-relevant conversion factors and allometric equations for all types of carbon pools and land classes.

Remote sensing data products are commonly used to monitor changes in land cover and, in combination with field data, can be used to estimate carbon stocks and change over time. Accurate field measurements are necessary to calibrate sensor data and produce high-quality estimates of biomass and carbon stocks and changes, however existing field datasets are not always sufficient. Remote sensing methods for the entire range of carbon pools and stock changes have not yet been fully commercialized. Dead wood, litter, and soil organic matter are generally not measured using remote sensing methods, but rather estimated using known relationships with above-ground biomass (Izaurralde and Rice, 2009).

Interpretation capability for remote sensing data streams can be technically demanding and / or expensive. Land use classification consistency is made more difficult when a variety of landscapes are included and where there is variability within land use categories. Additional guidance and experience is needed to determine how best to integrate different optical, laser, and radar remote sensing technologies (Smukler and Palm, 2009).

Some freely available coarse to medium resolution images (MODIS, Landsat) have not been suitable for use to monitor sub-national (parcel-scale) activities[20] and finer resolution images (eg, derived from IKONOS or QuickBird) are still too costly to use for widespread parcel-scale monitoring. Also, there are concerns regarding continuity of key sensor types.

Different sensors may be affected by technical challenges. "Cryptic deforestation" (ie, biomass removal which does not affect canopy closure) may not be detected by many sensors. Cloud cover over large

[20] This is changing for forest systems with the advancement of new tools such as CLASLite become widely available (http://claslite.ciw.edu/en/index.html).

regions of the tropics can cause major constraints on use of optical sensors alone. Inaccuracy due to sensor saturation for areas with high biomass density is a problem that, in some cases, can be overcome through use of LIDAR. Distinguishing among some land classes may be inhibited when they are spectrally inseparable using available image bands.

In addition to reliance on the quality of data inputs to achieve high-quality model outputs, modelling to estimate mitigation potential or change in stocks / emissions may require significant expertise and processing capacity. While there are a range of process models available, there is a need to adapt these models to places where they have not yet been validated. Also, advancements can be made to allow process models to more usefully accommodate remote sensing data streams (in addition to field inventory data).

Models are and will continue to be important tools for estimating emissions and sequestration. Many different types of models are currently in use and resulting estimates are not always comparable. For example, the range of available soil carbon models differ according to their intended purpose, relative emphasis on different carbon pools, required inputs, flexibility in basic model parameterization, and ability to be coupled with other carbon models.[21] As a result, current soil carbon models used for national carbon accounting and other purposes differ significantly both in how carbon is calculated and model outputs.

Default values such as generalized expansion and conversion factors used in estimating carbon stocks and emissions across large areas are available (eg, IPCC's default Biomass Emission Factor values). Allometric equations are typically available for many popular commercial plant species or species groups (Teobaldelli et al, 2008), although the literature is inconsistent or incomplete for many species even within Annex I countries. Further development of allometric equations is needed for non-commercial species and specialized locations.

Even where relevant default equations do exist, they may have an inherent inaccuracy associated with them. For example, in the case of root-to-shoot ratios, recent studies have shown that current default ratios significantly underestimate global below-ground biomass volumes, and therefore global terrestrial carbon volumes (Mokany et al, 2007). It may be difficult to estimate the level of error associated with applying these generalized equations to a given area as this depends on the similarity of the area to that on which the equation was developed (Gower et al, 1999). The uncertainty is heightened in species-diverse areas and, in general, the broader the equation in geographic scope and species included, the greater the uncertainty.

2.3.3 What can be done to meet research needs?

The research community can contribute to enhanced terrestrial carbon management and quantification in the full range of land classes, carbon pools, and geographic regions by enhancing measurement and monitoring capacity. (See Appendix 5.)

Gathering field and activity data for underrepresented regions, land classes, and carbon pools. To meet identified needs for regionally-relevant information (eg, base maps, allometric equations, remote sensing interpretation), in many cases new data-gathering will be required. Ideally, such efforts will be informed by an accurate understanding of existing datasets and will be designed to maximize data quality and utility and minimize costs. Data-gathering can draw on existing measurement tools and methods and, where appropriate, establishment of networks of permanent benchmark monitoring sites.

[21] For example, some models were developed largely for arable lands (eg, RothC) while others were developed for forests (eg, Biota). Models vary in the way they incorporate soil chemistry, physics, physiology, and ecology and also on use of zero or first order methods. Models vary in the frequency of required data inputs (eg, monthly, weekly) as well as requirements for quality and consistency of data for landform, soil classification, and other aspects.

Developing new cost- and labor-saving measurement tools and methods. Strategic investments can include development of new tools for extracting rich information from field sampling[22] as well as integrated sampling designs that allow field sampling to be highly targeted. Another area is developing integrated approaches for understanding complex landscapes (eg, stratified remote sensing and field observations).

Continuing to improve interpretation capacity for remote sensing. Advancements are needed in integrating data from different optical, laser, and radar remote sensing technologies and effort may be usefully directed toward "crosswalking" remote sensing data streams gathered over multiple decades. New remote sensing interpretation methods are needed to link biophysical variables to spectral reflectance in support of spatially distributed carbon sequestration models.

Ensuring continuity of major satellites and promoting appropriate use of new remote sensing technologies. Ongoing provision of widely used coarse- and medium-resolution remote sensing data streams is critical to development of national accounting systems across a wide range of countries. Also, there are new airborne and satellite sensors that have promise for a range of uses. Some provide fine-resolution imagery that can be important for achieving higher accuracy (Angelsen, 2008).

Expanding coverage of conversion equations to all regions and types of carbon. In cases where site-specific conversion factors and allometric equations do not exist or are not supported by robust data, it may be possible to use generalized or pooled equations (USDA, 2007; Zianis et al, 2005). However, broadening capacity to estimate a greater range of species (including invasive species) and carbon pools will increase accuracy of estimation.[23] In addition, greater understanding is needed for how to adapt allometric equations given changing climatic conditions or presence of invasive species.

Adapting and verifying existing models to broader set of regions and data streams. To use a model in a particular region, it is necessary to compile or gather required input data and calibrate and validate the model to regional circumstances. Work to adapt process models to accommodate remote sensing data streams (in addition to field inventory data) can increase the flexibility of data input options.

In evaluating the most useful elements of a terrestrial carbon research agenda, the relative impact of investment in "big, new" tools (eg, a next generation satellite system) relative to incremental improvement and technical transfer of existing tools (eg, building learning platforms for extracting information from existing data) should be considered.

2.4 Components of a tiered global information system

2.4.1 What is already known?

Carbon accounting systems will be required and delivered at multiple scales. Data requirements and measurement methods will vary by scale, country circumstances, and other factors. Project implementers will gather and use fine-scale, location-specific information to predict, measure, and document the carbon outcomes of changes in land management. National ministries will gather coarser-scale data that is comprehensive for major land classes for use in developing domestic policies and demonstrating fulfilment of national commitments. International bodies will aggregate data provided by participating countries as well as independently estimate regional- and global-scale terrestrial emissions and sequestration to assess impacts of current and alternative land management on atmospheric GHG concentrations (Waggoner, 2009).

[22] Such as developing new technologies for rapid in situ measurement of soil carbon and GHG fluxes (Paustian et al, 2006).

[23] There may be opportunities to "streamline" development of allometric equations (eg, sub-sampling for specific gravity and applying to tree form equations).

A tiered, global information framework is needed that can establish measurement protocols, integrate data generated through a variety of measurement approaches, and make information resources widely accessible. The existing set of information systems are an essential starting point for building a global framework. Some of the major existing information systems include:

National reporting to the UNFCCC. Annex I countries are required to submit annual and periodic information on removals and emissions to the UNFCCC and the majority of non-Annex I countries have submitted periodic National Communication reports. These reports provide useful estimates of emissions and removals for some countries and sectors, as well as background information on how data are derived. Several countries already have systems in place to estimate woody biomass stocks (eg, National Forest Inventories). Some countries, regions or states also have their own land use reporting requirements (eg, the State of California).

Commercial, academic, and other assessments. Commercially managed land areas often have comprehensive management, timber stock, harvest rate, and other relevant records that can be used to estimate the accuracy of national inventories, the size of biomass stocks and rate of, or changes in land use classes. Confidentiality or commercial sensitivity may limit accessibility of these records and commercial information may be lacking in areas with a short history of formal forest management. Academic field research, especially long-term plot studies, may provide useful information on terrestrial carbon and changes over time and has potential for development of local models and allometric equations or ground-truthing remote sensing data. Compliance and voluntary market projects often develop project-level field inventories which may be useful to incorporate into national estimates of carbon stocks and changes.

Global databases. Space agencies and other institutions routinely deliver remote sensing data products that are used for estimating land surface characteristics, land cover change, disturbance events, terrestrial carbon pools, GHG fluxes, and other features of interest over a range of temporal and spatial resolutions. There are several efforts to provide international, regional, or national databases of conversion and expansion factors.[24] Improvement to emissions factors is ongoing. For example, recent work highlights potential improvements to the default values provided for peatlands by the 2006 IPCC Guidelines including harmonizing with FAO's definition of organic soil, clarifying climate zones, and improving default values for key categories (Cowenberg, 2009).

Multilateral agencies, research institutions, and others are working to improve, integrate, and make accessible data resources needed to support terrestrial carbon accounting. For example, the FAO Global Forest Resource Assessment (FRA) recently launched a free internet portal with global coverages of high-resolution satellite imagery and indexes of tree canopy cover.[25] Using Landsat and other remote sensing imagery, local knowledge and field inventories, the FRA Remote Sensing Survey will improve knowledge of land use change dynamics over time, including deforestation, afforestation and natural expansion of forests.[26] Wetlands International has coordinated the integration of peatland carbon and GHG data for all countries and regions of the world.[27] (See Appendix 6 for further examples.)

There have been, and continue to be developments in standardizing land classification systems and, of even greater importance, in making them comparable. For example, the land cover project of the CORINE programme will provide consistent localized geographical information on the land cover of the 12 Member States of the European Community.[28] The only UN-endorsed land cover classification

[24] Examples of these include the IPCC's Emission Factor Data Base (EFDB, http://www.ipcc-nggip.iges.or.jp/EFDB/main.php), the European Allometric Biomass Carbon factors database (ABC database, http://afoludata.jrc.ec.europa.eu/v2007/DS_Free/abc_intro.cfm), and the World Agroforestry Centre's Wood Density Database (http://www.worldagroforestry.org/af2/index.php?q=node/109).

[25] See (http://geonetwork4.fao.org/geonetwork/srv/en/fra.home).

[26] See http://www.fao.org/forestry/fra/fra2010-remotesensing/en/).

[27] See (http://www.wetlands.org/LinkClick.aspx?fileticket=UyS7LBOOJa4%3d&tabid=56).

[28] See (http://www.eea.europa.eu/publications/COR0-landcover).

system, the FAO / UNEP Land Cover Classification System (LCCS),[29] is undergoing approval to become an ISO standard.

Resources are also becoming available to support REDD readiness, improvements in agricultural productivity, and other key areas for terrestrial carbon management. For example, the UNFCCC's REDD web platform houses resources for technical assistance, demonstration activities, country-specific information, and methodologies and tools.[30] The Global Futures for Agriculture project, launched by IFPRI with CGIAR and others, will combine economic modelling with location-specific environmental and management data to assess the impact of potential agricultural investments on economic growth, incomes, and poverty alleviation.[31] A consortium is working to produce a global digital soil map.[32]

Recent advances have been made in producing global and regional CO_2 budgets despite model uncertainties and the wide variety of methods represented in available datasets. For example, Le Quere et al (2009) reported an increasing global land use sink during 1959-2008, with large year-to-year variability, based on a constructed global CO_2 budget that incorporated deforestation and other land use data, satellite-based fire observations, and assumed carbon density values for vegetation and soils.

2.4.2 What are the primary research needs?

Terrestrial carbon information is commonly not consistent or comparable as methods vary widely according to the types of carbon pools measured, measurement scale (eg, fine, medium, coarse) and frequency, and measurement method.[33] To produce consistent, comparable, and geo-referenced datasets for terrestrial carbon, further coordinated work is needed to standardize data-gathering approaches and harmonize analytical methods.

Countries and sectors operate mapping programs which typically reflect their information needs and capacities. This has led to a variety of mapping and classification systems that differ in detail and quality as well as in age and timing. Classification consistency is made more difficult when a variety of landscapes are included and where there is variability within land use categories (eg, both permanent and annual crops in the category "croplands"). Integration of the wide variety of field data gathered in specific regions has potential to improve model-based estimation of the mitigation potential of new land management policies, practices, and technologies at multiple scales (Schlect et al, 2006).

Progress in developing global CO_2 budgets and assessing the effectiveness of land-based mitigation is inhibited by gaps for accurately linking land use emissions to atmospheric CO_2 concentration on a year-to-year basis. These uncertainties could be reduced by inclusion of key processes and reservoirs in land use models (eg, wildfires, peat) and improvements to data-gathering systems (Le Quere et al, 2009). There are similar challenges for regional-scale estimation. For example, drawing on data compiled through the CarboAfrica project, Bombelli et al (2009) found great variability in estimates of the biological carbon sink in Sub-Saharan Africa[34] and point to more accurate land classification, improved modelling for savannahs and tropical forests, and better understanding of disturbance and plant and soil processes (including methane and nitrogen fluxes) as key areas for improvement. Most models used in their analysis were developed for other regions and would benefit from validation with regionally-relevant data.

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[29] For more information on LCCS please refer to: Land Cover Classification System (LCCS): Classification concepts and user manual by Di Gregario, A. and L.J.M. Jansen. Environment and Natural Resources Service (SDRN), GCP/RAF/287/ITA Africover – East Africa Project and Land and Plant Nutrition Management Service (AGLN). FAO, Rome, 2000. http://www.fao.org/docrep/003/x0596e/x0596e00.htm

[30] See (http://unfccc.int/methods_science/redd/items/4531.php).

[31] See (http://www.ifpri.org/pressrelease/global-futures).

[32] See (www.globalsoilmap.net/).

[33] For example, Europe does not yet have sufficiently systematic and harmonized monitoring to adequately track and report changes in soil carbon (Alterra, 2008).

[34] Primary sinks were forests and savannas and primary sources were fires and deforestation.

2.4.3 What can be done to meet research needs?

There are a number of opportunities to build toward a tiered global information system by improving the consistency and comparability of data-gathering and estimation methods and resulting terrestrial carbon datasets.

Standardizing data-gathering and land cover classification. Existing efforts to harmonize field-based, flux, and remote sensing measurement and analysis approaches, in cost-effective ways that accommodate local conditions and capacities, will need to expand significantly to enable the production of synthesized terrestrial carbon estimates. National, regional, and global efforts to crosswalk and align land cover designations and terminology should be continued, expanded, and linked.

Continuing improvements in soil mapping. Harmonizing technical terminology and mapping methodologies, expanding capacity for fine-scale digital soil mapping, and making resulting data widely accessible are key steps for producing information needed to improve carbon and climate modelling and support better soil management (Sanchez et al, 2009).

Integrating existing datasets. Coherent approaches for combining datasets from different national and regional programs and datasets developed over different time periods can produce the spatially comprehensive, long-time series data needed to inform model predictions and improved land management.[35] Such efforts will require the development of standards for characterizing the robustness of individual and integrated datasets.

Synthesizing diverse data through modeling. Innovation in data assimilation and model-data fusion methods, through modelling frameworks that can adapt to future scientific and technical advances, is critical to synthesizing highly diverse field and remote sensing observations.[36] Making source code of models available to others in the research community can contribute to overall improvements and comparability of model-generated estimates.

Downscaling mitigation estimates. In addition to usefully integrating project-scale data into national and global information systems, down-scaling of global and regional estimates of land-based mitigation potential is needed to facilitate national policy development and project-scale planning. This can be enhanced through improved coordination and common geo-referencing across measurement systems (eg, in situ observations, flux towers, air-and space-borne sensors).

Increasing accessibility and coverage of remote sensing and other mapping efforts. The scale and quality of measurement and monitoring systems overall can expand if it becomes easier and cheaper to access and interpret remote sensing images through common platforms and if high-quality national initiatives to map land use and monitor carbon stocks (eg, through models) become more widespread.

Improving conversion and expansion factors. Investments in high quality, accessible databases for generalized or specific expansion and conversion factors and allometric equations[37], such as the IPCC's Emissions Factor Database (EFDB), will be important for extracting value from old and new field measurements and remote sensing images.

Building common archives. By building accessible common archives[38] for biomass and carbon studies, pilot projects, remote sensing images, and conversion equations, these information sources can be more widely and effectively utilized, especially when paired with training in data interpretation.

[35] Idea adapted from GEO Carbon Strategy Version 1.0 (in open review; http://www.fao.org/gtos/doc/2009-GTOS-SC/docs/8_GEO_Report.pdf).

[36] Ibid.

[37] For example, functions for estimating aboveground and total biomass from tree measurements and for converting from biomass to carbon estimates.

[38] For example, the AFOLU clearinghouse provided by the European Commission's Joint Research Centre (http://afoludata.jrc.ec.europa.eu/index.php/public_area/home).

Improving coordination. A wealth of public and private organizations, agencies and institutions, working at scales from local to global, are tackling many dimensions of terrestrial carbon management and quantification (eg, IPCC, GTOS). Coordinated networks and platforms for information sharing and research synthesis across sectors, disciplines, and scales can deliver the coherent, integrated information base that will be needed to bring about improved terrestrial carbon management at meaningful scales.[39]

2.5 Pathways to establishing national accounting systems that reflect country circumstances

2.5.1 What is already known?

National-scale carbon accounting systems will be an essential component of a tiered, global accounting framework, producing and compiling data for incorporation into global estimates and for informing sub-national planning and implementation of improved terrestrial carbon management. Wider implementation of terrestrial carbon projects that seek to capitalize on existing and emerging financial incentives in the voluntary and regulated markets will require robust national accounting.[40] Key needs are data for front-end project scoping (eg, estimating mitigation potential; establishing reference levels to address additionality) as well as data to 'cross-check' project-scale accounting.

