TOOLKIT

ENHANCING CARBON STOCKS AND REDUCING CO_2 EMISSIONS IN AGRICULTURE AND NATURAL RESOURCE MANAGEMENT PROJECTS

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THE WORLD BANK

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AFOLU	agriculture, forest, and other land-use
A/R	afforestation and reforestation
AGB	above-ground biomass
BCEF	biomass conversion and expansion factor
BEF	biomass expansion factor
BGB	below-ground biomass
BLS	baseline strata
C-benefits	carbon benefits
CDM	Clean Development Mechanism
CEMs	carbon enhancement modules
C-enhancement	carbon enhancement
CEPs	carbon enhancement practices
CFM	community forest management
DBH	diameter at breast height
EX-ACT	*ex ante* carbon-balance tool
FAO	Food and Agriculture Organization
FYM	farm yard manure
GBH	girth at breast height
GEF	Global Environment Facility
GEO	Global Environmental Outlook
GHG	greenhouse gases
ha	hectare
IPCC-GNGGI	Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories
MAI	mean annual increment
MRV	monitoring, reporting, and verification
NRM	natural resource management
NTFP	nontimber forest product
PA	protected area
REDD	Reducing Emissions from Deforestation and Forest Degradation
SOC	soil organic carbon
t	tons
tC	tonnes of carbon
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standards

PREFACE

Climate change is the biggest environmental and developmental challenge facing humanity. Projected climate change is likely to impact all natural resources, agriculture, and food security systems in the coming decades. There is realization at the global and national levels on the need for mitigation and adaptation to address the impending climate change. Land-use sectors (agriculture, forests, and grasslands) are critical to mitigating climate change in a cost-effective way along with providing multiple socio-economic and environmental cobenefits. Mitigation in land-use sectors or carbon stock enhancement could be realized synergistically with the enhancement of agriculture productivity. C-benefits (C-benefits), such as carbon stock enhancement or CO_2 emission reduction, in most natural resource management and agriculture projects could be realized as cobenefits. Further, enhancement of carbon stocks in soil and vegetation could contribute to soil and water conservation, enhanced soil fertility, increased crop yields, and provision of wood and nonwood tree (forest) products as additional sources of revenue and employment. Enhancement of C-benefits could contribute to reduction in vulnerability to climate risks and adaptation to climate change risks through enhanced and stabilized crop yields and diversification of income sources. Finally, most carbon enhancement (C-enhancement) interventions are likely to have positive socio-economic and environmental implications.

There is a need for guidelines or toolkits for enhancing carbon stocks in land-based projects for assisting project developers, managers, evaluators, and funding agencies. In this guideline or toolkit, approaches, methods, and detailed practical steps for enhancing C-benefits in land-based projects are provided for use by different stakeholders at different stages of the project cycle. Further, the toolkit also provides potential C-enhancement modules and practices for agriculture, watershed, and other land-based projects along with details of the practices and potential carbon stock enhancement. The project developer or manager can use these details along with information available from agriculture-, forestry-, and water-related research institutions.

Carbon stock enhancement interventions could be incorporated at the project planning and designing, post-project approval, or project implementation stage. Reliable estimation and monitoring of carbon stock enhancement (including CO_2 emission reduction) is necessary and feasible for all land-based projects. Quantification and estimation of the carbon stock enhancement is required at *ex ante* (during project proposal preparation) and *ex post* (periodically during project implementation and postproject) stages. Practical guidance on sampling, field studies, baseline development, and calculation of carbon stocks and modeling is provided for both *ex ante* and *ex post* phases.

I expect this toolkit will become a key reference document for many years to come for all sector partners involved in agriculture and land-use development projects, benefiting not only World Bank colleagues, but also government partners grappling with climate change impacts.

Simeon K. Ehui

Sector Manager, SASDA

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This toolkit is available in print and on the Internet (http://www.worldbank.org/ard). Subject to its demonstrated value and user feedback, it may be updated periodically, especially as an input for ongoing projects and related training activities.

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EXECUTIVE SUMMARY

There is global interest in promoting mitigation and adaptation in agriculture, forest, and other land-use (AFOLU) sectors to address the twin goals of climate change and sustainable development.

Agriculture production in different regions is facing complex challenges such as the impact of climate variability and change, land degradation, increased competition for water, increasing labor and input costs, and loss of carbon stocks in agricultural lands. While there is adequate literature and information on these issues, the impact on crop production due to loss of carbon stock and how to enhance crop production through increased carbon stocks have been ignored in most analyses. However, sustainable agriculture, low-carbon farming, and climate-smart agriculture initiatives that incorporate conservation agriculture, soil nutrient management, agro-forestry, etc., promote enhancement of carbon stocks as a cobenefit. **This guideline deals with how to enhance carbon stocks in general in all land-based projects and its specific relationship with agriculture productivity. It outlines specific steps and procedures that need to be followed by project proponents and managers of land-based projects to enhance carbon stocks synergistically with increasing crop productivity.**

This guideline for carbon stock enhancement or CO_2 emission reduction in agriculture and natural resource management (NRM) projects covering all land-use sectors presents two approaches. The first approach is a generic one covering all the land categories and interventions aimed at promoting the economic benefits (crop, timber, and non-timber wood product production, and employment or livelihood generation) and environmental benefits (soil and water conservation, land reclamation, and biodiversity protection) of a project, synergistically optimizing carbon stock enhancement as a cobenefit. The second approach provides guidelines for project developers to maximize project C-benefits along with promoting high-value cropping systems and production practices appropriate for a given agro-ecological region as well as to meet the needs of the local stakeholders, such as farmers or landless laborers. An illustration of the two approaches is presented at the end of the Executive Summary. **The guidelines provide methods for selection and incorporation of carbon stock enhancement modules and practices along with methods for estimation and monitoring of carbon stock changes as well as assessment of social and economic implications of carbon enhancement (C-enhancement) interventions.** The guideline consists of the following chapters:

PART A: APPROACH AND METHODS FOR ENHANCING CARBON STOCKS AND REDUCING CO_2 EMISSIONS IN LAND-BASED PROJECTS

A.1. Enhancement and monitoring of C-benefits from land-based projects presents the rationale for carbon stock enhancement, mitigation potential of land-use sectors, synergy between mitigation and adaptation, modes of realization of C-benefits, synergistic linkages between project developmental goals and carbon stock enhancement, and the need for monitoring C-benefits.

A.2. Approaches for carbon stock enhancement and CO_2 emission reduction describes a detailed, step-by-step approach to select, incorporate, and enhance C-benefits (carbon stock enhancement and CO_2 emissions reduction). Firstly, a generic approach covering all the land categories and interventions aimed at promoting the economic and environmental objectives of a project, synergistically optimizing the carbon stock enhancement as a cobenefit. Secondly, the guidelines enable project developers to manage project carbon scenarios for promoting high-value cropping systems and production practices appropriate for a given agro-ecological region as well as to meet the needs of the local stakeholders.

A.3. Implications of C-benefit enhancement presents the implications of C-benefit enhancement for the project cycle; costs and benefits; institutional and technical capacity needed; and methods of monitoring C-benefits, socio-economic and environmental impacts, vulnerability reduction to climate risks, and adaptation and promotion of mitigation-adaptation synergy.

PART B: C-ENHANCEMENT METHODS (CEMS), C-ENHANCEMENT PRACTICES (CEPS), AND C-ENHANCEMENT TECHNOLOGIES

B.1. Description of CEMs includes goals, activities, and features (including inputs required, physical structures, silvicultural or agricultural practices, timing of interventions, etc.) and the extent of C-benefits from the identified modules.

B.2. Description of CEPs presents goals, activities, and features of identified practices.

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C.1. Methods for carbon monitoring

C.2. Methods for different carbon pools

C.3. Carbon inventory for agro-forestry, shelterbelts, grassland management, and soil conservation activities

C.4. Data recording, compilation, calculation, and estimation of carbon stocks and CO_2 emissions and modeling

C.5. Reporting of C-benefits

PART D: PRACTICAL GUIDANCE ON SAMPLING, FIELD STUDIES, BASELINE DEVELOPMENT, AND MODELING

D.1. Field methods for estimating carbon stocks in land-based projects

D.2. Estimation of baseline or reference carbon stocks and CO_2 emissions

D.3. Application of models for projecting C-benefits (carbon stock changes and CO_2 emissions)

Land-use sectors (agriculture, forests, and grasslands) are critical to mitigating climate change in a cost-effective way along with providing multiple socio-economic and environmental cobenefits. Land-use sectors contribute to about 20 percent of the global CO_2 emissions. According to the Intergovernmental Panel on Climate Change (IPCC) (2007), the annual economic mitigation potential of forests and agriculture is estimated at 2.7 to 13.8 G-tonnes of carbon (tC)-O_2 and 3.87 $GtCO_2$, respectively. Agriculture soils alone have a mitigation potential of 1.5 to 4.4 $GtCO_2$. Further, land-use sectors are critical in achieving stabilization of global warming at 2°C. According to UNEP (2011), agriculture and forestry sectors together could contribute to about 24 to 36 percent of the mitigation scenario required to bridge the emissions gap and stabilize warming at 2°C.

Mitigation in land-use sectors or carbon stock enhancement could be realized synergistically with the main NRM or developmental objectives of land-based projects. C-benefits (carbon stock enhancement or CO_2 emission reduction) in most NRM and environmental and developmental projects could be realized as cobenefits. Further, enhancement of carbon stocks in soil and vegetation could contribute to soil and water conservation, enhanced soil fertility, increased crop yields, and provision of wood and nonwood tree (forest) products as additional sources of revenue and employment. Enhancement of C-benefits could contribute to reduction in vulnerability to climate risks and adaptation to climate change risks through enhanced and stabilized crop yields (through soil fertility enhancement and conservation) and diversification of income sources, such as agro-forestry. The guideline clearly demonstrates the synergy between carbon stock enhancement and NRM and other developmental benefits.

Guidelines and toolkits for enhancing carbon stocks in land-based projects for project developers, managers, evaluators, and funding agencies. In this guideline, approaches, methods, and detailed practical steps for enhancing C-benefits in land-based projects are provided for use by different stakeholders at different stages of the project cycle.

Land-based projects broadly aim at increasing crop production, NRM, environmental conservation, and sustainable development. These projects include agriculture and watershed development, poverty alleviation and livelihood improvement, irrigation and water conservation, biodiversity conservation, land reclamation, halting desertification, adaptation to climate change, and mitigation of climate change through Reducing Emissions from Deforestation and Forest Degradation and afforestation/reforestation through the Clean Development Mechanism. All the projects have the potential to generate C-benefits.

A large number of C-enhancement modules and practices are available to enhance carbon stocks as cobenefits of land-based projects. Land-based projects provide multiple opportunities for incorporating the carbon stock enhancement modules and practices.

Approach to carbon stock enhancement in land-based projects. Enhancement of carbon stocks from mainstream NRM and developmental projects would require a systematic approach to ensure optimized delivery of project goals and outputs along with enhanced C-benefits in a synergistic manner. The following step-by-step approach is provided in the guideline for enhancing carbon stocks along with the broad goals of any typical land-based project:

- Selection of land-based projects
- Identification and selection of land categories and subcategories for inclusion in the project
- Identification of broad outcomes or outputs of the project relevant to land categories and interventions
- C-enhancement modules and practices for C-benefits: features of and approach to selection
- Carbon implications of C-enhancement modules and practices
- Implications of C-enhancement goals, modules, and activities for the project cycle
- Implications of C-enhancement activities for monitoring
- Implications of C-enhancement interventions for cost, institutional and technical capacity, and socio-economic and environmental aspects
- C-enhancement and mitigation and adaptation: synergy and trade-offs.

Carbon stock enhancement interventions could be incorporated at the project planning and designing, postproject approval, or project implementation stage. The guideline could be used at the planning, designing, project proposal evaluation and approval, or implementation phase. The final decision-making authority for selection and incorporation could be the project developer, project funder, project evaluator, or project manager.

C-enhancement modules and C-enhancement practices for C-benefits. There are two broad categories of interventions for enhancing carbon stocks, namely C-enhancement modules and C-enhancement practices or technologies:

- ***CEMs*** are subprojects consisting of a single or, more often, multiple components or a package of activities or technologies aimed at enhancing C-benefits from any land-based developmental or environmental projects. The potential CEMs are *watershed, agro-forestry, soil conservation, water conservation, soil and water conservation, shelterbelts, protected area (PA) management, land reclamation, sustainable agriculture, afforestation and forest regeneration, biodiversity conservation, community forestry, irrigation (minor or major), fruit orchards, and gardens.*
- ***CEPs*** consist of a single technology or practice aimed at conserving or enhancing carbon stock in selected land categories. Potential CEPs are *mulching, organic manure application, green manure application, reduced or zero tillage, contour bunding, farm ponds, tank silt application, intercropping or multiple cropping, and cover cropping.*

The approach to selection of CEMs and CEPs would include identification of activities that are compatible with the broader objectives of the project and have the potential to deliver enhanced C-benefits. The approach could involve the following steps:

- Identification of outputs of the project
- Identification of the CEMs and CEPs to be incorporated into the project that may directly or indirectly contribute to C-benefits

- Selection of CEMs or additional activities could be based on the potential to positively contribute to the main outputs of the project, suitability for the land category and the region, and its cost-effectiveness

The selected C-enhancement interventions (CEMs or CEPs) should be cost-effective to the extent that the additional investment cost due to the intervention has positive financial implications for the project outputs. However, it is likely that sometimes positive financial benefits may occur in the long term. The procedure could involve selection of the CEMs/CEPs and estimation of the costs of inputs, labor, and technical expertise required. Often, it is possible to assess even the incremental crop productivity or biomass productivity due to a CEM or CEP.

Most C-enhancement interventions are likely to have positive socio-economic and environmental implications. C-enhancement interventions contribute to soil and water conservation and improved soil fertility, which contribute to increased crop production, grass and fuelwood production, and nonwood product availability, potentially leading to increased employment and income. Similarly, C-enhancement interventions contribute to conservation of natural resources, such as soil, water, and biodiversity; land reclamation; groundwater recharge; and forest conservation.

C-enhancement in land-based projects contributes to reducing the vulnerability to climate risks and demonstrating the synergy between mitigation and adaptation. Most interventions (CEMs and CEPs) in agricultural lands lead to soil and moisture conservation and improved soil fertility, contributing to improved soil moisture availability and thus enhancing resilience to soil moisture stress and droughts. Similarly, interventions such as agro-forestry, community forestry, and PA management contribute to diversifying the sources of income and employment, especially during drought years. It is necessary to recognize and increase the resilience enhancement potential of the C-enhancement interventions.

Information on the C-enhancement modules, practices, and technologies is necessary for project developers or managers to assist them in selecting such interventions and incorporating them into a project. The information required includes description of the practice, benefits accruing from the practice, applicability to a given region and land category, steps involved in implementing the practice, inputs required, impacts on crop or biomass productivity, and implications for biomass and soil carbon stock enhancement. These aspects are described in Part B of this guideline for most of the CEMs and CEPs based on literature.

Reliable estimation and monitoring of carbon stock enhancement (including CO_2 emission reduction) is necessary and feasible for all land-based projects. Quantification and estimation of the carbon stock enhancement is required at *ex ante* (during project proposal preparation) and *ex post* (periodically during project implementation and postproject) stages. Estimation and monitoring is necessary to assess the mitigation potential of projects and payment for C-benefits and to identify opportunities for increasing carbon stocks. Practical methods are available and are provided in Part C of this guideline. Broadly, estimating C-benefits involves the following steps:

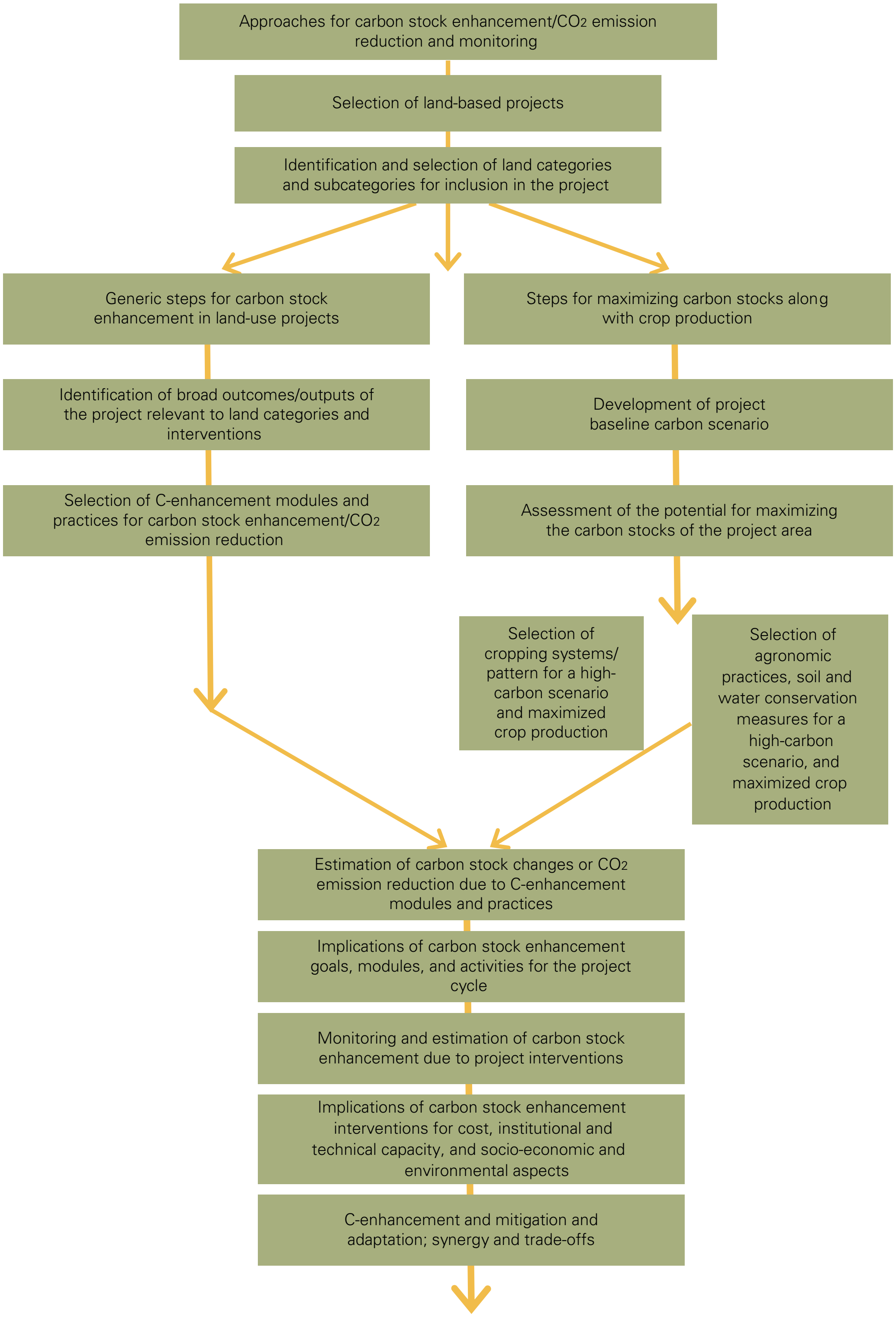
- Select a land-use category or project activity, define the project boundary and map the land-use category or project area subjected to C-enhancement interventions, stratify the project area or land-use category, select the plot method or farms, select carbon pools and frequency of measurement, identify indicator parameters to be measured, select a sampling method and sample size, prepare for field work and data recording, decide on sampling design, locate and lay sample plots, measure the indicator parameters in field and conduct laboratory analysis, analyze data, and estimate changes in C-stocks/CO_2 emissions

The estimates of C-benefits in agriculture and forestry projects are likely to be associated with uncertainties that could be estimated and minimized.

Practical guidance on sampling, field studies, baseline development, and calculation of carbon stocks and modeling is necessary for *ex ante* estimation and *ex post* monitoring. Part D of this guideline describes these details with illustrations.

Land-based projects provide a large opportunity for carbon stock enhancement or CO_2 emission reduction synergistically with the goals and objectives of NRM and agricultural developmental projects. This guideline provides practical steps for identification and incorporation of C-enhancement modules and activities as well as monitoring and estimation approaches and methods. There is a need for exploring cost-effective interventions that provide significant C-benefits in addition to enhancing the economic or environmental benefits from the projects. Most C-enhancement projects provide positive socio-economic and environmental benefits as well as enhance resilience to adverse effects of climate change. Thus, there is a need to identify, incorporate, implement, estimate, and monitor C-benefits in land-based projects.

The following illustration presents two approaches: (1) a generic approach aimed at promoting C-enhancement as a cobenefit of agriculture and NRM projects and (2) a project carbon maximization approach aimed at maximizing carbon stocks along with crop production.



Part A: APPROACH AND METHODS FOR ENHANCING CARBON STOCKS AND REDUCING CO_2 EMISSIONS IN LAND-BASED PROJECTS

A.1. RATIONALE, APPROACH, AND METHODS FOR ENHANCING CARBON BENEFITS (C-BENEFITS)

Land-use sectors (agriculture, forests, and grasslands) are critical to mitigating climate change by enhancing the stock of carbon in biomass and in soil or by reducing CO_2 emissions. Most land-based developmental projects have the potential to deliver C-benefits (carbon stock enhancement or CO_2 emission reduction) as a cobenefit of projects that have socio-economic development or improved management of natural resources as their main goals. **This toolkit provides a set of practical guidelines that describe in detail how to incorporate potential carbon enhancement (C-enhancement) modules and practices into land-based projects during the project design and implementation stages. Further, the guidelines provide methods for measurement, estimation, modeling, and monitoring of changes in carbon stock or CO_2 emissions for the *ex ante* and *ex post* phases**. In these guidelines, the term *C-benefit* is used to indicate carbon stock enhancement and/or CO_2 emission reduction. Often, carbon stock enhancement also includes reduction in CO_2 emissions. C-benefits from land-based projects could be enhanced synergistically while simultaneously pursuing the main aims of the projects as well as making the sector less vulnerable to adverse effects of climate change. The *Guidelines for Land-Based Projects to Enhance and Monitor C-Benefits* are organized into four parts.

Climate change and mitigation: Climate change is one of the most serious global environmental challenges facing humanity. Climate change driven by the increasing concentration of greenhouse gases (GHG) is projected to impact natural ecosystems and socio-economic systems. Assessments of the impact, such as the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001), indicate that developing countries are likely to be highly vulnerable to climate change. The Fourth Assessment Report of the IPCC (2007) also clearly indicates the vulnerability of developing countries due to the projected magnitude of climate change and the inability to cope with it. A recent study by MoEF (2010) in India highlights the severe impact of climate change on food production, availability of water, forest biodiversity, and coastal zones as early as 2030. To address climate change and to hold the global warming below the 2°C threshold, global GHG emissions need to be reduced by 25 to 40 percent by 2030 from their 1990 levels (IPCC 2007). The IPCC highlighted the need for mitigation and adaptation measures that are synergistic, particularly in land-use sectors (Ravindranath 2007), and for promoting sustainable development to cope successfully with adverse effects of climate change and to reduce emissions and vulnerability to climate change.

Mitigation potential of land-use sectors: The land-use sectors (agriculture, forests, and grasslands) contribute to nearly a third of the global GHG emissions (figure A.1), with agriculture contributing to 13.5 percent and forests contributing to 17.4 percent (IPCC 2007). The land-use sectors therefore offer a large mitigation opportunity to address climate change. The IPCC (2007) estimates that by 2030, the annual economic mitigation potential of forests and agriculture will be 2.7 to 13.8 $GtCO_2$ and 3.87 $GtCO_{2,}$ respectively, at less than \$100 per tCO_2. The most prominent mitigation opportunity in the agriculture sector relates to enhancing carbon sinks through sequestration of carbon in the soil by better management of cropland and grazing land. Thus, the annual carbon mitigation potential in agriculture and forest sector together, excluding bioenergy, is estimated at 6.57 to 17.6 $GtCO_2$ up to 2030 at less than \$100 per tCO_2 (IPCC 2007). Agricultural practices collectively can make a significant contribution at low costs, particularly by increasing the soil carbon sink, which has strong synergies with sustainable agriculture and reduces vulnerability to climate change.

Lal (2004) puts the annual mitigation potential of agricultural soils at 1.5 to 4.4 $GtCO_2$. Forest-related mitigation activities can also considerably reduce emissions from sources (reducing deforestation and degradation) and increase CO_2

PART A: APPROACH AND METHODS FOR ENHANCING CARBON STOCKS AND REDUCING CO_2 EMISSIONS IN LAND-BASED PROJECTS

A.1. Enhancement and monitoring of C-benefits from land-based projects: This section presents the rationale for carbon stock enhancement, mitigation potential of land-use sectors, synergy between mitigation and adaptation, modes of realization of C-benefits, synergistic linkages between project developmental goals and carbon stock enhancement, and the need for monitoring C-benefits.

A.2. Approaches for carbon stock enhancement and CO_2 emission reduction: This section presents a detailed, step-by-step approach to select, incorporate, and enhance C-benefits (carbon stock enhancement and CO_2 emissions reduction). Firstly, a generic approach will be presented covering all the land categories and interventions aimed at promoting the economic and environmental objectives of a project, synergistically optimizing the carbon stock enhancement as a cobenefit. Secondly, the guidelines will enable project developers to manage project carbon scenarios for promoting high-value cropping systems and production practices appropriate for a given agro-ecological region as well as for meeting the needs of the local stakeholders.

A.3. Implications of C-benefit enhancement: This section presents the implications of C-benefit enhancement for the project cycle; costs and benefits; institutional and technical capacity needed; and methods of monitoring C-benefits, socio-economic and environmental impacts, vulnerability reduction to climate risks, and adaptation and promotion of mitigation-adaptation synergy.

PART B: C-ENHANCEMENT MODULES (CEMs), C-ENHANCEMENT PRACTICES (CEPs), AND C-ENHANCEMENT TECHNOLOGIES

B.1. The description of CEMs includes goals, activities, and features (including inputs required, physical structures, silvicultural or agricultural practices, timing of interventions, etc.) and the extent of C-benefits from the identified modules

B.2. The description of C-enhancement practices presents goals, activities, and features of identified practices.

PART C: CARBON MEASUREMENT, ESTIMATION, MODELING, AND MONITORING METHODS

C.1. Methods for carbon monitoring

C.2. Methods for different carbon pools

C.3. Carbon inventory for agro-forestry, shelterbelts, grassland management, and soil conservation activities

C.4. Data recording, compilation, calculation, and estimation of carbon stocks and CO_2 emissions and modeling

C.5. Reporting of C-benefits

PART D: PRACTICAL GUIDANCE ON SAMPLING, FIELD STUDIES, BASELINE DEVELOPMENT, AND MODELING

D.1. Field methods for estimating carbon stocks in land-based projects

D.2. Estimation of baseline or reference carbon stocks and CO_2 emissions

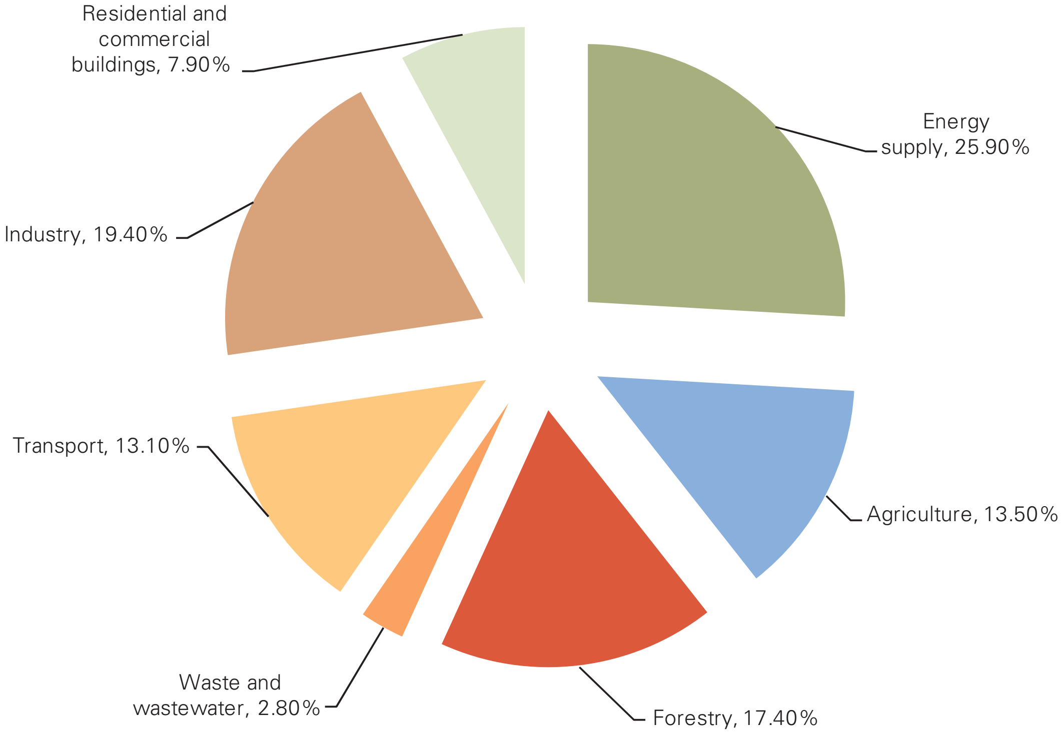
D.3. Application of models for projecting C-benefits (carbon stock changes and CO_2 emissions)

removals by sinks (through afforestation and reforestation (A/R) and sustainable forest management) at low costs. Together, mitigation opportunities in agriculture and forests can also be designed to create synergies with adaptation and sustainable development.

Agriculture, forest, grassland, and multi-land component watershed programs for climate change mitigation:

Despite the realization of the large potential of land-use sectors, practical mainstreaming and implementation of carbon stock enhancement in agriculture and natural resource management programs and projects are yet to be realized. One of the barriers could be the absence of practical guidelines or toolkits for enhancing C-benefits in land-based projects.

FIGURE A.1: Share of Different Sectors in Total Anthropogenic GHG Emissions ($CO_{2\text{-eq}}$) in 2004



Source: IPCC 2007.