Once fully operational, national systems will meet information needs for estimating terrestrial carbon mitigation potential associated with major land classes (accounting for geographic and temporal variability and natural disturbances) and actual land-based emission and sequestration (eg, in compliance with national commitments under international agreements). To produce information that is needed for global estimates and for project planning and investment, national accounting systems will be expected to produce and report information that is verifiable, comparable with information from other nations (eg, aligned with international guidance), and consistent over time. This does not imply that the same measurement tools and approaches should be used across all countries and regions. In general, national accounting will focus on achieving comprehensive geographic coverage at medium to coarse scale.

Establishment of robust and transparent national carbon accounting can draw on international guidance, available tools and methods for measurement and monitoring, and existing data systems (Smith 2004). Public and private organizations (eg, government agencies, multi-lateral organizations, independent researchers, forestry and agricultural businesses) can be important sources of remote sensing and other mapped data, inventories, environmental and historical management records, conversion factors, and socio-economic surveys. These can provide a useful foundation of experience and infrastructure for expanded measurement and monitoring systems. A range of mapping methods are currently available, and are being distributed and tested in a variety of countries. The national capacity of non-Annex I countries to measure and monitor terrestrial carbon (especially deforestation and degradation), is already being encouraged and developed with assistance from Annex I countries (Campbell, 2009), multilateral agencies, and a variety of other institutions.

2.5.2 What are the primary research needs?

Many developed countries and a handful of developing countries operate long-term inventory systems, especially for forest biomass. However, for the majority of developing countries, national carbon accounting is nascent or absent altogether. Even where inventories exist, geographically

[39] "The establishment of an international network to coordinate data collection and link sites would facilitate more precise prediction of agroecosystem sustainability and future global change" (Rasmussen et al. 1998).

[40] For example, terrestrial carbon projects under the Clean Development Mechanism and in the voluntary market appear to be more commonly sited in developed countries and more developed non-Annex I countries, suggesting that private sector project developers favor countries with a higher level of existing terrestrial carbon related information (see Measuring and Monitoring Terrestrial Carbon: The State of the Science and Implications for Policy Makers, www.terrestrialcarbon.org).

comprehensive and time series information is commonly unavailable.[41] There is considerable variety in the capacity to measure and monitor all types of terrestrial carbon (ie, full carbon accounting), even within developed countries, and this is likely to persist without greater investment, technology transfer, and information sharing.

Progress in building capacity for measurement and monitoring of all major land classes requires a combination of making cost-effective tools and methods widely available and providing coherent guidance and technical assistance for optimal system delivery in specific national and sub-national settings. This will require a commitment of financial and technical resources by both developed and developing countries and expanded coordination within the research community (particularly for non-forest lands).

Countries vary considerably in terms of biophysical conditions (eg, terrain, soil types, cloud cover), landscape patterns (eg, mix and distribution of land classes, drivers and rates of land use change), and existing data and infrastructure (eg, availability of existing inventories and project- and research-scale data; access to remote sensing data and regionally calibrated models; institutional capacity to gather and analyse data). The mix of tools, methods, and sampling designs used for national accounting systems will reflect specific country circumstances. For example, accounting systems for countries with high forest cover may be able to rely more heavily on remote sensing tools, (if necessary field data is available to interpret sensor data), while countries with more mixed landscapes may rely more heavily on field measurement programs that can adequately capture spatial heterogeneity. Countries with rapidly changing landscapes may require more intensive sampling schemes that rely on a mix of field and remote sensor measurements.

National terrestrial carbon accounting systems require appropriately scaled-up technical tools and infrastructure for documenting changes in carbon over space and time. Different measurement tools and methods can be complementary, and the optimal combination depends on national (or sub-national) characteristics. A range of countries have successfully combined field measurements, remote sensing, and models to quantify changes in terrestrial carbon, particularly in above-ground biomass (eg, Annex I GHG inventories, Brazil, Indonesia, Mexico). Most, if not all, of these methods have already been used alone, or in combination to measure carbon or biomass stocks and 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 for the voluntary market.

The choice of measurement methods to incorporate into long-term monitoring systems will be influenced by a number of factors. Use of "high tech" measurement tools, where cost-effective and appropriate to local biophysical conditions and land use, should be balanced with the value of using tools that are easier for landowners, local communities, and NGOs to understand and use as this may increase transparency and participation in measurement programs as well as generate economic opportunities. Unlike scientific research, monitoring and accounting systems require consistent application of the same methods over time or the ability to cross-walk existing datasets with data gathered using new tools and methods. This issue is particularly apparent with efforts to marry existing field inventories with evolving remote sensing technologies.

There are a number of barriers to establishment and improvement of national carbon accounting systems. In general, non-Annex I countries have limited data-gathering capacity and access to reliable existing datasets and conversion equations. Historical and current information for land cover, land use, and drivers of land use change may be inadequate, fragmented or inaccessible. Monitoring systems have been costly to develop especially for developing countries and for small-scale landowners, hindering greater global participation in improved terrestrial carbon management (Campbell, 2009; Wunder 2008). As carbon offset crediting systems evolve and expand, it will be important to avoid

[41] Where legacy information for terrestrial carbon is available, it is not always reliable, comparable, and accessible. For example, National Forest Inventories commonly do not include information on non-commercial and non-tree species and frequency of measurement may not be well suited to estimating changes in terrestrial carbon. There are also many parts of the tropics where inventories are out of date, incomplete, or entirely lacking. Little is typically recorded for non-forest biomass except through agricultural yield statistics or annual agricultural censuses.

perverse outcomes in participation, uptake, and benefit allocation and to minimize costs and bureaucratic obstacles for landowners and land managers including indigenous communities.

2.5.3 What can be done to meet research needs?

Developed nations can assist developing countries in establishing or expanding the infrastructure and expertise to collect and analyse terrestrial carbon data as part of credible and transparent national carbon accounting systems. (See Appendix 7.)

Prioritizing R&D and tech transfer investments. Research and innovation by the international community to develop more advanced combinations of measurement tools and methods that can provide higher quality data while containing costs can contribute to more comprehensive, accurate carbon information at national and global scales. Particular areas in need of advancement include non-forest land classes and non-Annex I countries. Further work is needed on incorporating parcel-scale monitoring into regional and national programs, optimizing use of remote sensing (eg, for national accounting, for detecting leakage), and adapting accounting system requirements to country circumstances.

Providing tools and training. Developed countries, multilateral agencies, research institutions, and NGOs can and do provide important assistance with accessing and using measurement and monitoring tools and methods and designing national systems. Manuals and related resources can be used to inform design of field inventories, linking field data with remote sensing data, and identifying and integrating diverse existing datasets.[42] Efforts to engage local communities in monitoring and ownership of information are underway in several locations[43] and offer potential for meeting important social and scientific goals simultaneously.

Facilitating agreement on standardized methods. Coordinating frameworks and venues for agreeing standards for regionally-appropriate, internationally-compatible methods of measurement and analysis can accelerate the uptake of these methods, resulting in greater comparability across national-scale data.

Tailoring technical assistance. Diverse circumstances across developing countries implies the need for country-specific strategies in support of technical and institutional investments. For example, for countries at earlier stages of system implementation, support may be best directed to gaining experience and making use of available data (eg, using coarse activity data for 'practice-based' assessment of changes in terrestrial carbon), while countries with more robust capacity may require support for enriching the quality of existing accounting systems (eg, fine-scale 'performance-based' measurements of carbon outcomes).

Fostering south-south technical transfer. Across the range of developing countries, experience and expertise in terrestrial carbon accounting and management is significant and growing and there are opportunities for bilateral, regional, or community-to-community engagement to share technical knowledge (Angelsen, 2008). Some countries have invested in measurement technologies (eg, Brazil's National Institute for Space Research) while others have invested in institutional capacity (eg, Indonesia's National Carbon Accounting System, INCAS). Developed country ministries, multilateral agencies, NGOs, and others can facilitate this type of cooperation by providing seed funding and coordination for meetings and networks.

Developing nations, with technical and financial assistance from developed nations, can continue to take concrete steps towards robust national accounting systems.

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[42] For example, U.S. agencies have funded Colorado State University researchers to work with government ministries in Central America and Southeast Asia.

[43] Examples include the Woods Hole Research Center's work on community engagement in monitoring in Columbia and the Millenium Villages project using SMS-based reporting.

Building on existing resources. At the national-level, creation of terrestrial carbon accounting systems can begin with taking stock of existing data systems (eg, national or sub-national inventories, commercial or research-scale data-gathering, regionally-relevant models and conversion factors), evaluating data quality and compatibility with information needs, and identifying gaps.

Designing inventory and monitoring strategies relevant to country circumstances. Once information resources and data gaps are understood, plans can be developed for marshalling the suite of available measurement tools and methods to work toward Tier 2 and 3 accounting. This may involve gathering new data through field measurements and remote sensing and / or generating new estimates through adaptation of models and conversion factors to local settings. Ideally, planning will focus on creating comprehensive, adaptive frameworks and statistical designs that allow for continual improvement and upward compatibility.

Improving the quality of estimates. Depending on country circumstances, there are a number of ways national accounting systems can produce higher quality estimates including using best available international guidance (eg, 2006 IPCC Guidelines) and most appropriate (eg, mineral vs organic soils) methods for estimating emissions, fully accounting for delayed emissions (eg, ongoing emissions from drained wetlands), disaggregating data (eg, by land class, soil type), and improving area estimates for land classes (Barthelmes et al, 2009).

Expanding the scope of monitoring. In many countries, monitoring in forests is more advanced than in other land classes. To expand monitoring capacity beyond deforestation to include degradation, more intensive field measurements and higher-resolution remote sensing imagery collected at appropriate temporal scales are necessary. For agriculture and other land uses, more refined land classification systems, more comprehensive models, better historical information on non-forest land use categories (ie, carbon density and area change), and regionally-relevant land management information (eg, fertilizer application) will be needed. Preliminary analysis of carbon pools and land classes with the greatest potential for emission or sequestration can inform the expanded scope of national accounting efforts.

2.6 Harmonization of reporting guidance across scales and sectors

2.6.1 What is already known?

To make pragmatic and cost-effective investments related to terrestrial carbon management, countries need to be able to understand the international landscape of incentives, whether under regulated markets[44] or voluntary offset markets. Greater clarity regarding expectations for receiving financial rewards under incentive schemes can help in navigating this landscape in a way that aligns with particular country circumstances and development goals. Similarly, clear expectations are an important need for carbon project developers and investors.

To be useful in meeting expectations for national and project reporting, data produced by terrestrial carbon accounting systems must align with existing and evolving international guidance, as well as local circumstances. Widely-accepted guidance for measurement, reporting, and verification of terrestrial carbon is available through the IPCC which has periodically produced refined guidelines since 1996 (see Appendix 8).

The set of IPCC reports, while not perfect, provides methodologies and guidance on preparation of national GHG emission inventories, including, but not limited to themes such as managing uncertainties, definitional issues, accounting practices, categories of land and land use change, and estimation and emission factors. They have also held expert meetings to provide guidance on the use of international datasets in the development of GHG emission and removal estimates for land use, land use change and forestry, and AFOLU sectors. Over time, the IPCC has expanded the scope of land

[44] To date, there have been relatively few land-based mitigation projects under the Clean Development Mechanism (CDM) and they are excluded from the European Emission Trading System (EU-ETS).

classes addressed (eg, forest degradation, land use change in wetlands) and refined reporting recommendations (eg, Tier 1 to 3, consolidated categories).

Additional guidance on activities to reduce emissions from existing terrestrial sources, or to enhance sinks, has also been developed by governments, multilateral agencies, NGOs, and scientific research organizations.[45] Organizations like the Voluntary Carbon Standard (VCS) emphasize the calculation of tradeable credits in a market setting for carbon storage projects. They provide tools for AFOLU project administrators, such as rules for addressing methodological issues, non-permanence risk analysis and buffer determination, and general guidance. Organizations such as Plan Vivo and the Climate, Community & Biodiversity Alliance (CCBA) develop guidelines that encompass social concerns (such as respect for indigenous rights, use of a participatory process, or equity) in addition to environmental benefits or potential economic gain.[46]

2.6.2 What are the primary research needs?

Under the Kyoto Protocol, expectations for project-level reporting (ie, the flexible mechanisms, CDM and JI) and national-level reporting of terrestrial emissions and sequestration are notably different in terms of scope, resolution, extent, and frequency (see Table 1). At the same time, there are diverse and evolving voluntary market standards for reporting outcomes of land-based mitigation. This variability in reporting expectations can create confusion or inertia for potential project implementers (especially smallholders) and for countries seeking to establish national accounting systems.

Table 1. Differences in national- and project-level reporting requirements.

National-level	Project-level (CDM & JI)
Requires annual assessment and reporting of some sources. Annex I countries' reports are independently assessed and changes made as a result. Non-Annex I country reports are independently assessed but do not need to make alterations to reports in response.	Requires more detailed reporting in a smaller area, following a strict process with independent assessment prior to registration and issuance of credits, but only requires assessment once every five years.
Focused on coarser measurement scales but may be more comprehensive for major land use categories.	Focused on smaller areas and emphasizes finer geographic and temporal scales of measurement.
Requires assessment of intra-national leakage.	Requires more onerous estimates of leakage effects.
May rely to a greater extent on remote sensing that can provide extensive coverage and detect changes in land uses.	May rely more heavily on field measurements to achieve greater accuracy and precision.

The IPCC has made significant contributions to clarifying and improving the quality of accounting and reporting standards, especially for subjects on which there is broad scientific agreement. The current IPCC guidance is designed for use by Annex I countries, against which they are audited. Also, methodologies for project-based activities under the Kyoto Protocol, most of which occur in non-Annex I countries, must be consistent with IPCC guidance. The IPCC guidelines are also the foundation

[45] For example, the Technical Working Group on Agricultural Greenhouse Gases (T-AGG) is developing research syntheses and assessments of agricultural GHG mitigation, in the U.S. and internationally, for future offsets protocol development (http://nicholas.duke.edu/institute/t-agg/).

[46] Plan Vivo uses local promoters to interact with farmers in the development of their work plans, which are then evaluated for technical feasibility, social and environmental impact, and carbon sequestration potential. Viable plans are registered and an agreement is signed. A Trust Fund provides farmers with technical and financial assistance to implement their work plans. CCBA's standards identify projects that simultaneously address climate change, support local communities and conserve biodiversity, innovate in project design, mitigate risk for investors, and increase funding opportunities for project developers.

for many of the voluntary market reporting requirements. However, while it is recommended that non-Annex I countries follow IPCC guidelines in producing their National Communications, they are not obligated to do so, and quality of these reports varies significantly.

In the voluntary market, there are numerous approved protocols for generating and documenting terrestrial carbon offset credits although these are primarily focused on forests. Despite the significant potential for GHG mitigation in agriculture and other land uses, only a few high-quality and widely approved methodologies for quantifying these GHG benefits have been developed.[47] In general, protocols provide guidance for addressing additionality, permanence, leakage, measurement error, and other issues. However, specific approaches vary considerably and there is a need for greater clarity regarding creditable monitoring and reporting strategies (eg, establishing baselines; use of carbon stock or flux). While approved CDM methodologies are generally accepted across the voluntary market, greater convergence on reporting standards could enable greater reciprocity and credit fungibility.

A key area for further work is harmonization of terminology, definitions[48], standards, methodologies and classification schemes. For example, terminology and definitions related to scale (eg, 'plot', 'landscape') are not universally understood across countries which range widely in total area, mix of land classes, and patterns of land ownership and management. Looking ahead to implementation of a REDD+ mechanism under a future UNFCCC treaty, it is not yet clear what types of land-based mitigation will be eligible for incentives. Also, there may be benefit to clarifying the relationship between monitoring change in land cover and interpretation of land use change so that reporting requirements are consistent and feasible. While there are clear benefits to improving the consistency and compatibility, progress in this area will need to be balanced with accommodating country-specific conditions and pre-existing data systems.

2.6.3 What can be done to meet research needs?

The international community can help to stimulate greater project-level activity and integrated terrestrial carbon accounting by harmonizing guidance for meeting expectations under financial incentive schemes. (See Appendix 9.)

Harmonizing guidance and methodologies. Investment in mechanisms for harmonizing reporting expectations across scales and scales can build on existing international guidelines and methodologies to produce greater data-gathering efficiency and data compatibility. Improved guidance for incorporation of project-scale accounting into national systems (eg, crosswalking datasets that differ in geographic and temporal resolution) would be beneficial. Greater support is needed for initiatives to review the full set of methodologies in the regulated and voluntary markets and recommend strategies for increasing consistency and identifying common principles for methodology development.[49] Activity within the UNFCCC process can encourage ongoing uptake of IPCC guidance by non-Annex I countries in development of National Communications.

Increasing consistency of terminology, definitions, and classifications. Streamlined processes, at regional and global scales, are needed for developing and approving consistent terminology and definitions to support the production of datasets that can be readily integrated with across scales.[50] Progress toward a common standardized land cover classification system that accounts for the full range of land cover types around the world is an important area for global cooperation.

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[47] For a summary of existing and developing agricultural offsets protocols , see http://nicholas.duke.edu/institute/t-agg/T-AGG_protocol_summary.pdf.

[48] For example, NFIs differ significantly in terms of definitions, variables included, standards applied, and technical quality.

[49] For example, as part of UN-REDD, the Food and Agriculture Organization is facilitating the review of existing methods for measuring carbon stock and changes across multiple land classes and scales.

[50] Examples of current work include FAO's Climate Change and Bioenergy Glossary which has compiled over 200 definitions and the IPCC Glossary based on the Third Assessment Report.

Updating of IPCC guidelines. The 2006 IPCC Guidelines which combine the agriculture and land use, land-use change and forestry (LULUCF) categories under 'agriculture, forestry and other land uses (AFOLU)' are widely accepted, but have yet to be formally approved (although they are used to inform voluntary market standards). Continual review, updating, and approval of IPCC guidelines can assure that scientific and technological advancements are appropriately incorporated into reporting standards and therefore monitoring activities. It can also ensure that guidelines evolve to adequately reflect requirements of incentive systems.

Accelerating acceptance of methodologies. Development of projects in the regulated market has been constrained by the time lag in developing accepted methodologies and by the complexity, high risk, and questionable financial returns of executing projects. Streamlined, transparent processes, supported by adequate administrative and scientific resources, are needed to overcome these obstacles.

Increasing emphasis on agriculture and other land use. To enable significant expansion of terrestrial carbon offset credits in non-forested systems, greater progress is needed in developing, vetting, and approving methodologies applicable to croplands, grasslands, and wetlands. Synthesis of existing and emerging knowledge as well as new scientific advances will be essential.