Globally, mitigation efforts in the land-use sectors have focused largely on forests, particularly on reducing emissions from deforestation and forest degradation (REDD) and on A/R. It is important to also consider nonforest land categories in mitigating climate change. In this context, watersheds, agricultural soils, grasslands, and wastelands or marginal lands could provide significant opportunities for mitigating climate change. Land-based mitigation activities offer significant economic and environmental benefits such as increased soil organic carbon (SOC) content, which could increase and stabilize crop productivity and reduce deforestation, which could, in turn, promote biodiversity conservation. **Therefore, these guidelines focus on land-use sectors such as agriculture, forests, grasslands, and multi-land-component watersheds** and provide a menu of technologies and practices aimed at enhancing carbon stocks or reducing CO_2 emissions in land-based projects. **The guidelines also explain and illustrate simple methods to estimate and monitor the C-benefits from such projects.**

Why focus on carbon/CO_2: In 2004, CO_2 accounted for 76.7 percent of the CO_2-equivalent global GHG emissions, and further deforestation, decay of biomass, land use, and land-use change accounted for 17.4 percent of the global emissions (IPCC 2007). Thus, CO_2 is the predominant component of GHG from land-use sectors, and deforestation and land-use change are the main contributors of that CO_2. Enhancing carbon stocks of agricultural, forest, and grassland soils not only contributes to enhanced biomass production including that of food, fiber, grass, fuelwood, and timber, but also has associated benefits in the form of reduced vulnerability to climate change—hence **the focus of these guidelines on CO_2.**

Integrating C-enhancement in natural resource management (NRM) and developmental projects: Developing countries have been implementing a large number of land-based developmental and NRM projects as part of the national development goals with domestic funding as well as funding from multilateral agencies such as the World Bank and the United Nations Development Program and from global mechanisms such as the Adaptation Fund, the Green Climate Fund, the Global Environment Facility (GEF), and several bilateral programs. The goal of securing C-benefits could be synergistically integrated into most land-based NRM and developmental programs and projects. This requires mainstreaming carbon mitigation into projects aimed at socio-economic and environmental benefits. Identification and incorporation of CEMs and CEPs in land-based projects can benefit from appropriate guidelines and additional institutional and technical capacity.

Promoting synergy between C-enhancement and adaptation: The IPCC has concluded that positive synergies exist between climate change mitigation and adaptation. Land-use sectors not only offer significant opportunities to promote agriculture development, conserve biodiversity, and improve livelihoods through C-enhancement projects, but they also contribute to making agriculture, biodiversity, and livelihoods **less vulnerable to climate change.** Projects related to soil and water conservation, soil fertility improvement, and forest conservation are some examples of synergy between mitigation and adaptation. Integration of C-enhancement with environmental and developmental goals and with adaptation to climate change is also critical to sustainable development.

Why C-enhancement and monitoring of C-benefits: Globally, the need to mitigate climate change is well recognized—the Kyoto Protocol was implemented as part of the United Nations Framework Convention on Climate Change (UNFCCC), and the Cancun Agreement was reached post-Kyoto. However, efforts to explore the potential for mitigation of climate change in different sectors have been limited, and further understanding of the implications of developmental and NRM programs and projects on the carbon stock gains or losses is limited.

The focus of these guidelines is on land-based projects and their potential for enhancing carbon stocks. Although the potential of most land-based projects to enhance C-benefits and contribute to climate change mitigation is well recognized, that recognition has not been matched by practical approaches and guidance for mainstreaming climate change mitigation in developmental and NRM projects. If C-enhancement and its monitoring are to be mainstreamed in all land-based development projects, it is essential to do the following:

- Recognize that most land-based projects can deliver C-benefits and in exceptional cases may lead to net CO_2 emissions
- Explore opportunities for synergistically enhancing C-benefits in all land-based projects with the broader environmental or resource conservation and developmental goals of such projects
- Ensure that all projects measure and monitor the implications of project activities for carbon stock changes or CO_2 emissions

Why carbon implications of developmental projects are often ignored: Most NRM, environment conservation, and developmental programs and projects could lead to enhancement of carbon stocks or reduction of CO_2 emissions. However, these benefits, although known, are neither recognized nor monitored at present. Further, most projects do not explicitly incorporate C-benefits among the objectives despite the potential for synergy between C-enhancement and increased crop productivity, soil and moisture conservation, biodiversity conservation, etc. C-enhancement is often ignored in developmental or NRM projects, probably because of these reasons:

- Enhancing or monitoring and reporting of C-benefits from land-based projects attract no special incentives other than Clean Development Mechanism (CDM) and, in the future, REDD
- No guidelines or toolkits are available to assist a project developer or manager to identify the potential of carbon gains or even to recognize them as a cobenefit
- Data on the stocks, growth rates, and gains and losses of carbon or CO_2 from different land categories resulting from different project activities are not available, a lacuna that limits the ability of project developers or managers to consider C-enhancement as an integral part of the project
- A technical capacity to take into account and to monitor carbon stock changes or CO_2 emissions resulting from project activities may not be available
- Enhancing C-benefits and even monitoring carbon stock changes are additional activities, and project managers often regard these as additional expenses and burden
- C-enhancement and monitoring are not part of the environmental and social safety guidelines drawn up by most multilateral and bilateral agencies; therefore, it is not mandatory for project managers or funding agencies to consider carbon stocks and monitoring changes in carbon stocks as an integral project activity

The World Bank focus for the guidelines: The World Bank is the biggest multilateral funding agency in areas such as energy, climate change mitigation and adaptation, forestry and environmental conservation, agricultural development, and social and economic development. The Bank has also pioneered many initiatives related to climate change, particularly in the land-use sectors. The Bank was the first agency to launch "The BioCarbon Fund," which piloted innovative carbon payments in the land-use sector. Further, the Bank was one of the first agencies to launch a large program on REDD, namely the Forest Carbon Partnership Facility. The Bank also hosts GEF, which has a dedicated program on REDD and sustainable forest management. Therefore, these guidelines for enhancing C-benefits from land-based projects focus on land-based projects funded by the Bank, although the guidelines, CEMs, and CEPs could be applied or adopted by other multilateral or bilateral agencies that support land-based NRM and developmental projects.

Target groups for the C-enhancement and monitoring guidelines: Carbon, its enhancement, and its monitoring in developmental and NRM projects will be of interest to project developers, managers, financing agencies, and project evaluators. In any typical land-based project, guidelines are required for the following agencies or personnel:

- *Project developers and local stakeholders*—to consider and evaluate various options available for enhancing carbon stocks and their socio-economic implications
- *Project proposal evaluators*—to assess the need for considering C-enhancement and its monitoring, options to enhance C-benefits synergistically with the main project goals, and recommendations on monitoring
- *Funding agencies*—to assist and guide project developers and managers in considering options for enhancing C-benefits as cobenefits and in monitoring the impacts of project activities and assessing cost implications
- *Project managers*—to assist in selecting appropriate project activities for enhancing C-benefits and institutions and technical capacity for monitoring C-benefits and in making periodic assessment of impacts for midcourse correction

Unique features of the guidelines: These guidelines are among the few that exist to assist project developers, financiers, and implementers. The unique features of the guidelines are as follows:

- Step-by-step guidelines for identification, incorporation, and monitoring of CEMs and CEPs in all land-based projects in an integrated manner
- Description of the CEMs and CEPs for different land categories
- Quantification of the C-benefits of different CEMs and CEPs from limited literature available
- Consideration and recognition of opportunities for C-benefits enhancement at the project planning stage (*ex ante*), the evaluation stage, and even at the project implementation stage (*ex post*)

In the agriculture and forestry sector, a set of carbon-foot printing methodologies and decision support tools are available. The EX-Ante Carbon-Balance Tool (EX-ACT) is a Food and Agriculture Organization (FAO)tool that provides ***ex ante*** **measurements of the mitigation impact** of agriculture and forestry development projects by estimating net carbon balance from GHG emissions and carbon sequestration. It is a **land-based accounting system to measure carbon stocks and stock changes** per unit of land; the CH_4 and N_2O emissions are expressed in tCO_2-eq per hectare (ha) per year. The **main output of the EX-ACT tool is an estimation of the carbon balance** associated with the adoption of improved land management options compared to that with a *business-as-usual* scenario. Thus, **EX-ACT allows for the carbon-balance appraisal of new investment programs** by ensuring that an appropriate method is available to donors and planning officers, project designers, and decision makers within agriculture and forestry sectors in developing countries (FAO 2011). Models such as TARAM, CATIE, and PROCOMAP are available for assessing the C-benefits from forestry projects during project proposal preparation or *ex ante*. These models are described in Part D.

The present guidelines are, however, not without limitations. C-benefits from project interventions per unit area are critical for decisions on incorporation of C-enhancement interventions. However, there is very limited literature on the C-benefits of different CEPs and CEMs in quantitative terms, and information on CEM- and CEP-specific costs and benefits at the regional level is equally limited. The technical details of CEMs and CEPs are not provided in the guidelines as they can be obtained from package of practices, literature, textbooks, and guidelines on watershed and sustainable agriculture and forest management at the regional level. Finally, **BioCarbon, A/R under CDM, and REDD+ projects are not the focus of these guidelines** since dedicated methodologies exist or will become available for these mechanisms. However, projects under these mechanisms could also

TABLE A.1: Roadmap for C-Enhancement and Monitoring Guidelines

TOPIC	DETAILS	SECTION
Carbon stock enhancement and monitoring in land-based projects	• Need and rationale for C-enhancement and C-monitoring	A.1
Guidelines for enhancing carbon stocks	• Principles and approaches for carbon stock enhancement in land-based projects	A.2
Identification of project outputs for C-enhancement	• Approach to identifying existing or new outputs relevant to C-enhancement in projects	A.2.3.5
CEMs and CEPs	• Examples of CEMs/CEPs	A.2.4
	• Features of CEMs/CEPs	
Approach to selection of CEMs/CEPs	• Criteria for selection of CEMs/CEPs	A.2.4.4
	• Quantification of C-benefits per ha	
Carbon implications of CEMs/CEPs	• Factors determining C-benefit	A.2.4.6
	• How C-benefits are realized	
Implications for monitoring	• Approach and process for estimation and monitoring C-benefits	A.3.2
Cost implications of C-enhancement interventions	• Importance of costs and benefits	A.3.3
	• Approach for estimating costs	
Socio-economic and environmental implications of C-enhancement interventions	• Determining the socio-economic and environmental impacts	A.3.5
	• Broad approach to identification and consideration	
C-enhancement implications for adaptation	• Approach to reduce vulnerability to climate change	A.3.6.1
	• Mitigation and adaptation synergy	A.3.6.2
Technical details of CEMs/CEPs	• Description of CEMs/CEPs	B.1 and B.2
	• C-benefits from CEMs/CEPs	
Carbon monitoring methods and practical guidance	• Approaches and methods for estimating and monitoring C-benefits	C.1.2
	• Generic steps for estimation and monitoring	C.1.3
Methods for carbon inventory of forestry and other tree-based projects	• Methods for different carbon pools for forests, plantations, orchards	C.2
Methods for carbon inventory of nonforestry projects	• Agro-forestry, shelterbelts, grassland management, and soil conservation activities	C.3
Practical guidance for carbon estimation and monitoring	• Field studies	D.1 to D.3
	• Baseline carbon stocks	
	• Application of models	

Source: Authors.

benefit from these guidelines on approaches for enhancing C-benefits. A road map for use of the C-enhancement and monitoring guidelines is provided in Table A.1.

A.1.1. Mitigation Potential of Land-Based Sectors and Activities

Forests and agriculture are critical to stabilizing CO_2 concentration in the atmosphere for mitigating climate change because both offer a large mitigation potential besides providing multiple sustainable development.

A.1.1.1. Agriculture

A variety of options exist for reducing CO_2 emissions in agriculture, the most prominent among them being improved management of cropland and grazing land (for example, better agronomic practices including application of fertilizers, tillage, and incorporation of crop residues into soil), restoration of organic matter, and amelioration of degraded lands. Other options that offer lower but nevertheless significant mitigation potential include improved water management (especially in rice cultivation), set-asides, incorporating a fallow period in crop rotations, change in land use (such as conversion of cropland to grassland), agro-forestry, and improved livestock and manure management.

The mitigation potential of the sector is dominated by carbon sink enhancement of agricultural soils; the potential of carbon sequestration in soils is estimated to account for 90 percent of the total mitigation potential of agriculture and involves the following measures (IPCC 2007):

- Restoration of cultivated organic soils (1260 $MtCO_2$)
- Improved cropland management (including agronomic practices, nutrient management, tillage, and residue management), water management, and agro-forestry contributing to 1110 $MtCO_2$)
- Improved grazing land management (including grazing intensity, increased productivity, nutrient and fire management, and suitable species introduction) contributing to about 810 $MtCO_2$
- Restoration of degraded lands (using erosion control and organic and nutrient amendments) contributing to about 690 $MtCO_2$)

According to the IPCC (2007), the annual global technical mitigation potential of agriculture (excluding fossil fuel offsets from biomass-based fuels) could be as high as 5.5 to 6 $GtCO_2$-eq by 2030, of which approximately 1.5 $GtCO_2$-eq is from grazing land management, over 0.6 $GtCO_2$-eq is from restoration of degraded land (that is directly linked to grassland and rangeland management), and more than 1.5 $GtCO_2$-eq is from cropland management (of which pasture management has an important share). Approximately 30 percent of this potential can be achieved in developed countries and 70 percent in developing countries.

Tennigkeit and Wilkes (2008) have estimated that improved rangeland management has the biophysical potential to sequester 1.3 to 2 $GtCO_2$-eq annually worldwide by 2030. Therefore, grasslands (including grazing land management and some contribution from restoration of degraded lands and better management of croplands) have a high potential to promote build-up of carbon if appropriate management practices are adopted.

Mitigation potential estimates from cropland, rangeland, grassland, and restoration of degraded and desertified soils: Strategies to increase soil carbon pool include soil restoration and woodland regeneration, no-tillage farming, cover crops, nutrient management, manuring, controlled grazing, water conservation and harvesting, efficient irrigation, agroforestry, and growing energy crops on spare land. Estimates made by Lal (2004) indicate that, globally, soil C-enhancement alone could contribute 0.4 to 1.2 GtC annually. Figure A.2 shows the mitigation potential of different land categories and different mitigation interventions. Cropland soils dominate the mitigation potential by contributing 0.4 to 0.8 GtC per year, followed by restoration of degraded soils (0.2 to 0.4 GtC per year).

Crop intensification: Most land-based developmental projects in agriculture aim at higher crop production through irrigation, increased inputs of nutrients (inorganic fertilizer application), and multiple cropping. Some of the activities that promote intensification may lead to increased CO_2 emissions, whereas sustainable agricultural practices could lead to increased carbon stocks or reduced CO_2 emissions. According to estimates by Burney *et al.* (2010), while emissions from fertilizer production and application have increased, the net effect of higher yields as a result of crop intensification has avoided emissions of up to 590 $GtCO_{2\text{-eq}}$ since 1961.

Multiple and mixed cropping: Projects aimed at changing only the crop varieties or shifting from one crop to another crop may not lead to any significant changes in carbon stocks or CO_2 emissions. However, changes in cropping pattern incorporating multiple or mixed cropping, accompanied by improved agricultural practices, such as soil and water conservation and sustainable agriculture technologies, may lead to enhanced C-benefits.

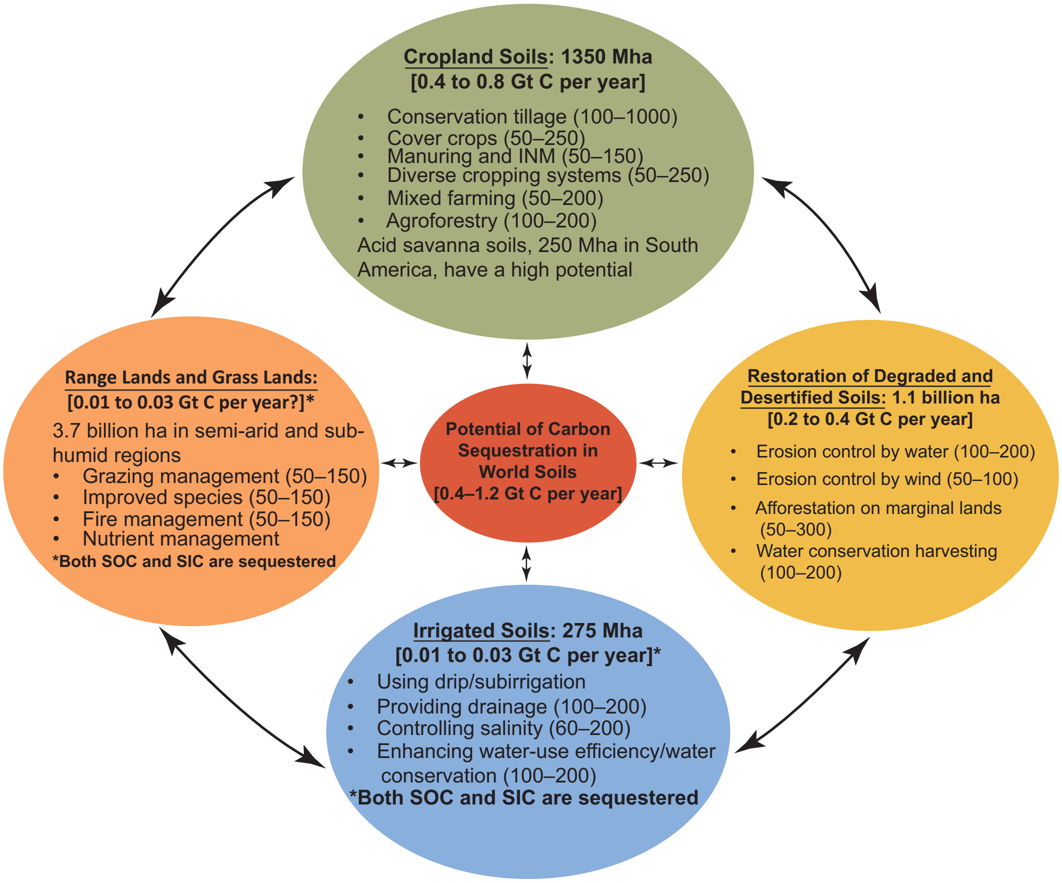
Sustainable agriculture practices: Sustainable agriculture aims at deriving continued higher crop yields without lowering soil fertility or depleting water resources. Incorporation of such practices may not only sustain crop yields, but may also provide C-benefits as cobenefits and even reduce vulnerability to climate change. Sustainable agriculture practices could be incorporated into any agricultural development or watershed project.

A.1.1.2. Forests

Forest-related mitigation activities can considerably reduce CO_2 emissions as well as enhance carbon sinks at low cost. Tropical countries dominate the mitigation potential of forests, particularly through REDD. The broad mitigation options in the forest sector include the following measures (IPCC 2007):

- Maintaining or increasing forest area through REDD and through A/R
- Maintaining or increasing the stand-level carbon density (tC per ha) through reduction of forest degradation and through planting, site preparation, tree

FIGURE A.2: Estimated Mitigation Potential of Cropland, Rangeland, Grassland, and Restoration of Degraded and Desertified Soils



Source: Lal 2004.

improvement, fertilization, management of stands of trees of uneven age, and other appropriate silviculture techniques

- Maintaining or increasing the landscape-level carbon density using forest conservation, longer forest rotations, fire management, and protection against insects
- Increasing off-site carbon stocks in wood products, enhancing product and fuel substitution using forest-derived biomass to replace products with high fossil fuel requirements, and increasing the use of biomass-derived energy to replace fossil fuels

According to the IPCC (2007), the annual economic mitigation potential of forests by 2030 will be 1.6 to 5 $GtCO_2$ at less than \$20 per tCO_2; however, at mitigation costs of less than \$100 per tCO_2, the potential rises to 2.7 to 13.8 $GtCO_2$ annually. It is important to note the wide range of the estimates, which reflects considerable uncertainty. Among the mitigation options in the forest sector, avoided deforestation offers the maximum potential.

Table A.2 presents estimates of mitigation potential. The total global mitigation potential ranges from 4.2 $GtCO_2$ to 7.8 $GtCO_2$ annually. Reducing tropical deforestation dominates the mitigation options.

A.1.1.3. REDD Potential

Globally, the total forest area is about 4.06 billion ha (FAO 2010), with tropical forests accounting for about 47 percent (Global Environmental Outlook [GEO]-3 2002). In the first decade of the 21st century, the gross annual rate of deforestation in the tropics was 13 Mha. Gross tropical deforestation during the 1990s was about 13.1 Mha per year, largely in South America, Africa, and South-East Asia (FAO 2009). Estimates of carbon emissions from land-use change range from 0.5 to 2.7 GtC for the 1990s with a mean of about 1.6 GtC, indicating high levels of uncertainty. If tropical deforestation continues at high rates in South America, under a *business-as-usual* scenario, 40 percent of the current 540 Mha of Amazon rain forests are projected to be lost, releasing 117±30 $GtCO_2$ (IPCC 2007). Reducing tropical

TABLE A.2: Mitigation Potential of Forest Sector Activities at the Global Level

REGION	ACTIVITY	MITIGATION POTENTIAL (MT OF CO_2 PER YEAR)	PERIOD
Tropical;[1] carbon price assumed to be constant at $30 per tCO_2	REDD: Reduced deforestation and forest degradation	2827	2020–2050
	Afforestation	1070	
	Forest management	698	
Temperate[1]	Afforestation	777	
	Forest management	1378	
	Total	**6750**	
Global total[2]	REDD	5100	By 2030
	A/R	2400	
	Forest management	300	
	Total	**7800**	
Global total[3] **RED by 50% and after reaching 50% of current area stopping RED**	REDD	3666	Up to 2050
Global[4]	A/R	586–4033	Up to 2100
	Total	**4252–7699**	

Source: [1]Sohngen 2008; [2]McKinsey and Co. 2009; [3]Gullison *et al.* 2007; [4]Canadell and Raupach 2008.

deforestation is thus a high-priority mitigation option and the basis for including forest-related climate actions in international agreements.

Analysis done by the World Resources Institute shows that the emission reduction pledges made by Annex I countries under the Copenhagen Accord translate to cumulative reductions of 13 to 19 percent below the 1990 levels, falling far short of the lower limit or the 25 percent cut by 2020 recommended by the IPCC (Levin and Bradley 2010). In a comprehensive study conducted by the Netherlands Environmental Assessment Agency (den Elzen *et al.* 2010), current emission reduction pledges are estimated to reduce global emissions of GHG to about 50 $GtCO_2$-eq by 2020, about 4 $GtCO_2$-eq short of the level needed to meet the target of limiting global warming to less than 2°C by 2050. The study suggests that by reducing emissions from deforestation by 50 percent below the 1995 levels, the global community could begin to close this emissions gap and be along the pathway to meeting the 2°C target by 2020. The Cancun Agreement fully recognizes this, and the REDD+ mechanism is an important component of mitigation strategy under this agreement.

Tavoni *et al.* (2007), using an integrated energy-economy-climate model with a forestry module, estimate that global forest sinks can contribute a third of the total abatement by 2050, with major contributions from avoided deforestation in countries rich in tropical forests. However, the IPCC (2007) estimates that 35 percent of the mitigation potential by 2030 could be realized through REDD. According to estimates made by the Elaisch Review (2008), the global cost of climate change caused by deforestation could reach $1 trillion a year by 2100. The review suggested that including REDD and additional action on sustainable management in a well-designed carbon trading system could provide the finance and incentives to reduce deforestation rates up to 75 percent in 2030, and the addition of A/R and restoration would make the forest sector carbon neutral. The review also estimated that the finance required to halve the emissions from the sector by 2030 could be about $17 to 33 billion a year. Nonetheless, even taking the costs into account, the net benefits of halving deforestation could amount to $3.7 trillion over the long term.

A.1.1.4. Afforestation and Reforestation (A/R) Under the Clean Development Mechanism

Under Article 12 of the Kyoto Protocol, A/R activities are included under the CDM. Although CDM was included under the Kyoto Protocol in 1997, the first A/R CDM project was registered only in 2006, and as of September 2011, only 31 projects have been registered, compared to 3,377 CDM projects covering all sectors, mainly the fossil-fuel sectors. The poor response of A/R CDM projects is largely due to complex methodologies, guidelines, and procedures. Critical issues in planning, designing, and implementing A/R CDM projects are related to the development of a baseline scenario of carbon stocks and changes, establishment of additionality of a CDM project, and measurement, monitoring, reporting, and verification (MRV) of C-benefits. Even after nearly 15 years of including A/R under CDM, very little progress has been made due to methodological complexities and capacity limitations in many tropical countries. This tardy progress emphasizes the need for developing simplified yet scientifically valid and reliable methods and guidelines for measuring C-benefit and for building technical and institutional capacity in developing countries.

A.1.1.5. Watershed

Watershed development is one of the major programs aimed at multiple economic and environmental objectives such as the development of agriculture, forest, and grassland; improvement of livelihoods; and reduction in vulnerability to climate change. A watershed is the land that drains to a particular point along a stream. Each stream has its own watershed. Topography is the key element governing the total area of a watershed: The boundary of a watershed is defined by the highest elevations surrounding the stream. A watershed encompasses multiple land categories (such as cropland, grassland, forest, and catchment areas) and water resources (irrigation tanks, streams, etc.). Potential watershed project activities that contribute to enhancing C-benefits include afforestation of catchment area, construction of farm ponds and check dams for water conservation and storage, soil conservation, grassland reclamation, desilting of water bodies, and multiple cropping. Each of the land categories and watershed activities offers an opportunity to enhance carbon in biomass and soil. Further, soil and water conservation practices could enhance annual and perennial biomass production and litter turnover, contributing to increased biomass and soil carbon stocks.

A.1.2. World Bank Projects with Direct or Indirect Implications for Carbon

The World Bank is one of the largest multilateral financial institutions providing technical and financial assistance to developing and transitional countries. The broad vision of the World Bank is a world free of poverty and the achievement of the Millennium Development Goals. The broad themes supported by the World Bank include economic management, environment and natural resources management, financial and private sector management, human development, public sector governance, rural development, social development including gender issues, social protection and risk management, trade and integration, and urban development. These themes are subdivided into sectors, and some examples of sectors currently in existence under project operations are as follows:

- Land-related sectors—agriculture, fishing, and forestry, water, sanitation, and flood protection
- Energy sector—energy and mining
- Finance, education, health, industry and others—public administration, law and justice, information and communications, education, finance, health and other social services, industry and trade, and transportation

These guidelines focus on C-benefit enhancement in all programs and projects related to land, which may include agriculture, forestry, grassland and desert development, and irrigation and watershed programs. Further, these broad sectors include programs that encompass agricultural extension and research, crops, irrigation and drainage, forestry, general agriculture, fishing, and forestry. Examples of Bank land-based projects with potential for C-enhancement are given in table A.3.

Table A.3 is an illustrative list of projects in the agriculture, forestry, and water supply sectors that can have implications for carbon, underscoring the need to assess the potential interventions aimed at C-enhancement in each of the sectoral projects linked to land-based activities. This is attempted in the following chapters. The broad sectors and themes of the World Bank projects relevant to providing C-benefits are as follows:

- Sectors—general agriculture, forestry, and water supply
- Themes—biodiversity, agriculture, forestry, environment and NRM, and irrigation

A.1.3. Broad Goals of Typical World Bank Projects Relevant to C-Benefits

Generally, most land-based agriculture and NRM projects are assumed to be carbon positive, leading to net C-benefits. However, it is necessary to estimate and monitor the carbon stock changes, first to understand the carbon impacts and secondly to ensure that the C-benefits are not negative or that there is no net increase in CO_2 emission. These guidelines

TABLE A.3: Examples of Land-Based Projects in Different Sectors of the World Bank with Potential for C-Enhancement

SECTOR	SUBSECTOR	TITLE OF THE PROJECT	PROJECT NO.
Agriculture	Agriculture and crop production	Assam Agriculture Competitive Project	**P084792**
	Biodiversity conservation	Sustainable Land and Ecosystem Project	**P11060**
Water Resources	Watershed, hydrology, and natural resource management	Uttar Pradesh Water Sector Restructuring Project	**P050647**
		Mid Himalaya Watershed Development Project	**P093720**
		Uttarakhand Decentralized Watershed Development Project	**P078550**
	Tank irrigation	Andhra Pradesh Tank Project	**P100789**
Livelihood	Microfinance	Andhra Pradesh Livelihoods Project	**P071272**
Forestry	Community-based forest management	Andhra Pradesh Forestry Project	**P073094**
	Carbon sequestration	*Himachal Pradesh BioCarbon Forest Carbon Sequestration*	**P104901**

Source: http://www.worldbank.org.in/external/default/main?menuPK=295615&pagePK=1411155&piPK=141124&theSitePK-295584

describe simplified methods for estimation and monitoring of carbon footprints of land-based projects. Typical World Bank projects in the land-use sectors could broadly seek to achieve one or more of the following objectives synergistically with enhanced C-benefits:

- *Agricultural and watershed development*—The World Bank has a large portfolio of agricultural development projects with a goal to increase and/or sustain crop (and animal husbandry) production. All activities leading to increased or sustained agricultural production lead to enhanced carbon stocks in soils and vegetation. Watershed and irrigation projects also aim at increasing and stabilizing crop yield, indirectly contributing to enhanced biomass production and accumulation of soil carbon. Some examples of potential goals of World Bank projects could be as follows:
  - Promotion of sustainable agriculture
  - Increased crop production
  - Crop intensification
  - Watershed conservation and development
- *Poverty alleviation and livelihood improvement*—The main goal of projects that aim at poverty alleviation and improved livelihoods would be to increase and sustain income from crop production, livestock management, and forestry, and most such projects provide indirect C-benefits. All activities aimed at increasing and sustaining incomes and employment generally involve improving soil fertility (and carbon stock), increased tree diversity and density, and sustainable management of forests and grasslands.
- *Irrigation and water conservation*—Projects related to irrigation and water conservation aim at increasing the area under irrigation, enhancing water supply for rain-fed crops, improving water-use efficiency, and promoting conjunctive use of water. These activities lead to increased biomass production and turnover of root and crop residue, increasing the soil carbon stocks.
- *Biodiversity conservation*—Projects on biodiversity conservation focus mainly on forests, grasslands, and wetlands; C-benefit is a cobenefit of such projects. The key projects that contribute to biodiversity conservation include management of protected areas (PAs) and REDD.
- *Land reclamation and halting desertification*—Projects related to land reclamation and halting desertification not only improve soil fertility, but also add to biomass in the form of vegetation barriers erected to check the spread of deserts.
- *Adaptation*—Adaptation is an emerging program in the World Bank portfolio, which is projected to grow in the coming years. The goal of adaptation projects is to reduce vulnerability of crop and forest production to climate variability and climate change. Adaptation projects, particularly in the agriculture sector, lead to enhanced soil fertility and soil carbon as well as increased biomass stocks, such as agro-forestry and shelterbelts.

- *Climate change mitigation*—The main goal of mitigation projects is to directly aim at generating C-benefits through technical, financial, and institutional interventions. The best examples of climate change mitigation projects include REDD and projects under the BioCarbon Fund. In these projects, carbon stock enhancement or CO_2 emission reduction is a direct project benefit.

Thus, a large number of categories or types of projects typically funded by the World Bank to advance its major themes will all provide multiple benefits including environment conservation, enhanced food production and security, and economic development as well as offering C-benefits, typically as cobenefits. Apart from the above types of NRM and development-oriented projects, there could be dedicated land-based C-benefit–enhancing projects related to:

- Reducing deforestation and forest degradation
- Sustainable forest management
- BioCarbon fund and CDM projects

Thus, typical land-based developmental projects have the potential to provide C-benefit as a cobenefit in bulk of the mainstream project types as well as dedicated C-benefit projects. Even land-based adaptation projects can provide mitigation benefits. Thus, there is a need to recognize and enhance the importance of most or all land-based projects in providing enhanced C-benefits.