Mandating coordinating and advisory functions. Existing institutions such as the IPCC, FAO, the World Bank, GEF, and others, are making important contributions to creating more coherent guidance, however, more formal agreement on necessary coordinating and technical advisory functions may accelerate progress. An essential function is to provide international scientific expertise, advice, review, and recommendations in regard to methods for sub-national, national, and international monitoring and assessment.

2.7 Summary

The major scientific and technical advancements needed to enable enhanced land-based mitigation and a tiered, global information system to support it are summarized in Table 2. The foundation for land-based mitigation and robust monitoring and reporting varies across major land classes. Table 3 provides an overview of priority research needs for four major land classes as well as a subjective assessment of the relative maturity and global capacity for each area of research activity.

Table 2. What we know and priority research needs

	1. Carbon dyamics	2. Alternative Management	3. Accounting Tools
What is already known	• Solid understanding of factors and processes controlling spatially-variable terrestrial carbon stocks and fluxes. • General predictions for effects of changing climatic / environmental conditions on carbon dynamics.	• Wide range of management practices can effectively maintain / enhance terrestrial carbon mitigation.	• Appropriate field measurements, remote sensing, conversion equations, and models can be combined to estimate C stocks and changes • Greatest experience in above-ground biomass and in homogeneous landscapes
Priority research needs	• Spatially-resolved prediction of carbon dynamics. • Effects of changing climate on carbon dynamics in specific land classes and regions.	• Synthesized, accessible, geographically-relevant scientific research base for net effects of alternative practices (including complex landscapes, variable land management). • Accurate, spatially-resolved data for land cover, C density, and land management. • Understanding of land use change drivers. • Extension activities, incentives, and infrastructure.	• Labor- and cost-saving field measurement approaches. • Improved remote sensing interpretation methods. • Data-gathering and model adaptation / validation for underrepresented land classes and regions. • Networks of permanent benchmark monitoring sites. • Regionally-relevant conversion factors and allometric equations for all carbon pools and land classes. • Continuity of key remote sensors. • Convergence / crosswalking of models.

	4. Global System Components	5. National Accounting Systems	6. Reporting Guidance
What is already known	• National reports, commercial / academic assessments, global databases, and other existing resources are building blocks for national systems. • Multilateral agencies, research institutions, and others are working on data improvement, integration, and accessibility.	• National systems can estimate mitigation potential for major land classes and actual emissions / sequestration by drawing on international guidance, available tools, and existing data systems.	• Scope and clarity of reporting guidance from IPCC, voluntary markets improving with experience and scientific advancement.
Priority research needs	• Improved, accessible global / regional datasets (eg, soil mapping, CO_2 budgets, conversion equations). • Modelling frameworks to build spatially-comprehensive, long-time series datasets from multi-scale, multi-temporal field and remote sensing observations. • Down-scaled estimates of mitigation potential. • Standardized data-gathering, analytical methods, and land classification systems.	• Cost-effective, regionally-relevant, internationally-compatible methods. • Country-specific sampling designs for all major land classes. • Coherent guidance and technical assistance. • Technical transfer (north-south; south-south). • Adequate resources and capacity for consistent, long-term operation. • Modelling / crosswalking to integrate diverse datasets. • Combining field measurement, remote sensing, and modelling.	• Harmonized guidance and methodologies across scales and sectors. • Consistent terminology, definitions, and classifications. • Accelerated methodology development / acceptance (especially for non-forest land classes). • Continual review, updating, approval of IPCC guidelines. • Mandates for coordinating and technical advisory functions.

Table 3. Research needs for major land classes

	1. Carbon dynamics	2. Alternative Management	3. Accounting Tools	4. Global System Components	5. National Accounting Systems	6. Reporting Guidance
Forests	Non-biomass carbon. Fire regimes.	Outcomes under specific conditions (eg, complex landscapes, tropics).	Monitoring degradation. Regionally-relevant models.	Data sharing across scales and sectors.	All countries. Capacity for monitoring degradation.	Compatible terms, definitions and standards.
Croplands	Partitioning to soil carbon pools. Variability with depth.	Outcomes under integrated cropping, agroforestry. Residence times for soil carbon pools.	Regionally-relevant field data and models.	Data sharing across scales and sectors.	Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.
Grasslands / Drylands	Soil carbon dynamics and sequestration rates. Fire regimes	Effects of grazing, fire management. Extent of sequestration, desertification, degradation, and conversion.	Regionally-relevant field data and models.	Integrated research and inventory data. Data sharing across scales and sectors.	Sampling designs. Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.
Wetlands / Peatlands	Depth, density, decomposition. Controls on GHG emissions. Peatland subsidence.	Outcomes of rewetting under specific conditions. Peat extent, depth, conversion, drainage, and degradation.	Tools / methods to accurately inventory area and fluxes. Regionally-relevant field data and models.	Integrated research and inventory data. Data sharing across scales and sectors.	Sampling designs. Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.

Robust knowledge base -incremental work needed

Existing knowledge base - additional coordinated research required

Growing knowledge base - more comprehensive research needed

Emerging knowledge base - significant research investment needed

3 Conclusion

3.1 General research needs

Through international discussions of REDD and other policy proposals for increasing terrestrial carbon mitigation, there is greater awareness of the need for a robust, multi-scale information base to support estimating mitigation potential, monitoring terrestrial carbon (and other GHGs), meeting international reporting expectations, and ensuring that actions cumulatively generate meaningful carbon emissions reduction and sequestration at global scale.

There are many opportunities to advance the scientific and technical foundation for land-based mitigation. In undertaking this review, clear themes have become evident:

- Rich scientific knowledge and field experience, available measurement tools and databases, and existing reports and international guidance provide a solid foundation for current and future work.
- Development of cost-effective, easy to use tools and methodologies and spatially-resolved, accurate data-gathering is needed to expand focus to all land classes (including complex landscapes), regions, and carbon pools.
- Diverse local, national, and regional circumstances can be accommodated by developing a regionally-relevant mix of management practices, measurement approaches, conversion equations, and models as well as planning for changing regional climatic conditions.
- Efforts to improve convergence and consistency can produce synthesized scientific knowledge (for carbon dynamics, management practices, and measurement), harmonized reporting guidelines and methodologies, compatible terminology, definitions, and classifications, and integrative modelling (for spatially-resolved time series data, downscaling).
- Expanding and building regional and global networks can provide needed linkages across field research and technological advancements and facilitate access to tools, databases, technical support, infrastructure, and extension services.

Progress requires adequate resources, expanded capacity, and clear incentives and mandates.

3.2 Research needs for major land classes

For all land classes, it will be important to extend general understanding about the effects of alternative management practices to specific conditions through field research and innovative modelling. Expanded effort to develop regionally-relevant conversion equations, sampling designs, and approved methodologies will be important for non-forest land classes. Some research needs are high priorities for specific land classes:

- Forest carbon dynamics and management options are well-understood in many parts of the world. A key remaining challenge is greater convergence in global estimates of emissions and sequestration as well as more effective and coherent tracking of changes in some regions.
- Many types of croplands are well-studied although some types and regions require more attention. Improvements are needed in process-level understanding of soil carbon distribution across pools and depth, over time, as well as under mixed management systems such as agroforestry. Greater convergence on robust monitoring methods is the central focus of several initiatives.
- Grasslands and drylands have received significant attention by the research community, but require additional regional- and global-scale synthesis of resulting knowledge. Important research frontiers include soil dynamics, sequestration rates, fire regimes, and grazing effects. Also, adaptation of monitoring methods and models to these ecosystems is needed to more fully integrate them into terrestrial carbon mitigation efforts.

- Technical work to support mitigation in wetlands and peatlands has been robust in some regions, but additional process-level knowledge is needed to enhance estimation of potential GHG emissions reduction and carbon sequestration. Additional work is needed to characterize geographic and temporal variability and relationships among drainage depth, subsidence, disturbance, and emissions. Current efforts to develop widely accepted monitoring methods need additional resources.

Also, there is emerging awareness of the need to synthesize the scientific understanding of major land classes into a more integrated characterization of ecological landscapes. While some large land areas can be described homogeneously (eg, contiguous unmanaged forests, extensive grasslands), land cover and land use in many regions are quite heterogeneous, making land classification difficult in many places. A number of research investments (eg, networks of benchmark sites, improvements in remote sensing interpretation capacity) offer promise for increasing our ability to accurately predict and monitor changes in carbon across whole landscapes.

3.3 Action and innovation

To translate policy frameworks and financial incentives into improved land management and significant climate change mitigation, action and innovation will be needed by international agencies, national governments, land managers, financiers, and project implementers and auditors. There are many different organizations already working on various aspects of terrestrial carbon management and quantification. Integration and expansion of investment in research and development and technology transfer as well as greater information sharing and coordination is needed across the public and private sectors, across scientific disciplines, and across geographic scales.

A variety of existing institutions and initiatives are already hard at work to address priority research needs. Commonly, efforts are, and will continue to be, organized around major land classes – forests, croplands, grasslands and drylands, and wetlands and peatlands. Within these communities of practice, there is a wealth of expertise available to be more fully harnessed in answering outstanding technical questions.

While there are some well-coordinated, multi-organization initiatives producing integrated responses to priority topics, other critical research needs are being addressed through an array of idiosyncratic projects and programs housed in various research institutions, private companies, and national and international agencies. While these are critically important and innovative contributions to the terrestrial carbon research agenda, they would generate greater impact and consistency if aggregated into more structured consortia.

3.4 Next steps

This *Roadmap for Terrestrial Carbon Science* assesses the scientific and technical advancements needed to maximize terrestrial carbon mitigation and document and reward outcomes. It identifies priority research needs that must be addressed, globally and in specific regions, to provide the quantitative basis for improved management of terrestrial carbon. It recommends technical investments and actions needed to accelerate avoided emissions and sequestration of terrestrial carbon that can complement important progress in understanding the social, economic, institutional, and governance dimensions of terrestrial carbon management.

Continued and expanded leadership by research institutions and multilateral agencies can promote translational research that builds on existing knowledge and infrastructure, improves accuracy while developing experience, and informs policy and practice. An essential step will be estimating costs and capacity needs associated with priority research initiatives and generating the necessary financial and technical support for phased implementation. Linkages among developed and developing countries and across the public and private sectors will be critical to filling research gaps through coordinated, multi-lateral, multi-scale cooperation.

REFERENCES

Alterra. 2008. Final Report: Review of existing information on the interrelations between soil and climate change. Wageningen UR, The Netherlands.

Angelsen, A. (ed.) 2008. Moving ahead with REDD: Issues, options and implications. CIFOR, Bogor, Indonesia. Available at: http://www.cifor.cgiar.org/publications/pdf_files/Books/BAngelsen0801.pdf

Batjes, N. 2004. Estimation of soil carbon gains upon improved management within cropland and grasslands of Africa. Environment, Development, and Sustainability 6: 133–143.

Bombelli, A., M. Henry, S. Castaldi, S. Adu-Bredu, A. Arneth, A. de Grandcourt, E. Grieco, W. L. Kutsch, V. Lehsten, A. Rasile, M. Reichstein, K. Tansey, U. Weber, and R. Valentini. 2009. An outlook on the Sub-Saharan Africa carbon balance. Biogeosciences, 6, 2193–2205.

Barthelmes, A., J. Couwenberg, and H. Joosten. 2009. Peatlands in National Inventory Submissions 2009: An analysis of 10 European countries. Wageningen, The Netherlands: Wetlands International (available at www.wetlands.org).

Batjes, N. 2004. Estimation of soil carbon gains upon improved management within cropland and grasslands of Africa. Environment, Development, and Sustainability 6: 133–143.

Bruce, J.P., M. Fromme, E. Haites, H. Janzen, R. Lal, K. Paustian. 1999. Carbon sequestration in soils. Journal of Soil and Water Conservation, 54(1):382-389.

Campbell, B.M. 2009. Beyond Copenhagen: REDD+, agriculture, adaptation strategies and poverty. Global Environmental Change, 19(4):397-399.

Canadell, J.G., and M.R. Raupach. 2008. Managing Forests for Climate Change Mitigation. Science 320:1456-1457.

Conant, R.T. 2009. Challenges and opportunities for carbon sequestration in grassland systems: a technical report on grassland management and climate change mitigation. Prepared for the UN Food and Agricultural Organization, Crop and Grassland Service, Plant Production and Protection Division.

Conant, R.T., K. Paustian, and E.T. Elliott. 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecological Applications, 11:343-355.

Couwenberg, J. 2009. Emission factors for managed peat soils (organic soils, histosols): An analysis of IPCC default values. Wageningen, The Netherlands: Wetlands International (available at www.wetlands.org).

DB Climate Change Advisors. 2009. Investing In Agriculture: Far-Reaching Challenge, Significant Opportunity An Asset Management Perspective.

Dumanski, J., R.L. Desjardins, C. Tarnocal, C. Monreal, E.G. Gregorich, V. Kirkwood, and C.A. Campbell. 1998. Possibilities for future carbon sequestration in Canadian agriculture in relation to land use changes. Climatic Change, 40:81-103.

Easterling, W.E., and M. Apps. 2005. Assessing the consequences of climate change for food and forest resources: A view from the IPCC, Climatic Change, 70 (1-2): 165-189.

FAO. 2001. Soil carbon sequestration for improved land management. World Soil Resources Reports 96. FAO of the United Nations, Rome.

FAO. 2009. Grassland: Enabling their potential to contribute to greenhouse gas mitigation. FAO of the United Nations, Rome. Based on workshop 15-17 April 2009.

Farage P., J. Ardö, L. Olsson, E. Rienzi, A. Ball and J. Prett. 2007. The potential for soil carbon sequestration in three tropical dryland farming systems of Africa and Latin America: A modelling approach. Soil & tillage research, 94(2): 457-472.

Gower, S.T., C.J. Kucharik, and J.M. Norman. 1999. Direct and indirect estimation of leaf area index, FAPAR, and net primary production of terrestrial ecosystems. Remote Sensing of Environment, 70: 29-51.

Greenland, D., D.G. Goodin, and R.C. Smith. C. 2003. Climate variability and ecosystem response at Long-Term Ecological Research Sites. New York: Oxford University Press.

Hobbie, J.E., S.R. Carpenter, N.B. Grimm, J.R. Gosz, and T.R. Seastedt. 2003. The US Long Term Ecological Research Program. BioScience, 53(1):21-32.

Hooijer, A., M. Silvius, H. Wösten, and S. Page. 2006. PEAT-CO2, Assessment of CO_2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943.

Hungate, B.A., K.J. van Groenigen, J. Six, J.D. Jastrow, Y.Q. Lue, M.A. de Graaff, C. van Kessel, and C.W. Osenberg. 2009. Assessing the effect of elevated carbon dioxide on soil carbon: a comparison of four meta-analyses. Global Change Biology 15:2020-2034.

IPCC. 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available from: http://www.ipcc-nggip.iges.or.jp/public/gl/invs4.html

IPCC. 2000. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available from: http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html

IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, and F. Wagner (eds). Japan. Available at http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

IPCC. 2003. Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types. Available from: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation_contents.html

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

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: AFOLU. Available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

IPCC. 2007. IPCC Fourth Assessment Report: Climate Change 2007. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC. Cambridge University Press, Cambridge, United Kingdom and New York. New York, United States.

Izaurralde, C.R., and C.W. Rice. 2009. Presentation: "Methods for Measuring and Monitoring Soil Carbon Sequestration," March 2, 2009. World Bank Soil Carbon Methodology Workshop. Washington, DC, USA.

Janssens, I. A., A. Freibauer, B. Schlamadinger, R. Ceulemans, P. Ciais, A. J. Dolman, M. Heimann, G.-J. Nabuurs, P. Smith, R. Valentini, and E.D. Schulze. 2004. The carbon budget of terrestrial ecosystems at country-scale – a European case study. Biogeosciences Discussions, 1:167–193.

Joosten, H., and J. Couwenberg. 2009. Are emission reductions from peatlands MRV-able? Wetlands International. Available at www.wetlands.org.

Kaat, A., and H. Joosten. 2008. Factbook for UNFCCC policies on peat carbon emissions, Wetlands International. Available at www.wetlands.org.

Keller, A.A., and R.A. Goldstein. 1998. Impact of carbon storage through restoration of drylands on the global carbon cycle. Environmental Management, 22(5):757-766.

Kimble, J.M., L.S. Heath, R.A. Birdsey, and R. Lal (Eds). 2003. The potential of US forest soils to sequester carbon and mitigation the greenhouse effect. CRC Press, Boca Raton, FL.

Lal, R. 1999. Global carbon pools and fluxes and the impact of agricultural intensification and judicious land use. In Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on Latin America and the Carribean. Proceedings of an IFAD/FAO Expert Consultation IFAD, Rome, Italy, 15 April 1999. World Soil Resources Report 89. FAO of the United Nations, Rome, pg 51.

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Climatic Change, 51:35–72.

Lal, R. 2004. Review: Soil carbon sequestration to mitigate climate change. Geoderma, 123:1–22.

Le Quéré, C.L., M.R. Raupach, J.G. Canadell, G. Marland, L. Bopp, P. Ciais, T.J. Conway, S.C. Doney, R.A. Feely, P. Foster, P. Friedlingstein, K. Gurney, R.A. Houghton, J.I. House, C. Huntingford, P.E. Levy, M.R. Lomas, J. Majkut, N. Metzl, J.P. Ometto, G.P. Peters, I.C. Prentice, J.T. Randerson, S.W. Running, J.L. Sarmiento, U. Schuster, S. Sitch, T. Takahashi, N. Viovy, G.R. van der Werf, and F.I. Woodward. 2009. Trends in the sources and sinks of carbon dioxide. Nature Geoscience, 2:1-6. Available at www.nature.com/naturegeoscience

Li, C., C. Jianbo, G. Sun, and C. Trettin. 2004. Modeling impacts of management on carbon sequestration and trace gas emissions in forested wetland ecosystems. Environmental Management, 33:S176–S186.

Matthews, E., R. Payne, M. Rohweder, and S. Murray. 2000. Pilot Analysis of Global Ecosystems: Forest Ecosystems, World Resources Institute, Washington, DC.

McKinsey & Company. 2009. Pathways to a Low Carbon Economy: Version 2 of the Greenhouse Gas Abatement Cost Curve. Available at https://solutions.mckinsey.com/ClimateDesk/default.aspx.