Section A.2 presents an approach and guidelines to recognize, enhance, and monitor C-benefits to assist project developers and managers in designing, implementing, and monitoring land-based projects. Section A.3 dwells on the implications of incorporating C-enhancement modules or practices, Part B describes the technologies and practices for enhancing C-benefits, and Part C gives details of the methods for estimating and monitoring C-benefits.

A.2. GUIDELINES FOR ENHANCING C-BENEFITS FROM LAND-BASED PROJECTS

This guideline for carbon stock enhancement or CO_2 emission reduction in land-use sectors presents two approaches. The first is a generic approach covering all the land categories and interventions aimed at promoting the economic (crop, timber, and non-timber wood product production, employment, or livelihood generation) and environmental (soil and water conservation, biodiversity protection, and land reclamation) objectives of a project, synergistically optimizing the carbon stock enhancement as a cobenefit. The second is a the management of project carbon scenarios for high-value cropping systems and production practices appropriate for a given agro-ecological region and meeting the needs of the local stakeholders such as farmers or landless laborers. The guideline provides methods for selection and incorporation of carbon stock enhancement modules and practices and methods for estimation and monitoring of carbon stock changes as well as assessment of social and economic implications of C-enhancement interventions. The steps for these two approaches are presented in figure A.3.

A.2.1. Principles for Carbon Stock Enhancement in Land-Based Projects

Carbon stock enhancement in land-based projects should also meet other socio-economic and environmental requirements and objectives.

A.2.1.1. Goals of Land-Based Projects and Carbon Mitigation

The objective of these guidelines is to promote climate change mitigation or C-benefit enhancement in World Bank's land-based developmental projects as cobenefits along with the following potential goals or objectives of the projects:

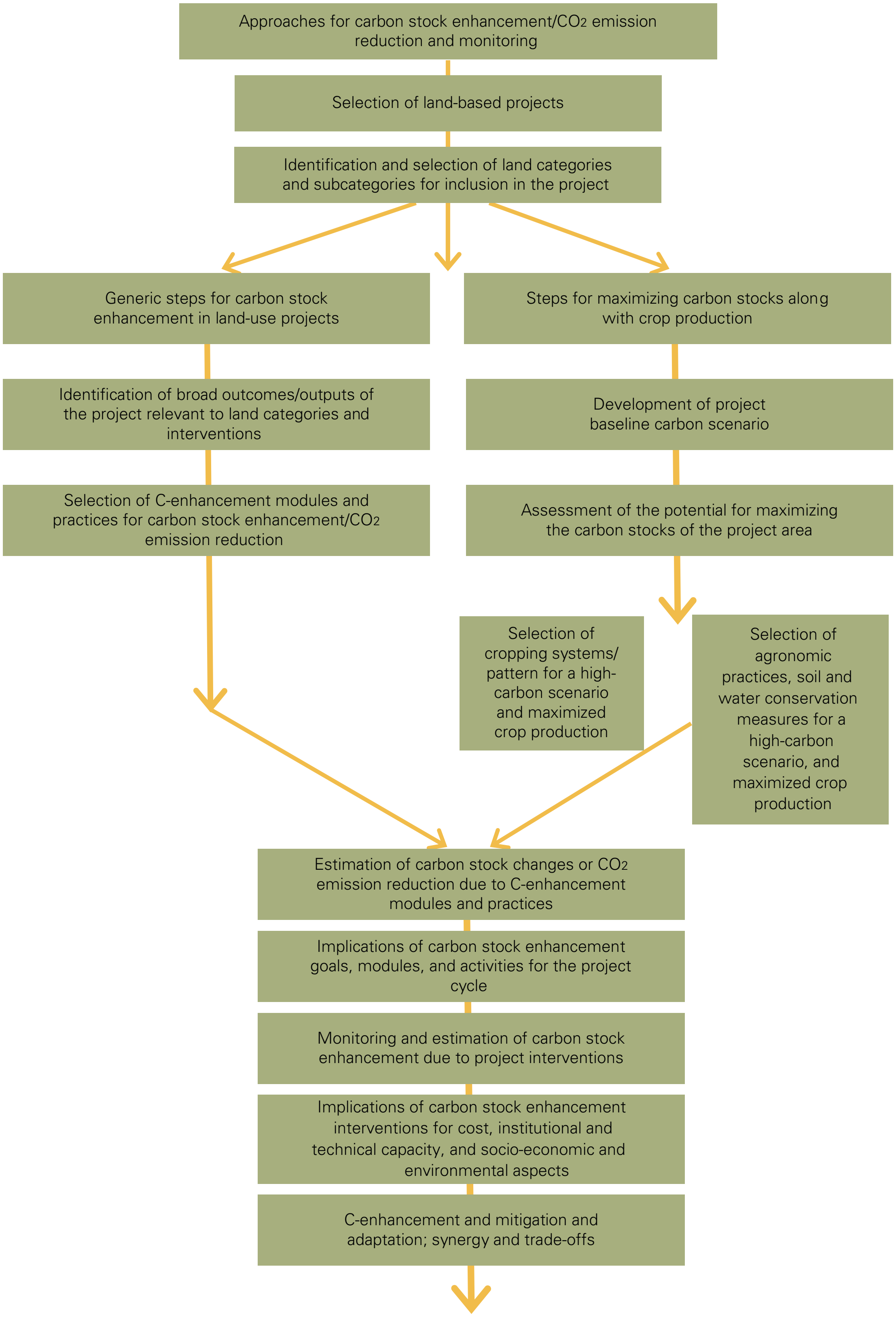
- Food production enhancement and stabilization plus carbon stock enhancement
- Promotion of sustainable agriculture production plus carbon stock enhancement
- Watershed development or soil and water conservation plus carbon stock enhancement
- Biodiversity conservation plus carbon stock maintenance or enhancement
- Afforestation or community forestry plus carbon stock enhancement
- Adaptation to climate change impacts plus carbon stock enhancement

These guidelines are practical in that the emphasis is on how to incorporate and/or enhance C-benefits in the World Bank land-based projects in agriculture, watersheds, and forests.

A.2.1.2. Modes of C-Benefits Through Land-Based Projects

Land-based projects can provide C-benefits directly or indirectly. The benefits could be in the form of conserving (PA management) or enhancing existing carbon stocks (agroforestry, sustainable agriculture, afforestation, and shelterbelts), reducing CO_2 emissions (such as REDD), and replacing fossil fuels (with biofuels and bioenergy).

FIGURE A.3: Approach to Enhancing C-Benefits in Agriculture and NRM Projects



Source: Authors.

1. Carbon conservation: There are many land-based systems with high-carbon density, which may have to be conserved and their carbon stocks maintained at the current level. Many of the land-based systems such as forests, grasslands, and wetlands are subjected to anthropogenic pressures, leading to reduction in carbon stocks without changing the land use. An illustrative list of projects aimed at carbon conservation is given in table A.4. Carbon conservation projects could be on forest land (involving native forests), grasslands (natural grasslands), and wetlands. The projects under this category are characterized by high-carbon stocks, which need to be maintained by improved management and reduced anthropogenic pressures. The plus component of the REDD+ mechanism includes forest conservation as one of the activities. There could be two options for carbon conservation in such projects: developing new projects aimed at carbon conservation and incorporating practices aimed at effective carbon conservation in existing projects or projects in the pipeline.

2. Carbon stock enhancement: The carbon stock of forests, grasslands, and croplands are subjected to degradation and loss. Globally, about 910 Mha is subjected to degradation (GEO-3 2002) and loss; in India, over 50 percent of the land is subjected to degradation, leading to loss of carbon. Projects in this category cover all the land categories subjected to anthropogenic stress or degradation. C-enhancement in land-based projects could be a direct benefit or a cobenefit. Practices focused on enhancing carbon stocks in croplands, grasslands, and forests aim at enhancing biomass productivity of crops, grasses, and trees. Potentially, all land-based projects are likely to lead to enhanced carbon stocks. C-enhancement projects could encompass agricultural development (including watershed and sustainable agriculture), grassland management, and A/R. The bulk of the World Bank land-based projects come under this category. The REDD+ mechanism includes carbon stock enhancement as one of the *plus* activities.

TABLE A.4: Potential Opportunities for Deriving C-Benefits from Land-Based Projects

CONSERVING CARBON STOCKS	ENHANCING CARBON STOCKS	REDUCING EMISSIONS
1. PA management **2. Wetland conservation** **3. Biodiversity conservation**	1. Agro-forestry and shelterbelts 2. A/R, community forestry 3. Watershed projects 4. Irrigation management (minor irrigation) 5. Sustainable agriculture 6. Land reclamation	1. Reducing deforestation 2. Reducing forest degradation 3. Reduced tillage 4. Halting land degradation

Source: Authors.

3. CO_2 emission reduction: According to the IPCC, reducing emissions from deforestation and degradation provides the largest opportunity to mitigate climate change. There are global efforts under the UNFCCC to reduce emissions from deforestation and forest degradation. The World Bank and other international agencies have dedicated programs aimed at reducing CO_2 emissions from forests. The focus of the world community, including the World Bank, would be on REDD as a priority activity in its effort to address climate change. The other major option aims at reducing CO_2 emissions from land degradation, particularly from croplands, grasslands, and wetlands. Other opportunities for reducing CO_2 emissions include reduced tillage in agriculture, improved grassland management, sustainable forest management, and fuelwood conservation and substitution programs.

4. CO_2 emission reduction through fossil fuel substitution: Several land-based technologies offer opportunities to produce biofuels as transportation fuels and biomass feedstock for power generation to replace fossil fuels. The major opportunities for CO_2 emission reduction through such substitution are as follows:

- Biofuels substituting fossil fuels in transportation
- Biomass power substituting fossil fuel power
- Biogas substituting fuelwood and fossil fuels (kerosene and LPG) used for cooking

Biofuel production is a controversial topic in the context of climate change mitigation because of potential CO_2 emissions resulting from conversion of high-carbon density forests, grasslands, wetlands, and peat. Biofuel production involving such land-use conversion may lead to no net negative CO_2 emission reduction and indeed may lead to increased emissions from land, which could be far higher than the CO_2 benefits from fossil fuel substitution (UNEP 2010). The biofuel option is not considered in these guidelines because the potential C-benefits, especially those arising out of land conversion and land use practices, are debatable.

A.2.1.3. Opportunity for Promoting Synergy: Environment and Developmental Goals and Climate Change Mitigation

Carbon mitigation is a global and long-term benefit—the benefit to local communities or the environment is neither significant nor immediate. Therefore, any intervention aimed at enhancing C-benefit should also aim at ensuring that the intervention also leads to some local economic or environmental benefits. Carbon mitigation in the land-use sector offers the means to ensure synergy between local and global benefits. The interventions for enhancing C-benefits, to be acceptable to local communities, farmers, or agriculture/forest departments, must be cost-effective, leading to tangible and preferably economic benefits (such as an increase in crop yield or water availability) and also environmental benefits (reduced soil erosion and increased soil fertility, biodiversity conservation), if possible. Thus, all efforts and approaches to enhancing C-benefits in NRM and developmental projects or in mainstreaming climate change mitigation must preferably adhere to the principles given below:

1. C-benefit enhancement should be a cobenefit of mainstream developmental projects
2. Potential must exist for synergy between the main project objective/goal and C-benefits
3. The interventions for C-enhancement must provide economic or environmental benefits
4. C-enhancement interventions should be cost-effective
5. C-benefit should be measurable or amenable to monitoring

A.2.2. Approaches for Carbon Stock Enhancement and CO_2 Emission Reduction

A detailed, step-by-step approach to select, incorporate, and enhance C-benefits (carbon stock enhancement and CO_2 emissions reduction) is presented in this section. The two approaches are presented in figure A.3. The first approach provides guidelines for project developers to manage project carbon scenarios for promoting high-value cropping systems and production practices, appropriate for a given agro-ecological region as well as to meet the needs of the local stakeholders. The second approach is a generic one covering all the land categories and interventions aimed at promoting the economic and environmental objectives of a project, synergistically optimizing the carbon stock enhancement as a cobenefit.

A.2.2.1. The "Carbon Baseline Scenario" and the "High-Carbon Scenario" Approach for Maximizing Crop Production Potential

Maximization of C-benefit in a land-based project focused on crop production systems can be achieved by (1) development of an understanding of the project baseline carbon stocks, (2) assessment of its crop production potential, (3) identification of the maximum carbon stocks that can be achieved in a project area along with maximizing the crop production potential, and (4) selection of appropriate cropping system and production practices. This approach helps to maximize C-benefits from a project synergistically with maximizing crop production. There is adequate scientific evidence to show that the soil organic matter or carbon stock is one of the key indicators of crop production potential, especially in rain-fed or dry land agriculture. This approach could be adopted along with the generic approach described in section A.2.2.2. This approach is different from the generic approach described in this guideline since it aims at maximizing project carbon stocks as the starting objective followed by increasing crop production potential. In the generic approach, predominantly, project outcomes and outputs are the focus of the project, and carbon is considered as a cobenefit. Steps for maximizing C-benefits in crop production systems are as follows:

Step A: Develop project baseline carbon scenario—In this step, baseline carbon stocks of all the land categories and the total project area is estimated at the beginning of the project *ex ante*. It is assumed that in most cases, the carbon density of the project land categories at the beginning of the project would be low, potentially leading to low crop production. Estimation of baseline carbon stocks (in tons per ha) provides opportunity for assessing the potential for maximizing the carbon stocks and crop production potential. It may also help in selecting cropping systems and production practices to increase C-benefits. The main steps for estimating the baseline carbon scenario are detailed in section D.2.

Step B: Development of high-carbon scenario for the project area—This involves estimating maximum potential carbon stocks that could be achieved in the project area for the given agro-climatic and soil conditions. This potential could be termed as a *high-carbon scenario*. This could be different for annual crops and tree or forest-based interventions. Here the focus is largely on crop-based interventions to maximize the carbon stocks. Estimation of the *high-carbon scenario* involves obtaining maximum carbon density values from one or more of the following sources:

- Experimental plots in local agricultural research stations
- Well-managed or undisturbed grasslands
- Well-managed agro-forestry systems
- Literature values for well-managed or high-yielding cropping systems
- Natural forests or grasslands in the region

The net potential for maximizing C-benefits in a project area can be estimated on the baseline carbon scenario and *high-carbon scenario* stocks. However, it has to be noted that maximum carbon density recorded for a given land use or cropping system could vary from region to region, soil types, cultivation practices, rainfall, and irrigation availability. Thus, *high-carbon scenario* stocks will only give a crude estimate of the potential available for maximizing the C-benefits.

Step C: Assessment of crop production potential under a high-carbon scenario—One of the factors determining crop yield is the soil organic matter or carbon stock density of the land. It is assumed that under the baseline or preproject scenario, SOC density as well as the crop yield is likely to be low, and the project aims to increase and sustain crop production. Maximum crop production potential under a *high-carbon scenario* could be obtained from agricultural research institutes or universities. However, it has to be noted that SOC is only one of the contributing factors for increasing the crop yield, the other factors being the crop grown, crop variety, cultivation practices, fertilizer application rates, soil type, rainfall, and irrigation availability. The information needed for linking crop production potential to soil organic matter/carbon may be limited in literature for a given project region.

Step D: Selection of cropping systems or practices for a high-carbon scenario—One of the main goals of any agricultural development or intensification project is to maximize and sustain crop productivity. Maximization of crop production would involve selection of the following:

- Alternate crops or cropping systems
- High-yielding varieties
- Multiple cropping
- Mixed cropping
- Crop-intensification practices.

Selection of a cropping system is critical to maximizing the crop yields. However, it is only one of the factors determining crop yields (the others are presented above). Selection of a cropping system is also one of the factors contributing to increasing carbon stocks in the croplands.

Step E: Selection of CEMs/CEPs for a high-carbon scenario—Selection of agronomic, soil, and water management practices in addition to cropping systems is critical to maximizing C-benefits. These could be termed as CEMs and CEPs. The approach and methods for selecting CEMs/CEPs is described in section A.2.3.

All the other aspects of the C-enhancement guidelines such as procedures for selecting the CEMs/CEPs, estimating the carbon implications, assessing the socio-economic and environmental impacts, and measurement and monitoring of carbon stock changes are described in section A.3.

A.2.2.2. Generic Approach to Enhancing C-Benefits in Environmental and Developmental Projects

Enhancement of C-benefits from mainstream World Bank NRM and developmental projects would require a systematic approach to ensure optimized delivery of project goals and outputs along with C-benefits in a synergistic manner. No clearly identified guidelines are currently available for mainstreaming C-benefits in typical World Bank projects. The approach should encompass not just technical interventions or inputs compatible with the project outputs/outcomes, but should also include the following aspects:

- Development of the baseline status of carbon stock changes or CO_2 emissions
- Selection and incorporation of CEMs and CEPs
- Assessment of the impact of dedicated interventions on carbon stock changes
- Monitoring of C-enhancement and socio-economic benefits
- Assessment of the incremental institutional and technical capacity needs
- Cost implications of the dedicated interventions
- Assessment of the economic and environmental implications of C-enhancement interventions
- Understanding any trade-offs between project goals and C-enhancement and potential for synergy
- Potential for adaptation to climate change as a cobenefit

A step-by-step approach to promoting the concept of C-enhancement is presented in figure A.4. These steps are described in detail in the following sections.

Incorporating the interventions cost-effectively and synergistically potentially requires modification of the project design, implementation and monitoring, and incremental technical and institutional capacity for certain categories of projects. However, this need not be true for many projects in which the activities to realize or enhance C-benefits may not involve any significant incremental investment or technical capacity. For example, afforestation and PA management for biodiversity conservation are likely to generate C-benefits without any incremental investment except that on monitoring.

A.2.3. Guidelines for Consideration and Enhancement of C-Benefits

The approach to and methods for identifying and selecting suitable CEMs and CEPs for enhancing C-benefits are presented here, along with the features and potential C-benefits. However, description and technical details of all the CEMs and CEPs are given in Part B.

A.2.3.1. Criteria for Selecting Projects for C-Enhancement

Selection of projects with potential for C-benefits is the first step. The main criteria for selecting projects for C-enhancement are as follows:

- Projects should have land as one of the components for intervention directly (such as forestry and biodiversity projects) or indirectly (such as water conservation and livelihood projects)
- Projects should offer the potential to conserve/enhance carbon stocks or reduce CO_2 emission directly (such as afforestation) or indirectly (such as soil or water conservation)
- C-benefit enhancement should be synergistic with the project's socio-economic or environmental goals

According to the World Bank's Global and India Country Strategy, the following categories of projects are likely to be eligible for delivering and enhancing C-benefits among the land-based projects. The broad themes and subsectors of the World Bank projects in agriculture and NRM directly relevant to C-enhancement are listed in table A.5.

Most of the projects in the subsectors or themes (table A.5) where land is an integral component of project activities will be relevant to C-enhancement. Direct and indirect C-benefits from land-based projects are as follows:

- Direct C-benefits
  - Watershed and sustainable agriculture projects enhancing biomass and soil carbon
  - A/R projects enhancing biomass and soil carbon
  - PA management conserving biomass and soil carbon stocks
  - Desert development programs enhancing soil and tree biomass carbon stocks
  - Agricultural intensification projects enhancing soil carbon
  - Minor irrigation projects increasing biomass production and turnover leading to enhanced soil carbon
- Indirect C-benefits
  - Soil and water conservation projects leading to increased biomass production and residue turnover
  - Sustainable livelihood projects depending on non-timber forest products (NTFP) and animal husbandry
  - Fuelwood conservation programs leading to reduced pressure on forests and tree resources
  - Practices, such as application of organic manure, leading to reduction in fertilizer use, indirectly reducing emissions of GHGs such as N_2O

TABLE A.5: World Bank Themes and Subsectors Relevant to C-Benefit Enhancement

THEMES	SUBSECTORS
• Biodiversity • Climate change • Land administration and management • Other environment and natural resource management • Water resource management	• Agricultural extension and research • Animal production • Crops • Irrigation and drainage • Forestry • General agriculture and forestry • Environment and natural resource management

Source: Authors.

A.2.3.2. Project Cycle Stages for C-Enhancement Interventions

The potential stages in the project cycle at which interventions to enhance C-benefits could be considered include the following:

- ***The project planning and designing stage*** is the ideal stage to identify potential interventions leading to enhanced C-benefits since it is possible to develop a package of interventions optimizing NRM or developmental benefits along with the C-benefits, such as agro-forestry activity incorporated into a watershed or an agricultural development project.
- ***The post project-approval stage*** is another possibility. If a project has been approved without any planned interventions dedicated to enhancing C-benefits but provides an opportunity to incorporate appropriate practices or technologies to enhance C-benefits synergistically with project goals (such as incorporating fuelwood conservation into a PA management project), it is possible to introduce those practices or technologies into the project.
- ***The implementation stage*** is probably the last stage at which appropriate interventions can be introduced. Although the project has started, it may be possible to incorporate a few practices to enhance C-benefits

so long as the practices are synergistic with the main goal of the project (such as incorporating mulching, organic manure application, or agro-forestry into an ongoing watershed project).

A.2.3.3. Decision Makers for Incorporation of C-Benefits

The final decision on incorporating the interventions related to C-benefits and their enhancement is a critical issue and one or more of the following could take the decision:

- ***Project developer—***The project proponent or developer will be the ideal decision maker given her or his first-hand knowledge of the project goals and objectives, land categories involved, socio-economic and environmental implications, and different stakeholders likely to be affected by the project.
- ***Project funder—***A funding agency could also alert the project developer to the potential for synergy between the project goals and C-enhancement. In fact, the funding agency is more likely to convince the project developer that most interventions aimed at C-enhancement also enhance or sustain NRM and developmental benefits.
- ***Project evaluator—***Technical experts who review and evaluate the project proposal could also suggest potential interventions to C-enhancement.
- ***Project manager—***Because C-enhancement activities could be incorporated or modified at various stages including the postproject sanction or project implementation stage, the project manager can also decide whether additional activities could be undertaken.

A.2.3.4. Selection of Land Categories

The land category chosen for intervention could include single or multiple land categories:

- ***A single land category*** such as grassland or degraded forestland or cropland is targeted for project intervention.
- ***Multiple land categories*** will feature in most projects since intervention in one land category (such as PA management) may require interventions in other land categories (such as grazing land outside the PA). Similarly, a watershed project would involve treatment of water catchment area, grazing land, and cropland.

Identification of land categories for the desired interventions could involve the following steps:

Step 1: Identify all the land categories considered in the project

- Cropland (irrigated and rain fed), grassland, catchment or watershed, degraded lands, settlement area, etc.

Step 2: Identify the land categories directly targeted in the project since all land categories in a village or watershed or landscape may not be included for treatment

- Water catchment in a watershed project, cropland in agro-forestry projects, and grazing land in grassland management projects

Step 3: Identify the current land use, which may include single or multiple uses.

- Wasteland or degraded forest land used for grazing and fuelwood collection apart from serving as a catchment area
- Forest land used for grazing, fuelwood collection, and as a source of green leaf manure
- Cropland for crop or grass production

Step 4: Identify all the interlinkages between the land categories directly targeted for intervention and other land categories in the project area

- Agricultural development project requiring catchment area treatment or wasteland for raising leaf biomass for organic manure application

Step 5: Select all the land categories that have direct or indirect linkage with the project objectives with respect to water flow, biomass production, grazing, etc.

Step 6: Develop different interventions for enhancing C-benefits in different land categories linked to one another (described in later sections).

Selection of land categories as described above makes it possible to select specific areas, interventions, and technologies or practices. The land category selected in the project will have implications for C-enhancement potential, as shown as follows:

- *Forestland:* Reducing deforestation will have the highest C-benefit per unit area
- *Degraded land:* Afforestation could have a large C-benefit potential
- *Cropland:* Sustainable agricultural practices could have a large potential for soil C-benefit

TABLE A.6: Examples of World Bank Projects Involving Multiple Land Categories Subjected to Interventions

PROJECT TITLE	LAND CATEGORY FOR INTERVENTIONS	ACTIVITIES	OUTCOMES
Community Management of Sustainable Agriculture	Cropland	• Conservative or deep furrows every four meters • Trench around the field, farm ponds • Tank silt application • Raising fruit gardens • Reduced dose of synthetic (inorganic) fertilizers and their eventual replacement with biofertilizers • Increased diversity and intensity of crops • Identification of appropriate cropping systems: intercropping, multicropping, and crop rotations • Enhancing and maintaining soil health through mulching, green manure, and vermicompost	Promotion of sustainable agriculture practices and production systems
Mid Himalayan Watershed Development Project	Agricultural land, common lands, wasteland within village boundaries, forest department lands • Undemarcated degraded forest land	• 60% of available treatable area of nonarable land is treated with forestry interventions • 60% of available treatable area of arable land is treated • 20% increase in fodder over baseline • 20% increase over baseline in area under high-value crops • 30% of farmers adopt new technologies • 4003 ha of carbon sink created	Reversal of the process of degradation of the natural resource base, improved productive potential of natural resources, and increased incomes of rural households in the project area through various water conservation techniques and plantation activities. In brief, • enhancement of carbon sinks (through comprehensive catchment treatment interventions)
Sustainable Land, Water and Biodiversity Conservation Management for Improved Livelihoods in Uttarakhand Watershed Sector	Degraded reserve forest land, common wasteland, agriculture wasteland, degraded grazing land	• 20 to 30% of the area in selected micro-watershed under improved sustainable land and ecosystem management techniques • Increase in availability of water in dry season by 5% in the treated micro-watersheds • 10% increase in tree and other vegetative cover in 20 micro watersheds • 50% reduction in incidents of fire in treated micro-watersheds • Cultivation of at least 5 local medicinal and aromatic plants by communities in 20 micro watersheds	Restoration and sustenance of ecosystem functions and biodiversity while simultaneously enhancing income and livelihood functions and generating lessons learned in these respects that can be upscaled and mainstreamed at state and national levels. In brief, reducing vulnerability to climate risks
Andhra Pradesh Community Forest Management Project	Forest land, including open forest and scrub, degraded forest land, degraded demarcated forest land, degraded undemarcated forest land, village common land, and revenue wasteland within forest area	• Area covered: teak forests, nonteak hardwoods, bamboo forests, red sanders forest, teak and bamboo mixed forests, nonteak and bamboo mixed forests, NTFP, medicinal plantations, and NTFP and fodder grasses • Number of seedlings planted through farm forestry • Increase in the extent of forest cover	Reduction in rural poverty through improved forest management with community participation

Source: Authors.

- *Cropland:* Water conservation projects could have a moderate potential for C-benefit
- *Grassland:* Livestock and grazing management could have a low potential for C-benefit

For example, PA management may require only protection from extraction or grazing, while an afforestation project could require raising a nursery, land preparation, planting, protection, and management. Table A.6 provides examples of land categories to be subjected to direct interventions, land categories likely to be impacted by project interventions, and project outcomes.

A.2.3.5. Identification of Broad Outcomes/Outputs of the Project

Each project will have broader project outcomes as well as more project-specific outputs. Most projects are likely to have multiple outputs related to objectives that are physical (such as reducing soil erosion and water conservation), biological (increased biomass production or crop productivity and biodiversity conservation), socio-economic (increasing incomes and employment), and institutional (capacity development). A good understanding of the outputs is critical for decisions on interventions for C-enhancement since the interventions will have direct or indirect implications for the project outputs. Table A.6 provides examples of outcomes/outputs of projects that have direct or indirect linkage to C-benefits. The carbon-benefit component of the outputs for the bulk of agricultural and NRM projects will be a cobenefit.

Most land-based projects may not require any drastic alteration or modification of the outputs to obtain C-benefits. Thus, it is possible to incorporate the objective of C-enhancement even at postapproval stages of the project prior to implementation.

The following approach could be adopted for identifying and selecting outputs for considering and enhancing the C-benefits:

Step 1: Identify all the outputs of the project—economic, environmental, capacity building, etc.

Step 2: Categorize the outputs into those linked to land-based interventions such as increasing soil fertility, tree cover and grass production, and biodiversity conservation, and those that are not land based

Step 3: Identify whether the outputs deliver direct or indirect C-benefits—most land-based projects may deliver carbon as a direct benefit of interventions aimed at delivering the project outputs

Step 4: Explore and identify the possibility of including additional outputs; it is desirable to add additional outputs aimed at enhancing the C-benefits synergistically with other project outputs, which may require

- potentially incremental interventions
- monitoring of the C-benefits

Step 5: Identify the activities or practices required for each of the outputs leading to direct or indirect implications for carbon.

A.2.4. CEMs and CEPs for C-Benefits

These guidelines seek to obtain higher levels of C-benefits in terms of enhanced carbon stocks or reduced CO_2 emissions from a given area of land. Obtaining higher levels of carbon stocks or reduced emissions of CO_2 requires a package of activities or interventions to be incorporated into any land-based project. These interventions could be considered at two levels, namely CEMs and CEPs or C-enhancement technologies. Although an attempt is made to distinguish between CEMs and CEPs, the two often overlap and could be used interchangeably.

CEMs are subprojects consisting of a single or, more often, multiple components or a package of activities or technologies aimed at enhancing C-benefits from any land-based project. These modules synergistically contribute to the main socio-economic or environmental goals of the project while providing C-enhancement as a cobenefit. Agro-forestry, watershed management, sustainable agriculture, and afforestation are examples of CEMs.

CEMs

- Watershed development
- Agro-forestry
- Soil conservation
- Water conservation
- Soil and water conservation
- Shelterbelts
- PA management
- Land reclamation
- Sustainable agriculture
- Afforestation and forest regeneration
- Biodiversity conservation
- Community forestry
- Irrigation (minor or major)
- Fuelwood conservation devices
- Fruit orchards and gardens

CEPs are technologies, activities, or practices aimed at conserving or enhancing carbon in selected land categories. Reduced tillage, mulching, organic manuring, etc., are examples of CEPs.

CEPs

- Mulching
- Organic manure application
- Green manure application
- Reduced or zero tillage
- Contour bunding
- Farm ponds
- Tank silt application
- Intercropping/multiple cropping
- Cover cropping

Practices leading to negative C-benefits

It is necessary to avoid certain land management practices that could potentially lead to increased emissions of CO_2 or reduced carbon stocks. Examples of such practices are:

- Disturbance of soil, leading to enhanced oxidation of SOC
- Harvesting and burning of trees, tree branches, crop residue, and weeds
- Conversion of carbon-rich forests and grasslands to croplands or managed grasslands

A.2.4.1. Categories of Projects for Developing CEMs or CEPs

Any NRM or developmental projects involving different land categories could fall into one of the following three categories in which CEMs or CEPs could be integrated:

- Projects in which C-enhancement is an integral part of the project delivering socio-economic or environmental benefits but C-benefit is neither recognized nor monitored
- Projects in which C-enhancement is not an integral component of the project delivering socio-economic or environmental benefits; however, potential exists for incorporation of cost-effective CEMs aimed at generating C-benefits synergistically with the project goals and outputs
- Projects in which C-benefit is one of the main outputs and would include activities directly aimed at enhancing C-benefits
- Projects in which additional activities or interventions could further enhance C-benefits

It is assumed here that the bulk of the World Bank projects belong to one of the first two categories mentioned above and will have the potential for additional or incremental interventions/activities that could enhance C-benefits.