McNamara, N.P., T. Plant, S. Oakley, S. Ward, C. Wood, and N. Ostle. 2008. Gully hotspot contribution to landscape methane (CH4) and carbon dioxide (CO2) fluxes in a northern peatland. Science of the Total Environment, 404:354-360.

Mokany, K., R.J. Raison, and A.S. Prokushkin. 2206. Critical analysis of root: shoot ratios in terrestrial biomes. Global Change Biology, 12:84-96

Murray, B., A. Jenkins, R. Kramer, and S.P. Faulkner. 2009. Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Nicholas Institute, Duke University NI R 09-02.

Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, and X. Zhang. 2007. Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nabuurs, G.J., E. Thurig, N. Heidema, K. Armolaitis, P. Biber, E. Cienciala, E. Kaufmann, R. Makipaa, P. Nilsen, R. Petritsch, T. Pristova, J. Rock, M.J. Schelhaas, R. Sievanen, Z. Somogyi, and P. Vallet. 2008. Hotspots of the European forests' carbon cycle. Forest Ecology and Management, 256:194–200.

Nepstad, D.C., B.S. Soares-Filho, F. Merry, A. Lima, P. Moutinho, J. Carter, M. Bowman, A. Cattaneo, H. Rodrigues, S. Schwartzman, D.G. McGrath, C.M. Stickler, R. Lubowski, P. Piris-Cabezas, S. Rivero, A. Alencar, O. Almeida, and O. Stella. 2009. The end of deforestation in the Brazilian Amazon. Science, 326: 1350-1351.

Niggli, U., A. Fließbach, P. Hepperly, and N. Scialabba. 2009. Low greenhouse gas agriculture: mitigation and adaptation potential of sustainable farming systems. FAO, April 2009, Rev. 2 – 2009.

Paustian, K., J.M. Antle, J. Sheehan, and E.A. Paul. 2006. Agriculture's role in greenhouse gas mitigation. Pew Center on Global Climate Change, Arlington, Virginia.

Paustian, K., B.A. Babcock, J. Hatfield, R. Lal, B.A. McCarl, S. McLaughlin, A. Mosier, C. Rice, G.P. Robertson, N.J. Rosenberg, C. Rosenzweig, W.H. Schlesinger, and D. Zilberman, 2004. Agricultural mitigation of greenhouse gases: science and policy options. CAST (Council on Agricultural Science and Technology) Report, R141 2004, ISBN 1-887383-26-3, 120 pp.

Rasmussen, P.E., K.W. T. Goulding, J.R. Brown, P.R. Grace, H.H. Janzen, and M. Korschens. 1998. Long-term agroecosystem experiments: assessing agricultural sustainability and global change. Science, 282:893-896.

Reid, R.S., P.K. Thornton, G.J. McRabb, R.L. Kruska, F. Atieno, and P.G. Jones. 2004. Is it possible to mitigate greenhouse gas emissions in pastoral ecosystems of the tropics? Development and Sustainability, 6:91–109.

Sanchez, P.A., S. Ahamed, F. Carré, A.E. Hartemink, J. Hempel, J. Huising, P. Lagacherie, A.B. McBratney, N.J. McKenzie, M. de Lourdes Mendonça-Santos, B. Minasny, L. Montanarella, P. Okoth, C.A. Palm, J.D. Sachs, K.D. Shepherd, T.-G. Vågen, B. Vanlauwe, M.G. Walsh, L.A. Winowiecki, and G.-L. Zhang. 2009. Digital soil map of the world. Science, 325:680-681.

Sathaye, J., W. Makundi, L. Dale, P. Chan, and K. Andrasko. 2006. GHG mitigation potential, costs and benefits in global forests: a dynamic partial equilibrium approach. The Energy Journal, Multi-Greenhouse Gas Mitigation and Climate Policy Special Issue. International Association for Energy Economics, Inc.

Schlecht, E., A. Buerkert, E. Tielkes, and A. Bationo. 2006. A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. Nutrient Cycling in Agroecosystems, 76:109–136.

Six, J., S.M. Ogle, F.J. Breidt, R.T. Conant, A.R. Mosier, and K. Paustian. 2004. The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. Global Change Biology, 10:155-160.

Smith, P. 2004. Monitoring and verification of soil carbon changes under Article 3.4 of the Kyoto Protocol. Soil Use and Management, 20:264-270.

Smukler, S., and C. Palm. 2009. Monitoring, reporting, and verification methodologies for agriculture, forestry, and other land use. *In* G. Nelson (ed.) Agriculture and climate change: an agenda for negotiation in Copenhagen, Focus 16, Brief 8, IFPRI, Washington, DC. Available at http://www.ifpri.org/sites/default/files/publications/focus16.pdf.

Stickler, W.Z., D.C. Nepstad, M.T. Coe, D.G. McGrath, H.O. Rodrigues, W.S. Walker, B.S. Soares-Filho, and E.A. Davidson. 2009. The potential ecological costs and cobenefits of REDD: a critical review and case study from the Amazon region. Global Change Biology, 15:2803–2824.

Teobaldelli, M., Z. Somogyi, M. Migliavacca, and V.A. Usoltsev. 2008. Generalized functions of biomass expansion factors for conifers and broadleaved by stand age, growing stock and site index. Forest Ecology and Management, 257:1004-1013.

Terrestrial Carbon Group Project, 2009a. 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 gases in the terrestrial system. Policy Brief 2, June 2009. Terrestrial Carbon Group.

Terrestrial Carbon Group Project, 2009b. Estimating tropical forest carbon at risk of emission from deforestation globally: applying the Terrestrial Carbon Group reference emission level approach. Policy Brief 3, June 2009. Terrestrial Carbon Group.

Terrestrial Carbon Group Project. 2009c. Measuring and monitoring terrestrial carbon: the state of the science and implications for policy makers. August 2009. Terrestrial Carbon Group.

Terrestrial Carbon Group Project, 2009d. Measuring and monitoring terrestrial carbon as part of "REDD+" MRV Systems. Policy Brief 5, October 2009. Terrestrial Carbon Group.

Tiessen H., C. Feller, E.V.S.B. Sampaio, and P. Garin. 1998. Carbon sequestration and turnover in semiarid savannas and dry forest. Climatic Change, 40(1):105-117.

Trumbore. S.E. 1997.. Potential responses of soil organic carbon to global environmental change. Proceedings of the. National Academy of Sciences (USA), 94:8284–8291.

Trumper, K., M. Bertzky, B. Dickson, G. van der Heijden, M. Jenkins, and P. Manning. 2009. The Natural Fix? The role of ecosystems in climate mitigation. A UNEP rapid response assessment. United Nations Environment Programme, UNEPWCMC, Cambridge, UK. Available at http://www.grida.no/publications/rr/natural-fix/page/3725.aspx.

UNFCCC. 2008. Challenges and opportunities for mitigation in the agricultural sector. United Nations Framework Convention on Climate Change Technical paper FCCC/TP/2008/8.

USDA, 2007. Measurement guidelines for the sequestration of forest carbon. USDA Forest Service, General Technical Report NRS-18. [Pearson, T.R.H., S.L. Brown, and R.A. Birdsey (authors)] USA.

van der Werf, G. R., D.C. Morton, R.S. DeFries, J.G.J. Olivier, P.S. Kasibhatla, R.B. Jackson, G.J. Collatz, and J.T. Randerson. 2009. CO_2 emissions from forest loss. Nature Geoscience, 2:737-738.

Venter, O., W.F. Laurance, T. Iwamura, K.A. Wilson, R.A. Fuller, and H.P. Possingham. 2009. Harnessing Carbon Payments to Protect Biodiversity. Science, 326(5958):1368.

Waggoner, P.E. 2009. Forest Inventories: Discrepancies and Uncertainties. Resources for the Future Discussion Paper 09-29. Washington, DC.

White, R., S. Murray, and M. Rohweder. 2000. Pilot analysis of global ecosystems: grassland ecosystems. World Resources Institute, Washington DC.

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.

Wunder, S. 2008. Payments for environmental services and the poor: concepts and preliminary evidence. Environment and Development Economics, 13:279-297.

Zhao, S.Q., S. Liu, Z. Li, and T.L Sohl. 2009. Ignoring detailed fast-changing dynamics of land use overestimates regional terrestrial carbon sequestration. Biogeosciences, 6:1647-1654.

APPENDIX 1: Selected global and regional-scale studies that estimate land-based mitigation potential, using a variety of units and timeframes, for major land classes

Some estimates project potential emissions reduction by a particular future date (some of these are based on a particular carbon offset credit price), others are based on annual rates. Estimates focus on mitigation potential of either carbon or all GHGs. Units of estimation include net carbon gain (mass, mass per unit area), net primary productivity, net global warming potential, and avoided emissions (in CO_2 equivalents). Some studies project potential sequestration for major regions or countries. It is expected that estimates for particular land classes do not necessarily use the same definitions and geographic areas. Note that a wide range of studies have used plot-level data to produce site-specific estimates of sequestration potential. For example, long-term studies at the Rodale Institute have shown sequestration rates associated with various management practices.

Land class	Study	C / GHG sequestration / mitigation unit
Forests (incl Agroforestry)	TCG, 2009	C loss from deforestation over the next 40 years (Gt C)
	Nabuurs et al, 2007	Potential mitigation through C sequestration and avoided emissions by 2030 at USD20 per t CO_2-eq (Pg C yr^{-1})
	Sathaye et al, 2006	Modeled global forest C storage (Gt C) over a century based on C prices scenarios
	Kimble et al, 2003	C storage in US forests over 1953-1997 (Mt C yr^{-1})
	FAO, 2001	Annual net carbon storage, annual rate of carbon gain (t C ha^{-1} yr^{-1}) for alternative land management
Croplands / Grasslands	UNFCCC, 2008	Potential GHG emissions reduction in 2020 at USD30 (t CO_2-eq)
	Smith et al, 2008	Technical mitigation potential by 2030 (all GHGs, all practices with croplands, grasslands, livestock) (Mt CO_2-eq yr^{-1})
	IPCC, 2007	Global technical mitigation potential by 2030 (N_2O, CH_4, CO_2) (Mt CO_2-eq yr^{-1})
	Paustian et al, 2006	C sequestration potential for US agricultural soils (MMT C yr^{-1})
	Lal, 2004	Potential soil C sequestration rates (kg C ha^{-1} yr^{-1}); cumulative potential over 25-50 years (Pg C)
	Batjes, 2004	SOC sequestration from improved management in African croplands and grasslands (Tg C y^{-1})
	Conant et al, 2001	C sequestration rates for improved grassland management over decadal time spans (Mg C ha^{-1} yr^{-1})
	FAO, 2001	Annual net C storage; annual rate of C gain from alternative land management (t C ha^{-1} yr^{-1})
	Bruce et al, 1999	Potential C gain in North American agricultural soils over two decades (Mg C ha^{-1} yr^{-1})
Croplands only	Niggli et al, 2009	C gain from net primary production (kg CO_2-eq ha^{-1} yr^{-1}); net global warming potential (kg CO_2-eq ha^{-1} yr^{-1})
	Six et al, 2004	Reduced GHG emissions from no-till & residue management; global scale CO_2, CH_4 and N_2O measurements over decades and their global warming potential (GWP)
	Lal, 1999	C sequestration rate from technological soil management options (t C ha^{-1} yr^{-1}); potential to sequester (Pg C yr^{-1})
	Dumanski et al, 1998	C sequestration for alternative land management practices for Canadian agricultural lands in (Tg C y^{-1})
Drylands	Farage et al, 2007	Modeled average C accumulation rates for African and Latin American regions for up to 50 years (Mg C ha^{-1} yr^{-1})
	Lal, 2001	Avoided C emissions by desertification control; rates of SOC sequestration (Mg ha^{-1} yr^{-1}); estimated 25-50 year C sequestration potential (Pg C y^{-1})
	Keller & Goldstein, 1998	Modeled C accumulation rate in restored dryland biomes over a century (Gt C yr^{-1})
	Tiessen et al, 1998	C gain rate over regions of South America and West Africa for periods of up to a decade (Mg C ha^{-1} yr^{-1})
Wetlands / Peatlands	Smith et al, 2008	Total biophysical mitigation potentials for rice paddies (all practices, all GHGs: Mt CO_2-eq yr^{-1})
	FAO, 2001	Annual net carbon storage; annual rate of C gain for alternative land management (t C ha^{-1} yr^{-1})
All land classes	McKinsey & Co, 2009	Abatement potential by 2030 (Gt CO_2-eq yr^{-1})
	Janssens et al, 2004	Regional-scale estimates of current C gains and losses (Europe); biome-specific C sequestration rates (g C m^{-2} yr^{-1})

APPENDIX 2: Organizations working on process-level understanding of carbon dynamics and mitigation potential

Initiative / Organization	Administrators	Geographic location	Details
Consortium for Agricultural Soils Mitigation of Greenhouse Gases (CASMGS)	Consortium of nine US research institutions and one government laboratory	United States; subnational / national	▪ Basic research on processes and mechanisms of agricultural soil carbon sequestration ▪ Includes Colorado State, Iowa State, Kansas State, Michigan State, Montana State, Nebraska, Ohio State, Purdue, Texas A&M; Batelle-Pacific Northwest National Laboratory
Earth System Science Partnership (ESSP)	DIVERSITAS, IGBP, IHDP, WCRP	Global; regional / international	▪ Research / synthesis on natural and human controls on sources and sinks of carbon, especially for vulnerable carbon pools and processes (Global Carbon Project, GCP) ▪ Re-evaluation of the carbon balance of large regions of the globe at the continent scale (GCP) ▪ Partnership among DIVERSITAS, International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP), and World Climate Research Programme (WCRP)
EcoAgriculture Partners	--	Global; subnational to international	▪ Organizes, increases, and synthesizes research on ecoagriculture systems ▪ Supports the dissemination of ecoagriculture research and field documentation to a broad range of target audiences
Global Canopy Programme (GCP)	Collaboration with / funded by the United Nations Environment Programme (UNEP) and the Global Environment Facility (GEF)	Developing countries; subnational / regional / international	▪ Analyze regional to global ecosystem services provided by the forests of Amazonia ▪ "Whole Forest Observatories" (WFOs) will monitor biodiversity and the impact of climate change in the forest from above the canopy to the soil (builds on 10 existing canopy crane locations mainly in temperate forest locations; five proposed tropical WFO locations in Brazil, Ghana, India, Madagascar, Malaysia)
Institute of Botany and Landscape Ecology	University of Greifswald	Finland and Russia; subnational	▪ Characterize carbon dynamics of boreal peatland ecosystems by evaluating small and medium scale variability of carbon dioxide, methane and dissolved organic carbon fluxes; scale from plot to landscape scale using aerial photography and satellite imagery; and

Initiative / Organization	Administrators	Geographic location	Details
			incorporate paleo-environmental information to assess variability of medium term carbon accumulation (The Eurasian Peatlands in a Changing Climate project, Ecosystem Dynamics Working Group)
Intergovernmental Panel on Climate Change (IPCC)	Established by UNEP and the World Meteorological Organization (WMO)	Global; international	▪ Review and assess current developments in the understanding of impacts of climate change on ecosystems ▪ 194 member countries
Joint Research Centre, Institute for Environment and Sustainability (JRC-IES)	European Commission	Europe; regional	▪ Conduct long-term observations of fluxes of CO_2, CH_4, and N_2O between the biosphere and the atmosphere
Land Degradation Assessment in drylands (LADA)	FAO (executing), UNEP (implementation), GEF (donor)	Argentina, China, Cuba, Senegal, South Africa, Tunisia; subnational to international	▪ Develop and implement strategies, methods, and tools to analyze the nature and impacts of land degradation on carbon storage in drylands at multiple spatial and temporal scales
Natural Resource Ecology Laboratory	Colorado State University	Southeastern US; subnational / national	▪ Create a knowledge base for reliably estimating the potential for carbon sequestration through the adoption of improved pasture and livestock management systems by collecting and analyzing comparative soil samples, establishing monitoring plots, incorporating land use databases, and ultimately use the information to calibrate the Century carbon model for aggregating soil carbon levels and changes to state, regional and national levels
The Nature Conservancy, Climate Change Program	--	Global; subnational	▪ Conduct research on forest carbon project sites to identify best restoration and protection strategies, improve forest management, and implement changes in grazing or cropland management activities
US Agricultural Research Service, GRACEnet	US Department of Agriculture	US; subnational	▪ Evaluate the soil carbon status and direction of change of soil carbon in existing typical and alternative agricultural systems, and determine net GHG emission of current agricultural systems in existing typical and alternative agricultural systems
US Department of Energy (DOE) Consortium for Research on Enhancing	Sponsored by the Climate Change Research Division (CCRD) of the	US; subnational / national	▪ Conduct research on the physical, biological and chemical processes controlling soil carbon input, distribution, and longevity; how these processes can be exploited to

Initiative / Organization	Administrators	Geographic location	Details
Carbon Sequestration in Terrestrial Ecosystems (CSiTE)	Office of Biological and Environmental Research within the U.S. Department of Energy's Office of Science		enhance terrestrial carbon sequestration; how terrestrial carbon sequestration strategies relate to and influence other strategies to mitigate climate change; and the long-term potential for terrestrial carbon sequestration to mitigate climate change at a global scale ▪ Multi-institutional research effort involving Argonne, Oak Ridge, and the Pacific Northwest National Laboratories and partnered Universities
US Forest Service	US Department of Agriculture	US; national	▪ Conduct research to enhance ecosystem health and sustainability, increase retention of newly sequestered carbon, and avoid carbon losses from major disturbances (Global Change Research Strategy)
US Geological Survey	US Department of the Interior	US and Canada; subnational to regional	▪ Process studies and modeling are being expanded to better understand the historic and modern interactions among climate, surface temperature and moisture, fire, and terrestrial carbon sequestration in Northern Landscapes ▪ Applying its expertise in satellite remote sensing, biogeochemical modeling, analysis of large spatial data sets, and geographic information systems applications to develop a quantitative understanding of the terrestrial carbon cycle
Wetlands International	--	Global; subnational to international	▪ Scientific research and extensive field projects contributing to a solid knowledge base on peatlands ▪ Conducted overview of peatlands and their status, carbon stocks and carbon emissions worldwide ▪ Analysis of peatland management, emission factors and reductions
Woods Hole Research Center (WHRC)	--	Global; national to international	▪ Study current and historic releases of carbon and the role of forests in sequestering carbon
World Conservation Monitoring Centre (WCMC)	United Nations Environment Programme	Global; subnational to international	▪ Assessed carbon capacity of drylands ▪ Produced global overview: The Natural Fix

APPENDIX 3: Organizations working on scientific research base for alternative management practices

Initiative / Organization	Administrators	Geographic location and scale	Details
BirdLife International (BL)	Global partnership	Africa and Asia; subnational	▪ BL Belarus and its partners are conducting a number of projects to sustainably restore, manage and monitor peatland areas throughout Belarus ▪ also helping to progress work on AFOLU standards in order to conserve peatlands in their efforts to conserve birds, their habitats and biodiversity
Bogor Agricultural Institute (IPB)	--	Indonesia; subnational	▪ Conducted a study that assessed leakage from carbon-sink projects that could potentially be implemented, estimating the probability of a given land use / cover being converted into other uses / cover
CarboInvent Project	Joanneum Research (coordinator)	Global; subnational to international	▪ Conduct carbon inventories of above- and below-ground biomass, soils and litter pools ▪ 14 partners from Austria, Belgium, Czech Republic, Finland, Germany, Hungary, Italy, Ireland, Spain, Sweden
Centre for Agricultural Greenhouse Gas Research	AgResearch (New Zealand)	New Zealand; national	▪ Long-term basic research on GHG mitigation (pastoral, arable, horticulture, poultry, and pig sectors; not including planted forestry, energy, or biofuels) ▪ Develop near-term outcomes for farmers, and strategies to promote farmer adoption and uptake of new technologies and practices
Centre for Social and Economic Research on the Global Environment (CSERGE)	University of East Anglia (UEA)	Global; subnational	▪ Improve knowledge of ecosystem services and find solutions to managing these services sustainably (Valuing the Arc programme, Tanzania)
Climate Investment Funds, Strategic Climate Fund	World Bank	Global; subnational / national	▪ Provide financial incentives for scaled-up action and transformational change through pilot projects that demonstrate ways to integrate climate risk and resilience into core development planning, while complementing other ongoing development activities in a given country (Pilot Program for Climate Resilience) ▪ The Forest Investment Program will mobilize significantly

Initiative / Organization	Administrators	Geographic location and scale	Details
			increased investments to reduce deforestations and forest degradation and promote improved sustainable forest management, leading to emission reductions and the protection of carbon reservoirs
Conservation International	--	Global; subnational	▪ Implementation of projects to reduce carbon dioxide emissions from deforestation while sequestering additional carbon on degraded agricultural areas
Conservation Technology Information Center (CTIC)	Member organization	US; subnational	▪ Review and communicate new research, technologies and innovative approaches to agricultural soil carbon sequestration ▪ supported by the US Environmental Protection Agency and the Natural Resources Conservation Service, and others
Consortium for Agricultural Soils Mitigation of Greenhouse Gases (CASMGS)	Consortium of nine US research institutions and one government laboratory	United States; subnational / national	▪ Development and assessment of best management practices ▪ Includes Colorado State, Iowa State, Kansas State, Michigan State, Montana State, Nebraska, Ohio State, Purdue, Texas A&M; Batelle-Pacific Northwest National Laboratory
Cooperative for Assistance and Relief Everywhere (CARE), Agricultural and Natural Resources	--	Ecuadorian Andes; subnational Peru, Bolivia, Ecuador; subnational	▪ Provide training in improved agricultural methods to improve production and protect natural resources ▪ Implementation of pilot activities in agricultural areas that illustrate the costs and benefits of adaptation (eg, Adaptation to the impact of Rapid Glacier Retreat in the Tropical Andean Region, or PRAA)
Duke University Wetland Center	--	US; subnational	▪ Study and quantify anticipated benefits of peatland restoration in North Carolina by quantifying changes in soil carbon flux and nitrogen dynamics in response to restoration, complete a carbon and nitrogen budget, and quantify carbon and nitrogen sequestration benefits from the restoration work.
Earth System Science Partnership (ESSP)	DIVERSITAS, IGBP, IHDP, WCRP	Global; regional / international	▪ Research dynamics of carbon-climate-human system into the future, and potential points of intervention (Global Carbon Project, GCP) ▪ Evaluation of the potential of different practices, technologies and policies on mitigating the impacts of agriculture on climate forcing from local to global scales

Initiative / Organization	Administrators	Geographic location and scale	Details
			[Challenge Program on Climate Change, Agriculture and Food Security (CCAFS), in partnership with the Consultative Group on International Agricultural Research (CGIAR)] ▪ Partnership among DIVERSITAS, International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP), and World Climate Research Programme (WCRP)
International Center for Agricultural Research in the Dry Areas (ICARDA)	CGIAR Institution	Global; subnational / national	▪ Develop holistic approach to improved land management to combat desertification ▪ Develop technologies and practices for sustainable management of land, biodiversity and rangeland resources, including community-based land management practices
International Center for Research in Agroforestry (ICRAF) (World Agroforestry Centre)	CGIAR Institution	Africa, Asia, Latin America; subnational	▪ Review "high carbon stock rural development pathways" to describe how shifting cultivation system can evolve into carbon-storing agroforests and diverse tree crop production systems (Reducing Emissions from All Land Uses, REALU)
International Center for Tropical Agriculture (CIAT)	CGIAR Institution	Developing countries; subnational to regional	▪ Quantify the benefits of improved forages in reducing global warming potential through improved carbon sequestration and reduced emissions of methane and nitrous oxide (Forages Program) ▪ Evaluate landscape impacts of integrated soil fertility management technologies on outcomes such as ecosystem services like carbon sequestration (Sustainable Land Management Program)
International Centre for Integrated Mountain Development (ICIMOD)	--	Asia; subnational to national	▪ Identify, develop and demonstrate good practices and effective adaptation strategies for scaling up across rangelands to enhance ecosystem services ▪ Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Pakistan
International Development Research Centre (IDRC), Canada	--	Global; subnational	▪ Fund research projects to explore the effectiveness of experimental, action-focused capacity development initiatives (Under the Rural Poverty and Environment Program, Social Learning and Adaptation theme)
International Fund for Agricultural	Specialized United Nations agency	Developing countries; subnational	▪ Fund projects that reward people for ecosystem services (future grant programme will focus on carbon emissions and

Initiative / Organization	Administrators	Geographic location and scale	Details
Development (IFAD)			avoided deforestation in Africa) ▪ Fund organizations that test, adapt, and disseminate technology to improve soil fertility
International Geosphere-Biosphere Programme (IGBP)	Co-sponsored by the International Human Dimensions Programme (IHDP)	Global; subnational to international	▪ Studies effects of land use practices on ecosystem services and resulting feedbacks; seeks to integrate socio-economic, political and cultural environmental characteristics in which land use decisions are embedded (Global Land Project)
International Institute for Applied Systems Analysis (IIASA)	Sponsored by National Member Organizations in Africa, Asia, Europe and North America	Global; regional / international	▪ Identify and quantify suitable measures of intervention in terrestrial GHG cycles within forestry and agriculture (Forestry Program, global terrestrial ecosystems research theme) ▪ Use scenario modeling to assess costs of reducing global deforestation and explored a range of mechanism designs to combat deforestation ▪ Evaluate robustness of adaptation options, strategies for extreme climate risks, and involvement of adaptation in integrated climate-change modeling (Greenhouse Gas Initiative)
International Institute for Geo-Information Science and Earth Observation (ITC)	University of Twente	Global; subnational to international	▪ Assess relationships between sustainable forest management and biomass sequestration, as well as the relationship biomass-forest degradation (Carbon cycle and climate change Research Theme)
International Livestock Research Institute (ILRI)	CGIAR Institution	Global; international	▪ Conduct research at the interface of livestock production and poverty; recently released a study exploring the tradeoffs between livestock rearing, human well-being and environmental sustainability; outlined research questions in order to develop options for simultaneous livestock production and agroecosystem sustainability
International Rice Research Institute (IRRI)	--	Asia; subnational	▪ Conduct research on changes in ecosystem functions and ecosystem resilience in diversifying rice landscapes (Sustaining Agriculture Research Program, Rice and Climate Change Consortium) ▪ Develop a pilot site for large-scale measurement of GHG, water, and energy fluxes in diversifying rice systems (Sustaining Agriculture) ▪ Evaluation of biochar for carbon sequestration and soil

Initiative / Organization	Administrators	Geographic location and scale	Details
			improvement (Sustaining Agriculture)
International Tropical Timber Organization (ITTO)	Established by the United Nations; intergovernmental organization	Global; international	▪ Understand impacts of emerging issues such as carbon sequestration and REDD on tropical forest development ▪ Review progress on and new opportunities for the management of secondary tropical forests, the restoration of degraded tropical forests, and the rehabilitation of degraded tropical forest land
Kenya Agricultural Research Institute (KARI)	--	Kenya; subnational / national	▪ Develop and adapt technologies and knowledge that have the potential for improving productivity and generating essential agro-ecosystem services or functions such as carbon sequestration (Natural Resource Management thematic area of research)
Land Degradation Assessment in drylands (LADA)	FAO (executing), UNEP (implementation), GEF (donor)	Argentina, China, Cuba, Senegal, South Africa, Tunisia; subnational to international	▪ Build assessment capacities to enable the design, planning and implementation of interventions to mitigate land degradation and establish sustainable land use and management practices
National Wildlife Federation (NWF)	--	Global; international	▪ Design pilot projects that demonstrate the potential for "sustainable commodities" markets to reduce agricultural impacts on tropical forests, and foster best practices
Nicholas Institute (NI)	Duke University	US and beyond; national	▪ Coordinate and complete a transparent review of GHG mitigation opportunities in the US and abroad
Program on Forests (PROFOR)	Housed at the World Bank within the Environmentally and Socially Sustainable Development (ESSD) Forests Team	Global; national	▪ Analyzed the reduced level of emissions that could be anticipated through introduction of improved land use and land conversion strategies (Indonesia) ▪ Supporting the development of an impact assessment toolbox for carbon project developers to help ensure market confidence that "additional" social and biodiversity benefits are being generated via the voluntary carbon market
Rodale Institute	--	US; national to international	▪ Long-running "Farm Systems Trial" comparing organic to conventional farming systems
Rothamsted Research	--	UK, Europe, Australia, US; subnational	▪ Develop and promulgate new management practices which reduce the UK carbon and nitrogen footprint by enhancing the long-term storage of carbon in managed land while simultaneously reducing the emissions of the other GHGs ▪ Evaluate the trajectory of carbon in soils planted from arable

Initiative / Organization	Administrators	Geographic location and scale	Details
			to perennial biomass crops, and the contrasting physical distribution of this carbon within the soil and with respect to depth; evaluation of biochar research needs (Centre for Bioenergy and Climate Change)
The Nature Conservancy	--	Developing countries; subnational	▪ Assist countries in exploring alternative management options; eg, Berau, Indonesia: ▪ Develop a carbon monitoring and verification system to measure changes in carbon storage over time
United Nations Framework Convention on Climate Change	International environmental treaty	Global; international	▪ Facilitate better understanding of costs associated with methodologies and monitoring systems for estimating emissions from deforestation and forest degradation, the assessment of carbon stocks and GHG emissions from changes in forest cover, and the enhancement of forest carbon stocks
US Agricultural Research Service (ARS), GRACEnet	US Department of Agriculture	US; subnational	▪ Through the GRACEnet project, determine net GHG emission of current agricultural systems in existing typical and alternative agricultural systems, and determine the environmental effects (water, air and soil quality) of the new agricultural systems developed to reduce GHG emission and increase soil carbon storage
US Department of the Interior (USDOI)	US government	US; national	▪ Developing methods for geological as well as biological (eg, forests and rangelands) carbon storage (the Carbon Storage Project)
US Environmental Protection Agency (USEPA)	US government	US; subnational / national	▪ Through the Carbon Sequestration in Agriculture and Forestry activity area, assess the carbon sequestration and GHG mitigation potential for US forestry and agriculture, conduct annual inventories of sequestration rates and emissions, assess project-based activities and issues, explore international opportunities, and identify co-benefits of these forestry and agricultural activities
US Forest Service (USFS), Research and Development	US Department of Agriculture	US; national	▪ As part of its Global Change Research Strategy, conduct research that will assist managers in enhancing carbon sequestration via management that could increase forest growth rates and areas of forested lands ▪ Estimates total carbon storage and changes in carbon

Initiative / Organization	Administrators	Geographic location and scale	Details
			storage over time in forests at national and subnational levels
US Geological Survey (USGS)	US Department of the Interior	Global; subnational to international	▪ Compile and synthesize site-specific data to estimate carbon storage and inventory in soils, reservoir sediments, wetlands, and lakes of the conterminous United States ▪ Characterize present-day carbon storage by landscape feature and environment ▪ Predict potential carbon storage for land areas identified as possible reservoirs for carbon sequestration ▪ Field-based measurements and modeling to develop a quantitative understanding of role of land-use change and associated erosion and sedimentation processes on carbon storage and nutrient cycles within the Mississippi River Basin ▪ The international science team at the USGS Earth Resources Observation and Science Center has cooperative projects with developing countries, using satellite-based data to monitor the changes to land cover features
Wageningen UR / Alterra	Wageningen University and Research Centre	Global; subnational to international	▪ Clarify understanding of the European biospheric carbon cycle from an atmospheric, vegetation, and management perspective (under Ecosystem Studies Specialisation) ▪ Have conducted a variety of research projects on forest ecology and management, soil management, and peatland management to promote carbon storage
Wetlands International	--	Global; subnational to international	▪ Provide a worldwide overview of peatlands and their status (stocks and emissions) ▪ Work with local authorities to measure the impact of different management options in marshland sites (China, Ruoergai marshes)
Woods Hole Research Center (WHRC)	--	Global; national to international	▪ Analyze the potential of REDD to provide ecological damage and / or promote ecological co-benefits ▪ Quantify biomass and carbon in forests (US, Russia, PanTropical -- Central Africa, Latin America, Southeast Asia)
World Conservation Monitoring Centre (WCMC)	United Nations Environment Programme	Global; subnational to international	▪ Studied potential displacement of activities such as agriculture as a result of funding REDD activities that benefit both biodiversity and carbon storage (especially in East Africa, Brazil)

APPENDIX 4: General methods for measuring terrestrial carbon

	What is it?	What can it do?	Pros	Cons
Field Measurement	In-situ measurement of woody biomass (DBH, crown cover, height) converted to aboveground biomass. Herbaceous biomass directly measured. Carbon estimated using conversion factors. Soil samples analysed in the lab.	Estimate organic carbon stocks per hectare (carbon density)and change over time if measured more than once. Cross-check remote sensing estimates of areal extent of land use classes.	Many proven methods for biomass (field) and soils (lab).Precise for measured variables. Low technology requirement. Major cost is labor (may generate local employment).	Costs are a function of area and labor costs (highly variable). Limited to measurable variables. Can be slow. May not provide results that are consistent over a large area. Accuracy may depend on quality of conversion factors.
Remote sensing	Techniques that use optical, radar, or lidar sensors mounted on aircraft or space-borne platforms.[1] Data typically interpreted using field estimates.	Estimate areal extent of land cover classes. In combination with field data, estimate carbon stock and change over time if measured more than once.	Some types may be cost-effective. Globally consistent. Temporally / spatially explicit. Accurate for area estimation. Can be routinely collected. Objective methods for interpretation. Supports field work performance.	Sensors may not be suitable for all land uses and carbon pools. Interpretation can be technically demanding / expensive. Not all forms available for all regions. Not suitable for estimating all types of soil carbon stocks.[2]
Models	Tools to combine field, sensor, and other types of information to estimate carbon stocks.[3]	Estimate stock / flux (and changes) from field measurements (DBH and H), or estimate below-ground (root) biomass.	Framework for integrating various types of data.	Dependent on quality of input data. May be resource intensive on expertise and processing needs.

[1] Laser (lidar) sensors are able to measure the digital surface model (DSM) and digital elevation model (DEM) which can be used in allometric models to infer carbon stocks. Radar-based systems can measure surface roughness, vegetation canopy structure, topography as well as surface (including soil) moisture. Information gathered using radar-based sensors can also be used with existing allometric models to estimate carbon stock. Radar and lidar technologies have developed in leaps and bounds in the last few years and are, in some cases efficient, measurement tools. They do however still rely heavily on the quality of data and models used for interpretation and are not yet widely applied.

[2] Direct, operational assessment of soil carbon stocks via remote sensing is not yet possible and estimation is limited to situations where soils are exposed and has relied on the strong relationship between the quantity of soil organic matter (SOM) and soil colour (visible reflectance) (Daughtry et al, 2005; Serbin et al, 2009). There are limitations for estimating SOM based on soil reflectance which is a function of many factors in addition to organic matter, including soil moisture, texture, chemical composition, parent material and surface conditions. Complications are magnified when it is necessary to map a large geographical area. Ground penetrating radar and other techniques have also been used to estimate soil horizons, soil depth (eg, peatlands), stones and coarse roots (belowground biomass) although not to estimate soil carbon stocks directly.

[3] Typical inputs for models include information related to carbon stock estimates and activity data, for example: current and historic natural disturbance, management, land use change, climate, soil properties, growth rates, decomposition rates, biomass pools (above and below ground estimates) and estimates of variability and error.