A.2.4.2. Factors Determining C-Benefits

The extent of C-benefits in terms of tC stock enhanced or CO_2 emissions avoided could depend on various factors:

- ***Land category***—A project may have a single land category, such as degraded community land for afforestation, or multiple land categories, such as a watershed project involving cropland, catchment area, grazing land, forest land, etc. The C-benefit would be high for an afforestation program in degraded lands or low for arid land reclamation in terms of tons of C-benefit per ha.
- ***Baseline carbon stock or CO_2 emissions***—The land selected for the project activity could have high-carbon density (such as well-managed grassland or forest) or low-carbon density (such as an eroded, rain-fed cropland). In a typical afforestation project on degraded lands, the baseline carbon stock, particularly biomass carbon, is generally low and the project interventions could lead to enhanced soil and biomass carbon.
- ***Region***—The C-benefit per unit of investment would be high in high-rainfall zones and in valleys and low-lying agricultural lands. The C-benefits per ha from project intervention would be low in arid lands or on sloping lands in hilly areas subjected to erosion.
- ***CEMs or CEPs***—An agricultural development project may include multiple practices (mulching, organic manure application, and soil conservation), providing higher levels of C-benefits. Similarly, afforestation of degraded lands may provide higher C-benefits. On the other hand, a soil conservation project may provide lower per ha C-benefits.
- ***Intensity of activity***—The greater or more intense the level of activity, the greater the benefits. The level can be expressed in such measures as tons of mulch or organic manure applied per ha, the number of irrigations, the depth of tillage, and the density of planting.

Types of interventions: The types of interventions could be grouped into the following categories:

- ***Biological interventions*** include enhancing vegetation cover (agro-forestry) and incorporating organic matter into soil (application of compost or mulch), where carbon accumulation occurs in perennial trees, shrubs, and soil.
- ***Physical interventions*** include construction of physical structures for soil and water conservation such as farm ponds, contour bunds, and check dams where C-benefit accrues indirectly in the form of enhanced growth of crops or trees.
- ***Institutional and capacity-building*** interventions such as selection of appropriate cropping patterns, a watershed plan, improved PA management, and improved monitoring of deforestation areas could contribute indirectly by reducing degradation and the resulting CO_2 emissions or by maintaining or improving biomass stocks.

A.2.4.3. Features of CEMs or CEPs for Enhancing C-Benefits

CEMs and CEPs could be considered at any of the three phases of a project cycle, namely p*roject design, postapproval,* *and implementation* (see section A.3.1.), and may belong to any of the following types:

- Project activities involving direct interventions on the land category selected, such as land preparation, planting of trees, and manuring.
- Project activities involving indirect interventions where C-enhancement is an unintended benefit, such as shifting of grazing, soil moisture conservation, increased irrigation, and alternative livelihoods in a PA project.
- Project activities involving improved monitoring of, for example, soil fertility, crop productivity, forest area, deforestation rate, biodiversity, and plantation biomass growth rates and capacity building for improved management.
- Project activities involving fuelwood conservation, promotion of stall-feeding of livestock, reducing water losses, etc.

In this section, an attempt is made to develop generic modules or models for land-based activities for enhancing C-benefits. These CEMs could be incorporated into any ongoing or proposed projects to enhance the C-benefits synergistically with the project's main goals. Potential examples of CEMs for land-based projects are given in tables A.7 to A.9, keeping in mind the broad sectors, themes, or categories of World Bank projects. These modules may or may not directly match with the World Bank's sectors or themes but could be incorporated into NRM and developmental projects under different sectoral or thematic areas. A project may consider one or multiple modules. Further, a module may involve a single activity or multiple activities, and a project developer or manager should select relevant activities compatible with the project goals and the region. Although the features of a CEM or CEP may vary from one agro-climatic region to another, typical CEMs/CEPs could have the following features:

- Applicable to land-based projects where potential exists for enhancing biomass and/or soil carbon stocks or reducing CO_2 emissions
- Contributes to the goals of typical land-based World Bank projects, such as
  - increasing economic benefits through increasing crop yields, livestock production, timber production, grass production, NTFP availability, and employment generation
  - environmental benefits such as biodiversity conservation, groundwater recharge, and improvement of soil fertility
- Could generate or enhance C-benefits in typical land-based projects such as increasing SOC in a watershed or land reclamation projects
- Could involve a single practice or technology (such as mulching) or multiple practices (such as soil and water conservation and afforestation in watershed projects)
- Could be incorporated into an ongoing project or at the design stage of a new project
- Enables estimation and monitoring of C-benefits

A large number of CEMs could be envisaged for land-based projects. The CEMs could be broadly categorized based on the overall goal or sector or land category as given below and explained in tables A.7 to A.9:

- *Agriculture intensification, watershed development, and sustainable agriculture:* A major sector of developmental projects comprises intensification or development of agriculture aimed at increasing, diversifying, and sustaining crop and livestock production in all regions including arid, semi-arid, and humid regions. The activities aim at increasing and stabilizing crop yields through soil and moisture conservation, irrigation, increasing soil fertility, changes in cropping systems (mixed and multiple cropping), agro-forestry, sustainable agriculture practices, and so on. Generally, most watershed projects aim at agricultural development through soil and moisture conservation, soil fertility enhancement, and afforestation of catchment areas. C-benefit accrues first through increased biomass production and litter or residue turnover, leading to increased soil organic matter or carbon content, and secondly through tree or perennial crop growth, leading to increased biomass carbon stock.
- *Forest conservation and afforestation:* The set of CEMs applicable to forest conservation and afforestation projects aims at restoration of degraded forests, afforestation of degraded lands, conservation of biodiversity, and production of fuelwood and timber. These projects could lead to enhanced carbon stocks (biomass and soil carbon) through forest regeneration and tree planting. Further, protection and sustainable management practices may contribute to maintenance of carbon stocks. CO_2 emission reduction could also be achieved by regulating biomass extraction and grazing practices.
- *Livelihood improvement and poverty alleviation:* Agriculture is the dominant livelihood activity for those with and without land in rural areas, followed by livestock rearing and exploiting forest produce. All

TABLE A.7: Features of C-Enhancement Modules for Projects Related to Agriculture

MODULE	FEATURES AND IMPLICATIONS FOR CARBON AND OTHER BENEFITS
Agro-forestry	**Feature:** Agro-forestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence. Agro-forestry systems involve mixing or intercropping of rows of trees and annual crops, where there could be synergy between trees and crops and also diversification of biomass products and incomes. **Outputs/Benefits:** Agro-forestry contributes to enhancing crop yields through soil improvement and provides tree-based products contributing to increased incomes and improved livelihoods, thereby enhancing resilience to climate risks. Growth of trees and litter turnover lead to enhanced biomass and soil carbon stocks.
Shelterbelts	**Feature:** Shelterbelts or windbreaks consisting of trees, shrubs, and grass strips of varying width are established in arid or desert areas to control soil erosion due to water and particularly due to wind. Tree rows are established at right angles to the prevailing wind direction. **Outputs/Benefits:** Windbreaks reduce wind velocity by 65 to 87%, reduce soil erosion by as much as 50%, increase crop yields ranging from 10 to 74% (Pimentel *et al.* 1997), and provide fuelwood and fodder. Growth of trees and litter turnover lead to enhanced biomass and soil carbon stocks.
Irrigation (minor or major)	**Feature:** Irrigation involves providing supplementary water to rain-fed cropland and bringing new area under cultivation. **Outputs/Benefits:** Irrigation leads to greater cropping intensity, increased crop productivity, and higher biomass production. In croplands, increased crop residue biomass production and turnover lead to soil carbon accumulation.
Sustainable agriculture **Integrated pest and nutrient management**	**Feature:** Sustainable agriculture is a form of agriculture aimed at meeting the needs of the present generation without endangering the resource base of future generations and involves a package of practices covering replacement of inorganic fertilizers with organic manures and of pesticides with integrated pest management, soil and water conservation, promotion of agro-forestry or shelterbelts, multiple cropping systems, etc. **Outputs/Benefits:** Sustainable agriculture and integrated management lead to stable crop yields, increased soil fertility, and reduction in the use of fertilizers and pesticides. Increased crop residue biomass production and turnover lead to increased soil carbon stocks.
Orchards	**Feature:** Orchards include cultivation of fruit trees such as mango, tamarind, sapota, guava, and *Zizyphus*, particularly on marginal croplands as block plantations. **Outputs/Benefits:** Orchards supply economically valuable fruits for the market and also protect the growers from failures of the annual crop. Growth of perennial fruit trees contributes to increased tree biomass carbon stock as well as SOC due to increased leaf litter turnover.

Source: Authors.

TABLE A.8: Features of C-Enhancement Modules for Forestlands

MODULE	FEATURES AND IMPLICATIONS FOR CARBON AND OTHER BENEFITS
Management of PAs	**Feature:** Management of PAs involves a package of practices covering banning or regulating grazing and the extraction of biomass and forest products, provision of alternative livelihoods, promotion of natural regeneration, and forest succession. **Outputs/Benefits:** Conservation of plant and animal biodiversity and regeneration of native species. Conservation of plant biomass, its accumulation, and litter turnover lead to enhanced biomass and soil carbon stocks.
Reducing deforestation	**Feature:** Reducing deforestation involves halting the conversion of forest land to nonforest purposes such as agriculture, infrastructure, and livestock farming. This may involve increasing the productivity of existing croplands, fodder production, provision of alternative livelihoods, and growing industrial wood plantations (as a substitute for industrial wood from forests). **Outputs/Benefits:** Conservation of forests, biodiversity, and watershed services and sustained supply of NTFP. Reducing deforestation is one of the most important carbon-benefit–enhancing mechanisms; it reduces CO_2 emissions by reducing the combustion of biomass and decomposition of organic matter in soil and litter.
Reducing forest degradation	**Feature:** Reducing forest degradation involves harvesting forest products such as timber and fuelwood sustainably and reducing pressure on forests by providing improved cookstoves and alternative cooking fuels such as biogas and LPG. Improved fire management can also contribute to reducing forest degradation. **Outputs/Benefits:** Practices aimed at reducing forest degradation lead to forest regeneration, conservation of biodiversity, and sustainable production of NTFP. Carbon stock enhancement occurs because of improved management of forest lands, reduced or sustainable extraction of wood, and provision of alternative cooking fuels.
Community forestry	**Feature:** Community forestry is similar to A/R with a focus on participation of local communities and meeting their diverse needs. **Outputs/Benefits:** Biodiversity conservation, such as increasing forest cover, production of timber, fuelwood, and NTFP for meeting local needs. Increased tree and nontree biomass growth and litter turnover lead to biomass and soil carbon stock enhancement.

Source: Authors.

TABLE A.9: Features of C-Enhancement Modules for Multiple Land Categories

MODULE	LAND CATEGORY	FEATURES AND IMPLICATIONS FOR CARBON AND OTHER BENEFITS
Soil conservation	Cropland, grassland, forest land	**Feature:** Soil conservation involves a package of practices aimed at reducing soil erosion due to wind and water and enhancing the water-holding capacity of soil and soil fertility, ultimately increasing biomass production through better growth of crops and forests. **Outputs/Benefits:** Prevention of the erosion of fertile topsoil and thereby reducing the loss of nutrients and sedimentation of water bodies. Soil conservation practices lead to increased biomass growth, litter turnover, and carbon stock enhancement.
Water conservation	Cropland, grassland, forest land	**Feature:** Water conservation involves a package of practices aimed at conserving moisture, reducing runoff and evaporation, and increasing groundwater recharge. Water conservation would lead to enhanced productivity of crops, grasses, and forests. **Outputs/Benefits:** Increased soil moisture favors growth of vegetation, thereby increasing crop/grass/tree biomass productivity and groundwater recharge. Increased biomass production and litter turnover lead to enhanced biomass and soil carbon stocks.
Soil and water conservation	Cropland, grassland, forest land	**Feature:** Soil and water conservation consists of a package of practices aimed at conserving soil and moisture by building suitable physical structures, applying organic amendments, and introducing agro-forestry and appropriate cropping systems. **Outputs/Benefits:** Soil fertility improvement, soil moisture conservation, increased crop/grass/tree growth, reduced vulnerability to droughts and moisture stress. Increased biomass production and litter turnover lead to enhanced biomass and soil carbon stocks.
Watershed	Cropland, grassland, forest land	**Feature:** Watershed development includes a package of practices aimed at catchment area treatment, soil and moisture conservation, improved cropping systems, and grassland management. **Outputs/Benefits:** Increased cropping intensity and productivity, reclamation of degraded lands, production of biomass in catchment area, afforestation, diversified income to farmers, and reduction of vulnerability to climate variability and moisture stress. Increase in perennial crop/tree biomass and soil carbon stocks.
Biodiversity conservation	Grassland, forest land	**Feature:** Biodiversity conservation involves preservation and protection of biological diversity through scientific management to maintain ecological balance and reduction of anthropogenic pressure on forests. Further, it could include a package of practices such as banning or regulating extraction of biomass and grazing. **Outputs/Benefits:** Maintenance of ecological balance, preservation of species, and genetic diversity. Preservation and enhancement of plant biomass and soil carbon stock and reduction in CO_2 emissions as a result of controlling extraction.
Afforestation and reforestation	Degraded forestland, wasteland, and grazing land	**Feature: Afforestation** involves growing forest or plantation species on degraded grassland, cropland, or wasteland to produce fuelwood, timber, and NTFP and indirectly contributing to forest biodiversity conservation. It could involve planting of single or multiple tree species. **Reforestation** involves growing trees for production of wood and other forest produce on lands originally covered with forests but degraded owing to biotic interference. **Outputs/Benefits:** Increased forest or plantation tree cover, biodiversity conservation, production of timber, fuelwood, and NTFP for meeting local as well as industrial needs. Increased tree and nontree biomass growth and litter turnover lead to biomass and soil carbon stock enhancement under both afforestation and reforestation and could also contribute to reducing CO_2 emissions by reducing pressure on natural forests.
Silvi-pasture/ horti-pasture	Grassland or grazing land	**Features: Silvi-pasture** is where woody perennials, preferably of fodder value, are planted and raised on grazing land to optimize land productivity, conserving species, soils, and nutrients and producing mainly forage, along with timber and fuelwood. **Horti-pasture** involves raising perennial horticultural crops such as mango, tamarind, guava, and sapota. **Outputs/Benefits:** Higher productivity of grass and trees leading to increased leaf-based forage productivity in the silvi-pasture system; fruits serve as additional produce in the horti-pasture system as a hedge against crop failure. Increased biomass carbon stocks under both the systems due to planting of trees (forage or fruit). In addition, enhanced stock of SOC following improved management of land and growth of trees, leaf litter, and root biomass turnover.
Land reclamation	Arid and semi-arid land, grazing land, degraded forest land	**Feature:** Land reclamation involves a package of practices covering enhanced vegetation cover (trees and grasses), soil moisture conservation, afforestation, agro-forestry, and shelterbelts. **Outputs/Benefits:** Reclamation of degraded land, increased vegetation cover, improved soil fertility, and reduced soil erosion. Increased tree and grass cover, biomass productivity, and litter turnover enhance biomass and soil carbon stocks.