APPENDIX 5: Organizations working on feasible accounting tools for all lands and carbon pools

Initiative / Organization	Administrators	Geographic location and scale	Details
CarboInvent Project	Joanneum Research (coordinator)	Europe; national / regional	▪ As part of the CarboInvent project, techniques for monitoring the impacts of forest management changes and disturbances on carbon stocks will be developed ▪ 14 partners from Austria, Belgium, Czech Republic, Finland, Germany, Hungary, Italy, Ireland, Spain, Sweden
Carbon Benefits Project (CBP)	Implemented by UNEP and consortium of organizations[i] Funded by Global Environment Facility (GEF) and others[ii]	Africa, Asia and South America; subnational	▪ Developing a standard, reliable method for accurately measuring, monitoring, reporting, and projecting how much carbon each kind of land use system is storing at the local level ▪ Modeling and projection specifically in cropland and grazing lands (Component A) ▪ Field measurement and monitoring of carbon changes across landscapes, particularly (agro-)forestry (Component B)
Carnegie Landsat Analysis System for non-expert users (CLASlite)	Carnegie Institution for Science, in partnership with Google (online version)	Initially in the Andes-Amazon region; subnational to regional	▪ An online version of CLASlite is in development by the Carnegie Institution for Science in partnership with Google; it will allow users to map and monitor forests with satellite imagery, which in turn can be used to make more accurate and transparent evaluations of carbon stocks in forested systems
Clinton Climate Initiative (CCI)	William J. Clinton Foundation	Developing countries; subnational / national	▪ Coordinates work with partner countries to create a measurement framework, develop and apply measurement tools and implement large-scale demonstration projects to establish certainty in forest carbon emissions, resulting in information that is essential for developing countries to achieve compliance with international treaties and to catalyze a market for reforestation and avoided deforestation
International Center for Tropical Agriculture (CIAT)	CGIAR Institution	Amazon communities; subnational	▪ As part of the Amazon Initiative, the Eco-Regional Research Program will work on options and support tools for farmers and communities to mitigate and adapt to climate change and to enhance their provision of environmental services, specifically the co-development and dissemination of recommendations for cost-effective and equitable REDD strategies in at least four Amazon countries, and development of a framework including principles, criteria, indicators, and verifiers for baseline

Initiative / Organization	Administrators	Geographic location and scale	Details
			measurements and monitoring of carbon stocks
International Development Research Centre (IDRC), Canada	Canadian Crown corporation	Developing countries; subnational / national	▪ Fund projects that include the development, testing and adaptation of user-driven environmental monitoring tools and systems, for shared and better understanding of ecosystem dynamics (Under the Rural Poverty and Environment program)
International Geosphere-Biosphere Programme (IGBP)	Founded by the International Council for Science; funded by contributions from ~40 countries	Global; international	▪ Participates in the Integrated Global Observation Strategy Partnership (IGOS-P) which facilitates the coordination of multiple databases around major Earth System Themes; IGBP has led the development of the carbon cycle observation theme ▪ Participates in the Group on Earth Observations (GEO) by contributing data and information
International Institute for Applied Systems Analysis (IIASA)	Sponsored by National Member Organizations in Africa, Asia, Europe and North America	Global; regional / international	▪ Develop tools and methodologies for assessing carbon storage and land use change in forests [especially the Global Forest Model (G4M) and the Global Biomass Optimization Model (GLOBIOM)]
International Institute for Geo-Information Science and Earth Observation (ITC)	University of Twente	Global; subnational / national	▪ Specific measurement and methods research areas under the Carbon Cycle and Climate Change (C-CYCLE) project include sensor suitability with respect to forest type, forest degradation status, sensitivity to tree species and physiognomy, geographic location and climatic zone, the issues of biomass saturation and cloud cover, appropriate vegetation indices, cost-effective sampling designs, development of allometric equations for standing biomass, biomass growth modeling, as well as error propagation and uncertainty at single scale and across scales (both up-scaling and down-scaling) in GIS modeling
Kenya Agricultural Research Institute (KARI)	--	Kenya; subnational / national	▪ In the future, the Land and Water Management programme will further develop user-friendly products via its land resource survey (commonly known as KSS) for better land utilization on a commercial basis for government and the private sector; KSS will continue to generate biophysical land resources information for multipurpose land use planning and will conduct soil, vegetation and land use surveys at various scales according to demand
Land Use & Carbon Analysis System	Ministry for the Environment, New	New Zealand; national	▪ Developed as a national-scale measuring, monitoring, reporting and accounting system to help New Zealand meet its

Initiative / Organization	Administrators	Geographic location and scale	Details
(LUCAS)	Zealand Government		international reporting requirements under the Kyoto Protocol and UNFCCC; tracks and quantifies land use changes since 1990
Natural Resource Ecology Laboratory (NREL)	Colorado State University (US)	US; national	▪ The Integrated Research Challenges project goal is to develop, implement, and utilize a new modeling framework to analyze processes controlling net carbon exchange in terrestrial ecosystems, based upon recent advances of ecosystem models, process studies, and analytical technologies
Nicholas Institute (NI)	Duke University	US; subnational	▪ Created a technical guide (2007) for US farmers, foresters, landowners and investors on the creation, measurement, and verification of GHG offsets
The Ecosystems Center at Marine Biological Laboratory	Woods Hole Oceanographic Institute	Global; regional / international	▪ The Terrestrial Ecosystem model describes carbon and nitrogen dynamics of plants and soils for terrestrial ecosystems of the globe; uses spatially referenced information on climate, elevation, soils, vegetation and water availability as well as soil- and vegetation-specific parameters to make monthly estimates of carbon and nitrogen fluxes and pool sizes of terrestrial ecosystems
The Nature Conservancy (TNC)	--	Belize, Bolivia, Brazil, China, Indonesia, US; subnational	▪ Have developed scientifically proven methods to measure and monitor the carbon dioxide forests store; manage more than a dozen forest carbon projects globally (Climate Change Program)
US Forest Service (USFS), Research and Development	United States Department of Agriculture	US; subnational to national	▪ Creates measurement tools and methods to provide carbon storage estimates for US forests based on data collected from nation-wide forest surveys
Woods Hole Research Center (WHRC)	--	Global; international	▪ Compiles primary data on global changes in land use, which allow appraisals of the trends in forests that influence their role in climate and the global carbon budget

[i] CBP Consortium made up of Colorado State University (CSU), University of Leicester, World Soil Information (ISRIC), Centro de Energia Nuclear na Agricultura (Brazil), GEF, Overseas Development Group – University of East Anglia (ODG-UEA), World Wide Fund for Nature (WWF), World Agroforestry Centre (ICRAF), Michigan State University (MSU), Centre for International Forestry Research (CIFOR)

[ii] UN Development Programme (UNDP), UNEP, World Bank, UN Food and Agriculture Organization (FAO), UN Industrial Development Organization (UNIDO), African Development Bank (AfDB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), Inter-American Development Bank (IDB), International Fund for Agricultural Development (IFAD)

APPENDIX 6: Organizations working on components of a tiered global information system

Initiative / Organization	Administrators	Geographic location and scale	Details
Applied Ecological Services	AES	US; subnational to national	▪ Seeking to assemble standard accrual time series relationships and data in a public password-protected data set that can be used to develop national, regional, state-wide, and ecosystem specific refined projections on the soil carbon and vegetation sequestration data and rates under various land management practices ▪ Organizers include C-AGR, NAS, USDA, USGS, USDOI, The Earth Partners, The Rodale Institute, Sustainable Food Laboratory
CarboInvent Project	Joanneum Resarch (coordinator)	Europe; subnational to regional	▪ Through the CarboInvent Project, multi-source inventory methods will be integrated in test sites toward stock-change estimates at national and project levels, based on the definitions and accounting rules of the Kyoto Protocol ▪ 14 partners from Austria, Belgium, Czech Republic, Finland, Germany, Hungary, Italy, Ireland, Spain, Sweden
Carbon Benefits Project (CBP)	Implemented by the United Nations Environment Fund (UNEP) and a Consortium of partner organizations[i] Funded by Global Environment Facility (GEF) and others[ii]	Global; subnational	▪ The CBP system will help project managers quantify carbon as a global environmental benefit and should enable developing countries to engage in emerging carbon-offset markets; system will be applicable across the full portfolio of land use projects implemented by the 10 Global Environmental Fund Agencies and will thus provide a way to compare and document project performance in contributing to climate change
Center for International Forestry Research (CIFOR)	CGIAR institution	First year, projects in: Bolivia, Brazil, Cameroon, Tanzania, Indonesia and Vietnam; subnational / national	▪ Establishing a four-year global comparative research project on first-generation REDD demonstration activities and national strategies in selected countries across Asia, Africa and Latin America to conduct an independent review of early REDD experience and lessons learned; knowledge from the project will help existing REDD initiatives to improve and adapt their management, and will inform the next generation of REDD projects, post-2012
Consortium for Agricultural Soil	Consortium of nine US research	United States; subnational / national	▪ Investigate the potential of agricultural soils to mitigate GHGs, by predicting and assessing carbon sequestration and GHG emissions,

Initiative / Organization	Administrators	Geographic location and scale	Details
Mitigation of Greenhouse Gases (CASMGS)	institutions and one government laboratory[iii]		providing field and farm-level decision support tools and evaluating alternative national economic and policy strategies using integrated models, and by providing measurement and monitoring tools for quantifying and verifying soil carbon sequestration rates and GHG emissions and emission reductions. ▪ Participate in the transfer to and adoption of technology by other countries for quantifying and verifying carbon sequestration rates
Earth System Science Partnership (ESSP)	DIVERSITAS, IGBP, IHDP, WCRP	Global; regional	▪ The REgional Carbon Cycle Assessment and Processes (RECCAP) is assessing the carbon balance of large regions of the globe at the scale of continents and large ocean basins, including their component fluxes, using a combination of bottom-up data and models from regional carbon cycle programs and global analyses ▪ Partnership among DIVERSITAS, International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP), and World Climate Research Programme (WCRP)
Food and Agriculture Organization (FAO), Forest Department	United Nations	Global; subnational to international	▪ In cooperation with IUCN and UNEP, organized regional workshops in Latin America and the Caribbean, Africa and Asia to improve the capacity of its developing-country members to participate in negotiations on the CDM ▪ FAO's recently initiated programme of support to national forest assessments will also help improve information on national forest inventories for developing countries in particular; in addition, a global data bank on biomass expansion factors is being assembled ▪ Contributed its experience in harmonizing diverging country information to the EC's effort to harmonize its members' reporting obligations under UNFCCC ▪ Working with partners on a Special Study on Forest Degradation aimed at enhancing capacities to assess and monitor different aspects of forest degradation; includes an analysis of existing forest degradation definitions, case studies to highlight proven and potential assessment methodologies and tools to monitor forest degradation in terms of changes in forest carbon stocks and sequestration rates in "forests remaining forests"
FAO Natural Resource	United Nations	Global; international	▪ Under the Natural Resources programme, their Geo-Information field

Initiative / Organization	Administrators	Geographic location and scale	Details
and Environment Department			houses a variety of global data sources for terrestrial carbon from FAO and its partners ▪ See also the Global Terrestrial Observing System
Forest Monitoring Agreement between FAO and INPE	Food and Agriculture Organization (FAO) and Brazil's National Institute for Space Research (INPE)	Global (developing countries)	▪ Make deforestation and forest degradation data available to developing countries, to advance national forest monitoring for the purposes of joining a REDD mechanism
Earth System Science Partnership (ESSP)	DIVERSITAS, IGBP, IHDP, WCRP	Global; subnational to international	▪ Develop and assess systems for GHG monitoring and accounting at the farm and landscape levels in the Indo-Gangetic Plains, and Western and Eastern Africa (CGIAR Challenge Program on Climate Change, Agriculture, and Food Security) ▪ Quantify and diagnose uncertainty in inversion calculations of the global carbon budget (Global Carbon Project, GCP) ▪ Integrate multiple observations (in situ and remotely sensed) to constrain regional carbon budget models (GCP) ▪ Partnership among DIVERSITAS, International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP), and World Climate Research Programme (WCRP)
Global Climate Observing System (GCOS)	WMO,IOC-UNESCO, UNEP, ICSU	Global; subnational to international	▪ Maintain an operational system that provides continuous data on the state and behavior of the global climate system including its physical, chemical, and biological properties ▪ Built on the WMO Integrated Global Observing System (WIGOS), Global Ocean Observing System (GOOS), Global Terrestrial Observing System (GTOS), others ▪ Co-sponsors: World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), UNEP, International Council for Science (ICSU)
Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD)	FAO; A panel of the Global Terrestrial Observing System (GTOS)	Global; regional / international	▪ A coordinated international effort working to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for sustainable management of terrestrial resources and to improve understanding of the terrestrial carbon budget ▪ Provide regional and global datasets on forest types, changes in forest cover, and biological functioning of forests (to help quantify

Initiative / Organization	Administrators	Geographic location and scale	Details
			the contribution that forests make as absorbers and emitters of GHGs), as part of GTOS ▪ Promote globally consistent data processing and interpretation methods, and of international networks for data access, data sharing, and international collaboration ▪ Provide a forum for users of satellite data on terrestrial carbon to discuss their needs and for producers to respond through improvements to their programs
Global Terrestrial Observing System (GTOS)	FAO, UNEP, IOC-UNESCO, WMO, ICSU (co-sponsors)	Global; regional / international	▪ Contributes to Global Earth Observation System of Systems (GEOSS), Integrated Global Observing Strategy (IGOS) ▪ Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS) are "sister" organizations ▪ See GOFC-GOLD, TCO
Global Forest Resources Assessments (FRA)	Food and Agriculture Organization (FAO)	Global (229 countries surveyed in 2005); national	▪ Compile and analyze status and trends of carbon stocks in the world's forests
GlobalSoilMap.net	World Data Centre for Soils (ISRIC) (global coordinator)	Global; subnational to international	▪ A global consortium of numerous partners worldwide is creating a new digital soil map of the world
Group on Earth Observations, Global Earth Observing System of Systems (GEO-GEOSS)	Voluntary partnership of governments and international organizations	Global; subnational to international	▪ Develop a global carbon observing system and advocate development of new sensors and platforms, and facilitate their use for routine field observations ▪ Facilitate validation of existing tools for measurement of ecosystem properties and the harmonization of a global carbon observing system, in accordance with the specifications detailed in the IGOS-P IGCO Theme Report ▪ Facilitate the networking of institutions making observations relating to ecosystems and the coordination and expansion of a network of land, ocean and coastal references stations for monitoring ecosystem properties such as carbon
International Food Policy Research Institute (IFPRI)	CGIAR institution	Developing countries; subnational to international	▪ The 2020 Vision Initiative generates information resources (brochure, web) on topics related to food, agriculture and the environment, including issues related to multi-scale (both geographic and time) measurement of carbon in agricultural systems; and provides fora for multi-stakeholder dialogue through seminars, workshops and

Initiative / Organization	Administrators	Geographic location and scale	Details
			conferences
International Geosphere-Biosphere Programme (IGBP)	Founded by the International Council for Science; funded by contributions from ~40 countries	Global; international	▪ Develop recommendations for climate research and observation frameworks ▪ Participate in coordination of earth system databases, including carbon cycle theme
International Institute for Applied Systems Analysis (IIASA)	IIASA	Global; regional to international	▪ Developed a comprehensive Harmonized World Soil Database integrating a variety of databases including data from the European Soil Bureau Network and the Chinese Academy of Sciences (Land Use Change and Agriculture Program of IIASA with FAO) ▪ An international research organization sponsored by its National Member Organizations in Africa, Asia, Europe and North America
International Institute for Geo-Information Science & Earth Observation, Geospatial Data for Space and Resource Management (ITC)	University of Twente	Global; subnational to international	▪ The Carbon Cycle and Climate Change (C-CYCLE) project aims to accurately quantify the various components of the carbon cycle in forests by identification and quantification of land-based sources and sinks (with a high need for 'ground truthing' the climate scenarios and macro data), tracking progress towards emission targets, and assessment of the relationships between biomass sequestration and SFM / forest degradation
International Union for the Conservation of Nature, World Initiative for Sustainable Pastoralism (IUCN-WISP)	--	Global; international	▪ WISP advocates and encourages capacity building in support of pastoral sustainable land management, by maintaining an international network of pastoralists, donors, UN agencies, NGOs and the private sector and enabling them to get in touch and create partnerships, on topics such as sustainable range management; with its partners, have produced a number of publications that provide perspectives on conservation and sustainable development including dryland carbon management and potential for carbon market participation
Joint Research Centre, Institute for Environment and Sustainability (JRC-IES)	European Commission	Global; subnational to regional	▪ Improve the intercomparability of measuring and reporting of CO_2 sinks and emissions of CH_4 and N_2O, through activities with Member States and Candidate Countries as part of the EU Greenhouse Gas Inventory System (Greenhouse Gases in Agriculture, Forestry and Other Land Uses action area) ▪ Create EU-wide data sets and model-based techniques relevant for monitoring carbon stocks and GHG fluxes and apply them to verify

Initiative / Organization	Administrators	Geographic location and scale	Details
			and improve official Member State submissions; develop schemes for monitoring CO_2 sinks and the effects of climate change (Greenhouse Gases in Agriculture, Forestry and Other Land Uses action area) ▪ Establish the European Soil Data Centre as a single focal point for all soil data and information in Europe (Soil Data and Information Systems action area) ▪ Create EU-wide data sets for carbon stocks and GHG fluxes (GHG-AFOLU Research Action) ▪ As part of TREES-3, mapped forest characteristics (forest cover, biomass indicators) in the Tropics and Boreal Eurasia from 2006-2007 using radar satellite data, ~100m resolution (Global Forest Resource Monitoring Resarch Action)
Kenya Agricultural Research Institute (KARI)	--	Kenya; subnational / national	▪ Foster networking between centres dealing with soil and water management research, created within KARI and collaboration with IARCs, extension services, NGOs and regional networks dealing with natural resource management (Land and Water Management Programme)
Natural Resources Conservation Service (NRCS)	US Department of Agriculture	US; subnational to national	▪ The National Resources Inventory captures data on land cover and use, soil erosion, prime farmland soils, wetlands, habitat diversity, selected conservation practices, and related resource attributes for 800,000 non-Federal land sample sites across the US ▪ The Voluntary Reporting of Greenhouse Gases-CarbOn Management Evaluation Tool (COMET-VR) provides an interface to a database containing land use data from the Carbon Sequestration Rural Appraisal (CSRA) and calculates in real time the annual carbon flux using a dynamic Century model simulation
Terrestrial Carbon Observation Panel (TCO)	FAO, A panel of GTOS	Global; regional	▪ Provide information on the spatial and temporal distribution of terrestrial carbon sources and sinks, with a particular mission to focus on: the production of an operational database system; validated and parameterized models; manuals, standard methodologies and related documentation; productivity estimates; and the creation of a common forum for scientists and stakeholders – as part of GTOS ▪ Aims to launch a global database for information on terrestrial carbon, which will bridge the gap between data-oriented models and process-oriented models, and will test the methodological

Initiative / Organization	Administrators	Geographic location and scale	Details
			approach of carbon accounting at various scales (with a specific emphasis on the regional scale)
Tropical Agricultural Research and Higher Education Center (CATIE)	Developed under agreement between the Inter-American Institute for Cooperation on Agriculture (IIA), Costa Rican government	Global; national to international	▪ Developing methodologies and assessing GHG emission projects related to REDD; generates and applies tools and databases and facilitates international dialogue on policies and positive incentives to facilitate implementation of forestry projects and programs that prevent deforestation and forest degradation in Latin America ▪ Promote development and dissemination of information among national forestry institutes in Ibero-America about methodologies and case studies related to forest management to mitigate climate change, with emphasis on tools and databases related to estimating GHG effects in forestry projects in developing countries ▪ Generate and apply tools and databases and facilitate international dialogue on policies and positive incentives for forestry projects and programs that prevent deforestation and forest degradation in the Latin American region ▪ Develop criteria and indicators for adaptive forest management (Tropical Forests and Climate Change Adaptation, TROFCCA) ▪ Work in Panama, Costa Rica, Nicaragua, Honduras, Guatemala, El Salvador, various countries in S. America, Spain; Indonesia, Philippines, Burkina Faso, Ghana, Mali, Costa Rica, Honduras, Nicaragua
United Nations Convention to Combat Desertification (UNCCD)	United Nations	Developing countries; national	▪ A Consortium of technical expert organizations[iv] helped to organize the First Scientific Conference of the UNCCD Committee on Science and Technology in 2009, which has prioritized bio-physical monitoring and assessment of desertification and land degradation, and has proposed a new mechanism to draw on existing networks of experts to channel scientific and technical information to member countries
United Nations Development Programme (UNDP), Environment Program Team	United Nations	Developing countries; subnational	▪ Through its sub-national initiatives, supports the efforts of developing countries and vulnerable groups for scaling up mitigation and adaptation action to successfully meet the climate change challenge and achieve the Millennium Development Goals, by providing services such as promoting tighter linkages from assessment, upstream policy and institutional change activities to investment and financing of solutions; complementing existing policy change and

Initiative / Organization	Administrators	Geographic location and scale	Details
			capacity development efforts at the national level by facilitating action at the sub-national levels; diversifying the funding sources that countries can access and enable them to effectively combine and sequence these different sources
United Nations Framework Convention on Climate Change (UNFCCC)	United Nations	Developing countries; international	▪ Facilitates access by developing countries to information made available by Parties, relevant organizations and stakeholders in a number of areas related to REDD in developing countries via the REDD Web Platform (http://unfccc.int/methods_science/redd/items/4531.php/); includes technical assistance, demonstration activities, country-specific information, and methodologies and tools
United States Department of the Interior (DOI)	--	US; subnational / national	▪ A new Climate Change Response Council will coordinate Interior's response to the impacts of climate change within and among its bureaus, and will improve the sharing and communication of climate-change impact science; eight (US) regional Climate Change Response Centers will synthesize existing climate change impact data and management strategies, help resource managers put them into action on the ground, and engage the public
Woods Hole Research Center (WHRC)	--	Developing countries; subnational to regional	▪ The Forum on Readiness for REDD, for which WHRC serves as Forum Secretariat, is a multi-stakeholder initiative focused on practical approaches for building REDD readiness through cross-stakeholder dialogue, South-South collaboration, and linking local expertise with regional readiness efforts
World Bank Agriculture and Rural Development Department (ARD)	--	Developing countries; subnational to national	▪ The Sustainable Land Management Sourcebook (2008) is intended to be a reference for practitioners (including World Bank stakeholders, clients in borrowing countries, and World Bank project leaders) seeking state-of-the-art information about good land management approaches, innovations for investments, and close monitoring for potential scaling up
World Conservation Monitoring Centre (WCMC)	United Nations Environment Programme	Global; subnational to international	▪ The Forest Restoration Information Service (FRIS) aims to provide an open-access internet information service to support forest restoration projects world-wide, facilitate exchange of knowledge and experience among forest restoration projects, and facilitate the prioritization, design and execution of forest restoration efforts by FRIS users; it includes a variety of resources such as definitions of key

Initiative / Organization	Administrators	Geographic location and scale	Details
			terms and concepts in forest restoration, introduction to key approaches and tools, case studies and database of projects, maps and datasets
World Data Centre for Soils (ISRIC)	Coordinated by ISRIC; partnership of 12 research organizations[v]	Global; regional / international	▪ The World Soil Information Database provides maps of carbon storage in developing countries (mainly small-scale, 1:250.000 or smaller) ▪ Th e-SOTER project is a European contribution for a global soil observing system as part of GEOSS; will improve continental scale information and develop advanced methodologies at a regional scale, end product will be a layer of soil information with standardized soil attributes for the 1:1 million and the 1:250,000 scale
World Meteorological Organization (WMO), World Climate Programme	Specialized agency of the United Nations; membership of 189 member states and territories	Global; subnational to international	▪ Facilitates the establishment of global networks of meterological, climatological, hydrological and geophysical observations ▪ Development and incorporation of science-based climate information and prediction into planning, policy and practice at local to global scales to enable better management of climate change risks and adaptation (Global Framework for Climate Services)

[i] CBP Consortium made up of Colorado State University (CSU), University of Leicester, World Soil Information (ISRIC), Centro de Energia Nuclear na Agricultura (Brazil), GEF, Overseas Development Group – University of East Anglia (ODG-UEA), World Wide Fund for Nature (WWF), World Agroforestry Centre (ICRAF), Michigan State University (MSU), Centre for International Forestry Research (CIFOR)

[ii] UN Development Programme (UNDP), UNEP, World Bank, UN Food and Agriculture Organization (FAO), UN Industrial Development Organization (UNIDO), African Development Bank (AfDB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), Inter-American Development Bank (IDB), International Fund for Agricultural Development (IFAD)

[iii] Colorado State, Iowa State, Kansas State, Michigan State, Montana State, Nebraska, Ohio State, Purdue, Texas A&M,; Batelle-Pacific Northwest National Laboratory

[iv] The 1st Scientific Conference was organized with the support of the Dryland Science for Development Consortium (DSD). DSD Consortium members are DesertNet International, the International Centre for Agricultural Research in the Dry Areas (ICARDA), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Joint Research Centre's Institute for Environment and Sustainability of the European Commission (JRC-IES) and the United Nations University's International Network on Water, Environment and Health (UNU-INWEH)

[v] University of Miskolc, Federal Institute for Geosciences and Natural Resources (BGR), European Commission Joint Research Center, Institute for Environment and Sustainability (JRC-IES), Cranfield University, Alterra / Wageningen UR, Szent Istvan University, Scientific Landscapes, Science du Sol - Institut National de la Recherche Agronomique, University of Nottingham Centre for Geospatial Science, Czech University of Life Sciences, Institute of Soil Science - Chinese Academy of Sciences, - Institut National de la Recherche Agronomique du Maroc, Wageningen University - Laboratory for Geo-information Science and Remote Sensing

APPENDIX 7: Organizations working on pathways to establishing national accounting systems that reflect country circumstances

Initiative / Organization	Administrators	Geographic location and scale	Details
Bogor Agricultural Institute (IPB) (Rizaldi Boer)	--	Indonesia; national	▪ Developed proposal on defining Indonesian National reference emission levels (REL) ▪ In partnership with CIFOR, strengthening REDD implementation by researching cost-efficient methods for REDD baselines and for monitoring changes in forest carbon stocks, while developing international strategies which take into account barriers to adopting REDD schemes
CarboAfrica project	Funded by European Commission – Directorate-General for the Environment (EU)	Africa; subnational to regional	▪ Builds on existing carbon observing systems and establishes new infrastructure to improve the understanding of GHG emissions in Sub-Saharan Africa and its associated spatial and temporal variability; project carried out in Benin, Botswana, Burkina Faso, Congo, Gabon, Ghana, Mali, Niger, South Africa, Sudan and Zambia
Carbon Benefits Project (CBP)	Implemented by the United Nations Environment Fund (UNEP) and a Consortium of partner organizations[i] Funded by Global Environment Facility (GEF) and others[ii]	Global; subnational / national	▪ Develop a system to enable developing countries to engage in emerging carbon markets by creating tools to estimate and model carbon stocks and flows and GHG emissions under present and alternative management, measuring and monitoring carbon changes under specified land use management, and developing a standard protocol applicable to all natural resources management projects (forestry, agro-forestry, agriculture, pasture management) in all climatic zones, soil types and land uses
Center for Clean Air Policy (CCAP)	--	Brazil, Mexico, Cambodia and Indonesia; national	▪ CCAP is conducting an analysis of forest sector mitigation opportunities to identify alternative land use options, estimate their relative cost-effectiveness and emissions reduction potential, and propose policies for implementation under national REDD programs in the post-2012 period. ▪ Assist governments with designing and implementing policies that will provide the foundation for successful REDD programs, eg, analyze forest sector mitigation opportunities and strategies (such as PES and agricultural intensification); identify needs for applying

Initiative / Organization	Administrators	Geographic location and scale	Details
			REDD strategies; prepare cost analyses
Center for International Forestry Research (CIFOR)	CGIAR institution	Developing countries; national	▪ Several projects dedicated to supporting design and implementation of REDD in Indonesia by researching cost-efficient methods for REDD baselines and for monitoring changes in forest carbon stocks, while developing international strategies which take into account barriers to adopting REDD schemes
Conservation International (CI)	--	Developing countries; subnational / national	▪ Supported Guyana the Guyana Forestry Commission to evaluate the amount of carbon stored by Guyana's forests, and to sell carbon credits to other countries ▪ Created an extensive REDD training and education program, developed tools of engagement and benefit sharing, worked with partners in developing decision-making tools for policy development and economic planning, and set up pilot forest carbon projects around the world
EcoAgriculture Partners	--	Developing countries; subnational	▪ The Landscape Measures Resource Center provides a compilation of guides and supporting information regarding the measurement of carbon sequestration at a landscape scale
Food and Agriculture Organization – Natural Resources and Environment Department	--	Global; subnational to regional	▪ Assist member countries in their responses towards climate change, including coordination of the UN-REDD programme, and development of a repository for general storage and dissemination of geoinformation (Environment, Climate Change and Bioenergy Division) ▪ Provides assistance to member nations in developing policies, programmes, best practices and tools, such as promoting the development of cost-effective methods for land and soil survey and classification, providing information and technical guidance, and maintenance of a database and web-based information system on land resources and land use at national and regional levels (Land and Water Division)
Forest Carbon Partnership Facility (FCPF)	World Bank	Developing countries; national	▪ Assist countries with activities such as arriving at a credible estimate of their national forest carbon stocks and sources of forest emissions, working out their national reference scenarios for emissions from deforestation and forest degradation, and designing national monitoring, reporting and verification systems for REDD

Initiative / Organization	Administrators	Geographic location and scale	Details
			▪ Garners a body of knowledge and experiences that can facilitate development of a much larger global program of incentives for REDD over the medium term
International Institute for Environment and Development (IIED)	IIED	Developing countries; subnational / national	▪ Through the South-South REDD project, a national strategy for REDD in Mozambique will be developed based on lessons learned through Brazil's Bolsa Floresta programme and will be accomplished with the support of an MOU between the two countries; will include identification of baseline and MRV options ▪ Funded by the Norwegian Embassy, Maputo ▪ Partnership between IIED, Mozambique Ministry of the Environment (MICOA), Mozambique Ministry of Agriculture (MINAG), Centro Terra Viva (CTV), Universidade Eduardo Mondlane (UEM), The Sustainable Amazon Foundation (FAS), Indufor
Joint Research Centre, Institute for Environment and Sustainability (JRC-IES)	European Commission	Global; regional / international	▪ Provides training to experts from the new and candidate EU countries on monitoring and reporting of carbon stocks and GHG emissions and sinks (Climate Change Unit, GHG-AFOLU Action)
New Partnership for Africa's Development, Comprehensive Africa Agriculture Development Program (NEPAD-CAADP)	CAADP is the agricultural programme of NEPAD, which is a programme of the African Union	Africa; national	▪ The TerrAfrica project's work in the promotion and support of Sustainable Land Management (SLM) throughout Africa has laid the groundwork for recent new initiatives related to carbon market development and participation
Nicholas Institute (NI)	Duke University	Global; international	▪ In a 2007 working paper, reviewed existing data and methods to measure global historical deforestation and degradation baselines, including FAO national statistics and various remote-sensing sources, to aid in the creation of a credible benchmark against which future emissions reductions could be measured
Prince's Rainforest Project (PRP)	Part of the Prince's Charities Foundation	Global; subnational to international	▪ In partnership with the Government of Norway, commissioned the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) to carry out a study to specify and scope, for 99 tropical non-Annex I countries, the near-term capacity-development activities that would be required to implement an accurate forest area change and carbon stock monitoring system

Initiative / Organization	Administrators	Geographic location and scale	Details
United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD)	Partnership of FAO, UNDP, UNEP	Developing countries; national / international	▪ Partners support in-country processes for REDD readiness and contribute to the development of national REDD strategies by providing technical advice on ways to address deforestation and forest degradation, methods and tools for measuring and monitoring GHG emissions and forest carbon flows, by promoting REDD financing, facilitating consultations among stakeholders, and helping to establish linkages with existing national programs ▪ At the country level, FAO assumes primary responsibility for REDD readiness for monitoring and assessment, and REDD data management; UNDP assumes responsibility for REDD payment structuring and distribution (and all three agencies assume responsibility for scoping and alliance building)
United Nations Development Programme (UNDP), Environment Program Team	United Nations	Global; international	▪ Generate publications to reinforce capacity building efforts in Eastern & Southern Africa, on topics such as forest carbon accounting principles and bio-carbon finance opportunities
United Nations Framework Convention on Climate Change (UNFCCC)	United Nations	Global; international	▪ Provides an assessment of steps and requirements needed to develop and implement a national monitoring system for estimating emissions from deforestation and forest degradation, assessing carbon stocks and GHG emissions from changes in forest cover, and assessing the enhancement of forest carbon stocks
Woods Hole Research Center (WHRC)	--	Africa; subnational to international	▪ In 2008, the WHRC's Africa program team conducted a workshop in Uganda designed to bring together practitioners in forest biometrics to share information on tools, techniques, and protocols to improve forest inventory designs for the purpose of more readily enabling the integration of forest field measurements and remotely sensed data; standardized protocols that ensure consistency in measurement acquisition and statistical soundness in sampling design were discussed to produce protected-area as well as national-level, continental, and pan-tropical maps of biomass/carbon stocks
The World Agroforestry Centre (ICRAF)	Member of the Consultative Group on International	Developing countries; subnational / national / international	▪ Through the ALLREDDI[iii] project, assist Indonesia in the development of national carbon accounting systems that comply with Tier 3 of the IPCC guidelines for AFOLU, strengthen national

Initiative / Organization	Administrators	Geographic location and scale	Details
	Agricultural Research (CGIAR)		and subnational capacity in carbon accounting and monitoring, and design operational REDD mechanisms in five pilot areas
World Conservation Monitoring Centre (WCMC)	Collaboration between the United Nations Environment Programme (UNEP) and WCMC 2000	Global; international	▪ UNEP WCMC is supporting the Environmental Management Group to coordinate a UN-wide response report on drylands (including sustainable land management and climate change issues) to be released in 2010; report will guide action of all UN agencies and act as an investment guide
World Resources Institute (WRI)	--	Global; international	▪ Provides assessments and reviews of issues such as major research and innovations in climate change science and technology, and globally-relevant lessons learned from developed countries' experiences related to implementation of the land use, land use change and forestry (LULUCF) provisions of the Kyoto protocol

[i] CBP Consortium made up of Colorado State University (CSU), University of Leicester, World Soil Information (ISRIC), Centro de Energia Nuclear na Agricultura (Brazil), GEF, Overseas Development Group – University of East Anglia (ODG-UEA), World Wide Fund for Nature (WWF), World Agroforestry Centre (ICRAF), Michigan State University (MSU), Centre for International Forestry Research (CIFOR)

[ii] UN Development Programme (UNDP), UNEP, World Bank, UN Food and Agriculture Organization (FAO), UN Industrial Development Organization (UNIDO), African Development Bank (AfDB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), Inter-American Development Bank (IDB), International Fund for Agricultural Development (IFAD)

[iii] Accountability and Local Level Initiative to Reduce Emission from Deforestation and Degradation in Indonesia

APPENDIX 8: IPCC Guidelines related to terrestrial carbon

This table illustrates the evolution of IPCC guidance, from the initial 1996 guidance on national GHG inventories to the most recent 2006 guidance which consolidates agriculture and LULUCF into AFOLU.

Category	Title	Chapters^	Main points
National GHG Inventory	Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories	*Volume 1, Reporting Instructions*: (1) Understanding the Common Reporting Framework (2) Reporting the National Inventory *Volume 2, Workbook*: (1) Energy (2) Industrial Processes (3) Solvent and Other Product Use (4) Agriculture (5) Land Use Change & Forestry (6) Waste *Volume 3, Reference Manual*: (1) Energy (2) Industrial Processes (3) Solvent and Other Product Use (4) Agriculture (5) Land Use Change & Forestry (6) Waste	• First guidelines on how to plan, carry out and report results of a national inventory using the IPCC system to develop reports that can be comparable and compatible • Stipulates 3-year averages for agriculture and LULUCF • Recommends estimation of emissions from agriculture and LULUCF for two periods: (a) 0-20 years ago (b) 20-100 years ago • Provides initial default values • www.ipcc-nggip.iges.or.jp/public/gl/invs4.html
National GHG Inventory	Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000) *Referred to as GPG2000*	(2) Energy, (3) Industrial Processes (4) Agriculture, (5) Waste (6) Quantifying Uncertainties in Practice (7) Methodological Choice and Recalculation (8) Quality Assurance and Quality Control (QA and QC) *Annexes*: (1) Conceptual Basis for Uncertainty Analysis (2) Verification	• Introduces g*ood practice guidance*• as a way to manage uncertainties by assisting countries in producing inventories where uncertainties are reduced as far as practicable • Defines *good practice* by sector and source category • LULUCF excluded from this document because the LULUCF Special Report published concurrently • Pushes for the control and reporting of uncertainties in a systematic manner • www.ipcc-nggip.iges.or.jp/public/gp/english/index.html
Special Report	Land Use, Land Use Change and Forestry (2000) *Referred to as SR LULUCF*	(1) Global Perspective (2) Implications of Different Definitions and Generic Issues (3) Afforestation, Reforestation and Deforestation (ARD) Activities (4) Additional Human-Induced Activities-Article 3.4 (5) Project-Based Activities (6) Implications of the Kyoto Protocol for the Reporting Guidelines	• Introduces definitional issues relevant to LULUCF accounting and reporting by Annex I countries • Describes issues regarding processes, time scales and carbon accounting rules specific to ARD activities • Managed land is used as a proxy for identifying anthropogenic emissions by sources and removals by sinks (as adopted by GPG-LULUCF)
Methodology Report	Good Practice Guidance for Land	(2) Basis for Consistent Representation of Lands (3) LUCF Sector Good Practice	• Builds on GPG2000

Category	Title	Chapters^	Main points
	Use, Land Use Change and Forestry (2003) *Referred to as GPG-LULUCF*	Guidance (4) Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (5) Cross-cutting Issues	• Describes the concept of *good practice* when applied to LULUCF • Extends key source analysis to LULUCF categories • Inter linkages with GPG2000 in estimation of agricultural emissions, particularly N_2O from soils • Updated emission / removal factors and model parameters • Provides advice on different approaches for consistently representing land area and conversions depending on data available in terms of the 6 land categories: forest land, cropland, grassland, wetlands, settlements and other lands • Provides guidance on how to account for natural disturbances in managed forests • Guidance on HWP is included in an Appendix as it was not being considered by SBSTA for inclusion at the time, as was guidance for settlements and wetlands. • www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html
Methodology Report	Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of other Vegetation Types (2003)	(2) Definitions of Forest Degradation and Devegetation (3) Methodological Options for Estimating Emissions from Forest Degradation and Devegetation (4) Implications of Methodological Options to Accounting under Article 3.4 of the Kyoto Protocol	• Related to the possible election of accounting of this land use class by Annex I countries • Introduces the concept of *unbalanced*, *incomplete* and *asymmetric* accounting[+] • Definitions for direct human-induced degradation of forests and devegetation of other vegetation types • Methodological options to inventory emissions from degradation and devegetation activities • Approaches to reporting and documentation • Discussion of implications of methodological and definitional options for accounting under the provisions of Article 3.4 of the Kyoto Protocol (scale, costs and accuracy) • www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation_contents.html
National GHG Inventory	2006 IPCC Guidelines for National	(2) Generic Methodologies Applicable to Multiple Land-Use Categories (3) Consistent Representation of Lands (4) Forest Land (5)	• Consolidates approach for LULUCF (in GPG-LULUCF) with agriculture (GPG2000) into AFOLU to allow for better integration of land use data and more consistent use of

Category	Title	Chapters^	Main points
	Greenhouse Gas Inventories* *Volume 4*: AFOLU	Cropland (6) Grassland (7) Wetlands (8) Settlements (9) Other Land (10) Emissions from Livestock and Manure Management (11) N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application (12) Harvested Wood Products *Appendixes*: (1) CO_2 Removals in Residual Combustion Products (Charcoal): Basis for Future Methodological Development (2) Possible Approach for Estimating CO_2 Emissions from Lands Converted to Permanently Flooded Lands: Basis for Future Methodological Development (3) CH_4 Emissions from Flooded Land: Basis for Future Methodological Development	activity data, thereby reducing possibility of double counting or omission • Provides additional estimation methods and emission factors • Provides estimation advice for Tier 1 through to Tier 3 – ie, mathematical specification of methods, information on emission factors or other parameters to use in generating estimates, sources of activity data to estimate overall level of net emissions • Includes the concept of key categories • Provides advice on i) ensuring data collection is representative and consistency of time series ii) estimation of uncertainties at the category level and for the whole inventory iii) guidance on QA and QC procedures to provide cross-checks during inventory compilation v) information to be documented, archived and reported to facilitate review and assessment of inventory estimates Specific additions for AFOLU: • Consolidation of previously optional categories (eg, fires on managed lands removal previous optional distinction between wildfires and prescribed burning) • Detailed methods which can be used to include Harvested Wood Products (HWP) in inventories • Includes methods to estimate CO_2 emissions due to land use change from managed wetlands (although this is also the basis for future methodological development) • www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

**All National Greenhouse Gas Inventory guidelines must be accepted by the IPCC Plenary prior to formal adoption. Although adopted by many countries, the 2006 Guidelines have not, as yet, been formally accepted.*

^Excluding Executive Summaries, Foreword, Preface, Introductions, Conclusions, only includes relevant Appendixes and Annexes

•*Good practice – national inventories of anthropogenic GHG emissions and removals are those which contain neither over- nor under-estimates so far as can be judged, and in which uncertainties are reduced as far as practicable*

[+]*Unbalanced accounting occurs if all emissions and removals are not reported. This may be due to incomplete accounting, which occurs if the area (eg, of managed forest elected under Articles 3.3 and 3.4) is different from the area where relevant activities occur (eg, the full extent of managed forest), or asymmetric accounting (where some emissions and / or removals are not accounted within the area included); the former may have implications for area coverage whilst the latter does not.*

APPENDIX 9: Organizations working on harmonization of reporting guidance across scales and sectors

Initiative / Organization	Administrators	Geographic location and scale	Details
Blue Source Canada	Partnership between Blue Source LLC and Baseline Emissions Management, Inc.	North America; subnational	▪ Proposing a project to conduct a broad review of the state of science on quantification of GHG emissions and / or sequestration potential in the agricultural sector (eg, best practice guidance), as well as quantification tool and protocol development; results of the review would provide a road-map of current activities and where further activity should be concentrated ▪ Focused on companies and institutions interested in understanding best practices and protocols to mitigate and measure agricultural GHGs; also meant to provide focus to national and international level policymakers
California Climate Action Registry (CAR); The Climate Registry	Collaboration among North American states, provinces, territories and Native Sovereign Nations in Canada, the US and Mexico	North America; subnational	▪ Developed protocols to assist members and verifiers in the process of calculating, reporting and verifying a GHG emissions inventory. ▪ Reporting will transition to The Climate Registry in 2010 ▪ Focused on members, including industry (eg, building, food and beverage, manufacturing, retail, utilities); local, state and federal government; nonprofit organizations (eg, NRDC, WRI)
Carbon Finance Assist	World Bank	Developing countries; subnational / national	▪ Provides capacity building and technical assistance for CDM and JI projects as a complementary component of its carbon finance activities, including training activities for participants / members along with international experts to collaborate on strategies, discuss ideas and build upon best practices in carbon market development, and to eventually support client countries of the World Bank to fully participate in the flexible mechanisms defined under the Kyoto Protocol; implementation phase efforts focus on portfolio development and project implementation, and assisting countries with establishment of efficient designated authorities
Center for Clean Air Policy (CCAP)	--	Global; international	▪ Developed the “dual markets” approach to REDD, which advocates the development of a REDD market separate from the existing global carbon market, with eventual integration with the carbon market over time as questions of volatility are resolved; in the

Initiative / Organization	Administrators	Geographic location and scale	Details
			approach, proposes that Annex I countries specify at the outset which developing countries' credits they will eventually buy. ▪ Focused on (Annex I) national governments (dual markets approach) and on senior-level negotiators (REDD support framework)
Center for International Forestry Research (CIFOR)	Consultative Group on International Agricultural Research	During the first year the project is working in six countries: Bolivia, Brazil, Cameroon, Tanzania, Indonesia and Vietnam; subnational / national	▪ Establishing a four-year global comparative research project on first-generation REDD demonstration activities and national strategies in selected countries across Asia, Africa and Latin America to conduct an independent review of early REDD experience and lessons learned; knowledge from the project will help existing REDD initiatives to improve and adapt their management, and will inform the next generation of REDD projects, post-2012 ▪ Focused on negotiators, national-level REDD policymakers and subnational practitioners
Climate, Community and Biodiversity Alliance (CCBA)	Partnership ofresearch institutions, companies, and NGOs; made up of Members, Advising Institutions and CCB Standards Sponsors	Global; subnational	▪ A partnership of research institutions, corporations and non-governmental organizations (NGOs) that developed standards to evaluate land-based carbon mitigation projects in the early stages of development, and promotes their use ▪ Focused on subnational practitioners
Food and Agriculture Organization	United Nations	Global; international	▪ Interdepartmental Working Group on Climate Change develops integrative normative and methodological approaches in the context of climate change, and to open new channels of financing and other support measures for mitigation and adaptation ▪ Facilitate a systematic review of the existing evidence on methods to measure and assess terrestrial carbon stocks and carbon stock changes, across multiple land classes and scales ▪ EX-ante Appraisal Carbon-balance tool is a software programme developed to provide ex-ante measurements of the impact of agriculture and forestry development projects on GHG emissions and carbon sequestration, and thus its effects on the carbon balance; designed to help project designers select activities with higher economic and mitigation benefits and its output ▪ Compiled a Climate Change and Bioenergy Glossary with over 200 definitions

Initiative / Organization	Administrators	Geographic location and scale	Details
			▪ Focused on national REDD implementers and international negotiators (UNREDD), project designers and practitioners
Global Canopy Programme (GCP)	Collaboration with / funded by the United Nations Environment Programme (UNEP) and the Global Environment Facility (GEF)	Developing countries; subnational / regional / international	▪ Publishes The Little REDD Book, a guide to UN negotiations on REDD which helps forest stakeholders to understand and compare current and future proposals; reference levels, the reference period and scale against which the activities within scope are measured, are one aspect of the proposals that are evaluated ▪ Focused on international negotiators
Carbon Benefits Project (CBP)	Implemented by UNEP and consortium of organizations[i] Funded by Global Environment Facility (GEF) and others[ii]	Africa, Asia and South America; subnational	▪ Will develop a standard protocol for establishing the carbon benefits of sustainable land management interventions; the protocol will be applicable across land classes (agro-forestry, forestry, agriculture, and pasture), climatic zones, soil types and land uses
Global Mechanism	A subsidiary body of the UN Convention to Combat Desertification (UNCCD); originally housed by the International Fund for Agricultural Development	Global; regional	▪ Through the Climate Change Finance Programme, contributes to the convergence of the UNCCD and the UN Framework Convention for Climate Change policy dialogue, by developing conceptual arguments, particularly on issues related to the future of financial mechanisms for GHG mitigation, adaptation funding and carbon trading as yet to be defined ▪ Focused on international negotiators and country parties to the Convention
Intergovernmental Panel on Climate Change (IPCC)	Intergovernmental body established by UNEP and WMO; 194 member countries	Global; international	▪ Provide methodologies and guidance on preparation of national GHG emission inventories, including but not limited to managing uncertainties, definitional issues, accounting practices, land class categories and land use change, and estimation and emission factors; Annex I countries are audited against IPCC guidelines, Non-Annex I countries are not obligated to follow IPCC guidelines except regarding methodologies for project-based activities ▪ Focused on country-level preparers of inventories
International Federation of Agricultural Producers (IFAP)	--	Global; international	▪ Promote best farming practices resulting from scientific and technological progress, an outcome of dialogue generated by IFAP conferences and member activities ▪ Focused on farmer member organizations (eg, cooperatives, councils, unions)

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Land Degradation Assessment in Drylands (LADA)	United Nations Environment Programme (implementing agency), FAO (executing agency), GEF (funding agency), and partnerships	Argentina, China, Cuba, Senegal, South Africa and Tunisia; subnational to international	▪ A scientifically robust methodology to assess land degradation in dryland eco-zones is being finalized; LADA will provide harmonized tools and methods for land degradation assessment; conduct detailed national studies in six pilot countries; provide a framework methodology for establishing a baseline to monitor the success of actions to combat degradation; increase national capacities for assessment and monitoring; and disseminate and replicate LADA results worldwide through UNCCD, GM, GEF and countries ▪ Focused on national, regional, and international practitioners and policymakers; partnerships with international organizations, universities, research centers, and national institutions
Plan Vivo	--	Mexico, Mozambique and Uganda; subnational	▪ Registers and monitors carbon sequestration activities implemented by farmers ▪ Focused on small-scale project implementers (using local partners as project coordinators)
Program on Forests (PROFOR)	Housed at the World Bank, Environmentally and Socially Sustainable Development (ESSD) Forests Team	Developing countries; international	▪ Through a project aimed at developing carbon payment schemes on certified forest concessions, assessed challenges of integrating REDD and Sustainable Forest Management (SFM) certification into concession-based forest tenure system or at a forest management unit in general; and aimed to generate a broader discussion on the practical implementation options and benefits of integrating REDD MRV to the SFM management system ▪ Focused on providing funds to international organizations that support project development at subnational to national scales
Rainforest Alliance	--	Developing countries; subnational	▪ Trains local organizations on the development and design of effective forestry and agroforestry-based carbon sequestration projects; is an accredited verifier for standards of the Climate, Community and Biodiversity Alliance, Plan Vivo, Chicago Climate Exchange, and the Voluntary Carbon Standard ▪ Encourage governments to adopt climate policies that reward the reduction of GHG emissions through forest conservation and reforestation ▪ Focused on local project implementers and national policymakers
Restore America's Estuaries	--	US; national	▪ Convening a Blue Ribbon Panel on Coastal Wetlands and GHG Sequestration; mandates include the development of

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			recommendations for methodologies for measuring GHG emissions and sequestration in tidal wetland habitats, monitoring and verifying carbon sequestration and GHG flux in these habitats, and establishing eligibility and performance standards for wetland-based GHG offset projects
The Forests Dialogue	Ad hoc group, supported by Secretariat hosted by the Global Institute of Sustainable Forestry at Yale University	Developing countries; international	▪ Convened a dialogue to define the challenges and opportunities of the current financial mechanism options for REDD+, explore possible solutions, and provide recommendations to the international community to ensure the success of REDD+; is currently convening another dialogue around REDD Readiness at the country level ▪ Focused on providing information to international level implementers, policymakers and negotiators
The Nature Conservancy	--	Developing countries; subnational / international	▪ The Conservancy has contributed to the development of several forest project standards including those set by the Kyoto Protocol; the Climate, Community and Biodiversity (CCB) standards; the California Climate Action Registry (CCCR); and the Regional Greenhouse Gas Initiative (RGGI) ▪ Focused on international standards organizations
TerraCarbon	--	Global; subnational	▪ Have worked with buyers to successfully evaluate, design and develop forest and land-based carbon projects under a variety of standards; examples include: methodology development for REDD projects under the VCS; monitoring services for voluntary reforestation projects for a major forestry project developer in the US; methodology development to quantify the emission reductions related to the restoration of peatlands in SE Asia for an international NGO ▪ Focused on project implementers (eg, international developers, local project developers, regional NGOs)
Voluntary Carbon Standard (VCS)	--	Global; subnational to international	▪ Develops and implements global standards for approval of credible voluntary carbon offsets, provides tools and guidance for development of VCS-compliant AFOLU projects and methodologies; Focused on project implementers ▪ Provides guidance on land use and land management activities that are eligible for crediting under VCS AFOLU projects

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Wetlands International	--	Global; subnational to international	▪ Promotes an international peatland emissions reduction methodology being considered for adoption by the Voluntary Carbon Standard ▪ Focused on project implementers
Winrock, Ecosystem Services	--	Global; subnational to international	▪ Conducts large-scale environmental assessment at the regional, national, state or municipality scales of existing GHG emissions and removals (sequestration); creates tools to track GHG emissions and sequestration from properties and investments ▪ Develops new project sectors, and methodologies for accurately and precisely measuring and monitoring within new sectors; creation of new AFOLU methodologies for all regulatory and voluntary GHG markets, including CDM, VCS, ACR, and CCX ▪ Designs project elements including baseline establishment and leakage assessment, monitoring plan design and implementation ▪ The EPA Stratus REDD project includes the analysis of the data and methodological needs for reducing emissions from deforestation and degradation in developing countries ▪ Focused on project implementers (local to global; industry to government to nonprofit organizations)
World Bank – Agriculture and Rural Development	--	Developing countries; regional	▪ Developed reference sourcebook on state-of-the-art information about good agricultural land management approaches, innovations for investments, and close monitoring for potential scaling up. ▪ Through the Reduced Emissions and Enhanced Adaptation in Agricultural Landscapes (REAL) project, identifies key issues for the inclusion of agricultural systems in REDD ▪ Focused on project implementers, national / regional / international policymakers
World Bank - Carbon Finance Unit (CFU)	--	Global; subnational to international	▪ The CFU purchases project-based GHG emission reductions in developing countries and countries with economies in transition, within the framework of the Kyoto Protocol's Clean Development Mechanism (CDM) or Joint Implementation (JI) ▪ The CFU's Methodology systematically observes the CDM regulatory process and contributes to bottom-up rulemaking for CDM by interpreting regulatory decisions, providing input, and

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			developing new methodologies, thus bridging the gap between general guidelines and methodologies with their application to real-world projects; the CFU also prepares policy and position papers and takes an active role in initiating research and studies on methodological and policy issues related to CDM ▪ The **BioCarbon Fund** under the CFU provides carbon finance for projects that sequester or conserve GHGes in forests, agro- and other ecosystems; has been developing a project-based REDD methodology which will allow project developers to establish a project reference scenario and adopt monitoring measures for accurately assessing emissions reductions from reduced deforestation resulting from project activities; focused on project developers (local communities, individuals, and cooperating organizations such as natural resource management agencies, NGOs, academic institutions, and private industries)
World Conservation Monitoring Centre (WCMC)	United Nations Environment Programme	Global; subnational to international	▪ The Forest Restoration Information Service aims to provide an open-access internet information service to support forest restoration projects world-wide, and includes a variety of resources such as definitions of key terms and concepts in forest restoration, introduction to key approaches and tools, case studies and database of projects, maps and datasets ▪ Focused on project implementers
World Wildlife Fund (WWF)	--	Developing countries; subnational to national	▪ Through the Forest Carbon Initiative, will identify and support country-level implementation of REDD programmes through building capacity, testing approaches and implementing activities ▪ Published the Green Carbon Guidebook, defining a meta-standard framework to guide carbon project developers and investors

[i] CBP Consortium made up of Colorado State University (CSU), University of Leicester, World Soil Information (ISRIC), Centro de Energia Nuclear na Agricultura (Brazil), GEF, Overseas Development Group – University of East Anglia (ODG-UEA), World Wide Fund for Nature (WWF), World Agroforestry Centre (ICRAF), Michigan State University (MSU), Centre for International Forestry Research (CIFOR)

[ii] UN Development Programme (UNDP), UNEP, World Bank, UN Food and Agriculture Organization (FAO), UN Industrial Development Organization (UNIDO), African Development Bank (AfDB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), Inter-American Development Bank (IDB), International Fund for Agricultural Development (IFAD)