Source: Authors.

land-based projects aimed at improvement of livelihoods will target increasing and stabilizing crop yields and forest conservation and regeneration, in turn leading to C-benefits as described above for agriculture and forestry projects.

- *Land reclamation and arid land development:* Land degradation and desertification are major environmental challenges to global agricultural production. A large number of CEMs, which aim at halting degradation of cropland, grazing land, and forest land as well as reclaiming marginal lands to achieve higher growth of crops, grasses, and trees, could be considered. All CEMs under this category lead to improved management of land through soil and water conservation, afforestation, shelterbelts, and agro-forestry. These activities contribute to enhanced C-benefits through increased soil organic matter or carbon and tree growth.
- *Water conservation and irrigation:* Projects aimed at water conservation and minor irrigation incorporate construction of various types of structures to conserve water, recharge groundwater, and increase the capacity to store water for irrigation. Largely, minor irrigation and water conservation projects aim at providing increased and reliable water supply, particularly for enhancing crop production. Additional CEMs such as agro-forestry and soil conservation could be incorporated into these projects to further increase crop or tree growth through water conservation and irrigation activities, leading to increased biomass production and litter turnover, thereby contributing to enhanced carbon stocks, particularly soil carbon stocks as well as biomass carbon stocks through tree growth (such as restoration of traditional water bodies).
    - ◆ *Climate change mitigation:* IPCC (2007) has highlighted the large mitigation potential of land-based projects in the forestry and agricultural soil sectors. The dominant climate change mitigation project opportunities or CEMs include REDD in addition to afforestation, reforestation, and bioenergy projects.
    - ◆ *Climate change adaptation:* Agricultural production, forests, and biodiversity are projected to be adversely impacted by climate change in the coming decades (IPCC 2007). Therefore, it is necessary to reduce vulnerability to climate change and enhance the resilience of crop production and forest systems to climate risks. Adaptation projects in the agricultural and forest sector could lead to enhanced biomass and soil carbon stocks indirectly through increasing crop production, litter and residue turnover, and conservation of forest biodiversity.

The modules described in tables A.7 to A.9 are specific to particular land categories. The technical details of each of the activities and practices are described in Part B.

A.2.4.4. Approach to Selection of CEMs and CEPs

C-enhancement could be achieved in all land categories such as cropland, grassland, forestland, and degraded forestland as well as arid, irrigated, and rain-fed croplands. Different CEMs are relevant to different land categories—some CEMs may be relevant to only one land category (such as shelterbelts for arid croplands), whereas others may be relevant to multiple land categories (such as soil conservation for watershed catchment areas, degraded forestlands, and grasslands). Land categories relevant to different modules are presented in tables A.7 to A.9 to help project developers and managers to select the relevant CEMs while designing a project.

The following steps could be used in identifying potential CEMs and CEPs for enhancing C-benefits:

Step 1: ***Identification of outputs—***Identify outputs and interventions relevant to each land category

Step 2: ***Assessment of CEMs and activities to be included in the project—***Identify the CEMs and CEPs to be incorporated into the project that may directly or indirectly contribute to C-benefits (grassland improvement, agro-forestry, soil conservation, mulching, shelterbelts, afforestation, etc.)

Step 3: ***Selection of CEMs or additional activities—***A given outcome (such as increased and stable crop yields in rain-fed lands) could be achieved through multiple activities; all activities that could potentially increase crop yields and enhance C-benefits cannot be adopted in any one project owing to constraints of costs and labor so appropriate criteria are necessary to select the activities to be adopted in a project. Such criteria could include following:

- Potential to contribute to the main outputs of the project, such as implications of a module or an activity for enhancing crop yields (Refer to Part B)

(*continued*)

- Suitability for the region or project and the output, such as agro-forestry species to be selected for a given set of rainfall, soil, and crop conditions
- Cost implications and benefit-cost ratio, such as cost per ha and the likely increase in crop yield; limited data availability is the norm
- Potential to enhance carbon stocks (for example, choice of agro-forestry species and planting density will determine the biomass carbon growth rate [tons per ha per year]) or to reduce CO_2 emissions (for example, reduced tillage leading to reduced loss of SOC [in tCO_2]) (See tables A.10 to A.12).

Step 4: ***Seeking information on CEMs and CEPs—*** Identify CEMs or additional activities or practices relevant to land categories that may contribute to increasing carbon stocks or reducing CO_2 emissions based on recommendations of local agricultural universities or research institutes or traditional knowledge. Selection of activities for incorporation could be based on the following sources of information:

- The package of practices recommended by local agricultural universities, forest departments, or watershed authorities
- Expert consultations with, for example, agricultural extension officers, scientists, irrigation engineers, and foresters
- Traditional knowledge from, for example, farmers

Information on the C-benefit potential (in tons of C or CO_2) of each activity is required at project preparation phase for a number of purposes

- For selecting activities with high C-benefits potential per ha
- For estimating the C-benefit per unit area (such as a ha) over different periods (such as annually or periodically) using models
- For estimating potential carbon revenue from the project based on the quantity of C-benefit per ha
- For estimating the cost-effectiveness of incorporation of CEMs and CEPs (dollars per ton of carbon)

The source of information on potential C-benefits at the project preparation stage will have to be literature, experiments, and previous projects implemented in the region. Examples of potential C-benefits from different project activities are given in tables A.10 to A.12, and the details are given in Part B for each CEM or CEP

Step 5: ***Features of the CEM or activity—***The features of each intervention or practice aimed at enhancing C-benefits include the following:

- Applicability to a land category (such as a water catchment area or rain-fed cropland)
- Time of implementation (immediately after the monsoon rains, at sowing, or at the time of land preparation)
- Input or material required (such as green manure)
- Labor required (person days per ha for the activity)
- Method of application (spreading of mulch or incorporation of green manure)
- Machinery or equipment required (tractor or plough)
- Preparation of physical structures (such as contour bund or farm pond)
- Practice—planting (trees or grasses) and incorporation into soil (manure application)

The details of relevant activities or practices could be obtained from local agricultural, forestry institutions, experts, published literature, or experienced practitioners (traditional or modern). Details are provided for each activity in Part B, and an example is provided in table A.13.

Step 6: ***Carbon pools to be impacted—***Identification of the carbon pools likely to be impacted by the activity/practice proposed for enhancing C-benefits:

- Single carbon pool such as soil carbon (due to application of mulch or organic manure and above-ground biomass [AGB])
- Multiple carbon pools including biomass and soil carbon (afforestation or agro-forestry)

Based on an extensive literature search, tables A.10 to A.12 were prepared. There are serious gaps in literature on the rates of change in different carbon pools (biomass and Soil Organic Carbon (SOC)) in lands subjected to different CEMs and CEPs. Further, the values of rates of change in carbon pools could vary from region to region, even for a given CEM/CEP. It was also not possible to convert all values into tC or tCO_2 per ha per year. The values in tables A.10 to A.12 mainly illustrate the positive impact of CEMs and CEPs on C-benefits. Project developers will have to seek region-specific C-enhancement values for a given CEM/CEP.

Estimation of the C-benefit per unit area and for the total project is critical for decisions on incorporation of C-enhancement interventions. This requires carbon stock changes or CO_2 emissions reduction (in tons per ha of biomass and soil) for different CEMs/CEPs at the regional level. However, there is very limited literature on the C-benefits of different CEPs and CEMs in quantitative terms. This is one of the limitations of the efforts aimed at enhancing C-benefits.

A.2.4.5. Matching Generic CEMs and CEPs to World Bank Projects

The project designer or manger has to identify the CEM or CEPs relevant to the project goals, land category, and agro-climatic conditions of the project area. An illustration of matching CEMs and CEPs to World Bank projects is presented in table A.14. The following approach is to be adopted for matching or selecting appropriate modules:

Step 1: Select the project and identify project goals and outputs

Step 2: Select the module or modules relevant to the project goals and outputs

- Identify the output relevant to land-based project activities
- Identify the land category to be subjected to project interventions

Step 3: Select the CEM/CEP relevant to a land category and project output

Step 4: Identify the carbon pools that will be impacted as a result of incorporation of the CEM and CEP

Step 5: Refer to literature for default values or consult local experts for potential increments in C-benefits due to the proposed activities (refer to tables A.7 to A.9 for examples of estimated potentials); average soil carbon stock values (tC per ha) in different land categories and for different practices are the following (Jha *et al.* 2001):

- Barren land: 20.0
- Pasture: 40
- Agriculture: 66
- Plantations: 80.5
- Agro-forestry: 83.6
- Natural forest: 120

Step 6: Estimate the incremental biomass and/or soil C-benefit, such as 59.5 tC per ha if barren land is converted into plantations (80.5 tC per ha – 20 tC per ha = 59.5 tC per ha) and 17.6 tC per ha if agricultural land is converted to agro-forestry (83.6 tC per ha – 66 tC per ha = 17.6 tC per ha)

Step 7: The module may have multiple activities; if so, aggregate the C-benefit from each activity or the combined effect and its impact on different carbon pools.

TABLE A.10: Impact of C-Enhancement Modules on Biomass Carbon Stocks

C-ENHANCEMENT MODULE	LAND CATEGORY	TREATMENT	BIOMASS STOCK ENHANCEMENT (T/HA/YEAR)
Agro-forestry	Degraded forestland	Control	1.79
		Agri-silviculture	3.9–6.72
Orchards[1]	Farmland/ cropland	Control	0.02
		Multi-species orchard	3.10
Afforestation[2]	Degraded forestland	Control	0.007
		Mixed species forestry	4.2–4.6
	Degraded community land	Control	0.007
		Mixed species forestry	4.2–4.6
	Long-term fallow cropland	Control	0.007
		Mixed species forestry	4.4–5.2

Source: [1]Ravindranath *et al.* 2007; [2]http://cdm.unfccc.int/Projects/DB/TUEV-SUED1291278527.37/view.

TABLE A.11: Impact of C-Enhancement Modules on Soil Carbon

C-ENHANCEMENT MODULE	PRODUCTION SYSTEM	TREATMENT	CARBON STOCK ENHANCEMENT (tC/HA/YEAR) OR % INCREASE IN SOC
Agro-forestry[1]	General	Agri-silviculture	32%/year
		Agri-horticulture	30%/year
		Silvi-pastoral	111%/year
		Boundary plantation	11.5%/year
		Alley cropping	5%/year
Silvi-pastoral[2]	Semi-arid pasture system	Control	0.29%
		Leucaena leucocephala *Stylosanthes hamata*	0.68% (after 5 years)
		Leucaena leucocephala *Cenchrus ciliaris*	0.52% (after 5 years)
Orchards and gardens	*Coconut and cashew*	Marginal cropland	0.71–1.1%
		Orchard/Garden	1.4–1.8%
Shelterbelt	*Dalbergia sissoo* row-based system	Control (10 × tree height)	0.04%
		0 × tree height	0.08%
		1 × tree height	0.06%
		2 × tree height	0.05%
	Acacia tortilis	Control (10 × tree height)	0.12%
		0 × height of the tree	0.28%
		1 × tree height	0.17%
		2 × tree height	0.13%
Cover cropping[3]	General	Control	0.530
		Stylosanthes hamata	0.720%
		Lucerne	0.740%
		Centrosema	0.695%
		Calapagonium	0.720%
Afforestation in sodic soils[4]	*Prosopis juliflora*	Year 0	3.5 tC/ha
		Year 5	5.0 tC/ha
		Year 7	14.3 tC/ha
		Year 30	21.5 tC/ha
Afforestation[5]	*Leucaena leucocephala*	Year 8	0.65%
	Sesbania grandiflora		0.63%
	W. exserta		0.58%
	Control		0.30%

Source: [1]Solanki *et al.* 1999; [2]Venkateswarlu 2010; [3]Basavanagouda *et al.* 2000; [4]Bhojvaid and Timmer 1998; [5]Das *et al.* 2008.

A.2.4.6. Carbon Implications of CEMs and CEPs

The main objective of the CEMs and CEPs chosen will be to enhance carbon stocks or reduce CO_2 emissions in all land-based projects where C-benefit is likely to be a cobenefit of mainstream NRM and developmental projects. The activities described in tables A.10 to A.12 and table A.13 contribute directly or indirectly to carbon stock enhancement or CO_2 emission reduction. This section presents an approach to assessment and estimation of C-benefits.

TABLE A.12: Impact of C-Enhancement Practices on Soil Carbon

CEP	PRODUCTION SYSTEM	TREATMENT	CARBON POOL IMPACTED	CARBON STOCK ENHANCEMENT (tC/HA/YEAR) OR % INCREASE IN SOC
Mulching (10 t/ha)[1]	Corn	Control	Soil	1.90%
		Flemingia macrophylla		2.05%
		Indigofera tinctoria		2.28%
		Tephrosia candida		2.21%
		Alnus nepalensis		1.96%
Organic manuring/ Farmyard manure (FYM) application[2]	Rice	Control	Soil	–0.014 tC/ha/year
		100% nutrients from organic manure/FYM		0.128 tC/ha/year
		100% nutrients from fertilizer		0.005 tC/ha/year
	Sorghum	Control	Soil	0.10%
		50% of nutrients from crop residue, rest from fertilizer		0.26%
		50% of nutrients from FYM, rest from fertilizer		0.29%
	Soybean	Control	Soil	–0.22%
		FYM (6t/ha)+ fertilizer		0.34%
		Soybean residue (5t/ha) +fertilizer		0.28%
Mulching with crop residue[3]	Corn stover	Control (0 t/ha)	Soil	19.7 g/kg of soil
		2.5t/ha		28.7 g/kg of soil
		5t/ha		29.6 g/kg of soil
		10t/ha		32.1 g/kg of soil
Green manuring[4]	Green manure–rice–wheat	Before treatment	Soil	0.50%
		Incorporation of sun hemp		0.58%
	Green manure-wheat	Before treatment		0.50%
		Incorporation of sun hemp		0.60%
Zero tillage[5]	Corn	Conventional tillage	Soil	5.8 g/kg SOC
		Zero tillage		5.7 g/kg SOC
		Zero tillage+residue incorporation		6.7 g/kg SOC
	Mustard	Conventional tillage		6.4 g/kg SOC
		Zero tillage		6.6 g/kg SOC
		Zero tillage+residue incorporation		6.9 g/kg SOC
Reduced tillage[6]	General		Soil (at 30 cm)	0.59–1.30 t/ha
Tank silt application[7]	General	Control	Soil	0.22–0.56%
		Cropland		0.58–1.07%
		Cropland+silt		1.02–3.18%
Intercropping[8]	Coconut+guava	Control	Soil	3.4 g/kg SOC
		Intercropped		7.8 g/kg SOC

Source: [1]Laxminarayana *et al.* 2009; [2]Rao *et al.* 2009 (Central Research Institute for Dryland Agriculture, Hyderabad); [3]Blanco Canqui *et al.* 2006; [4]Sharada *et al.* 2001; [5]Saha *et al.* 2010; [6]Fleige and Baeume 1974; [7]NREGA report 2010; [8]Manna and Singh 2001.

TABLE A.13: Features of Mulching

FEATURE	EXPLANATION
Explanation of the practice	Mulching is a soil and moisture conservation practice, particularly in arid and semi-arid regions It involves spreading of organic matter (straw, leaf litter, weeds, etc.) on the soil surface.
Benefits of the practice	Mulching leads to soil and moisture conservation, ultimately improving crop yields
Suitable regions	Arid and semi-arid regions
Land category	Cropland, rain fed
Cropping system	Rain-fed annual crops and orchards or perennial crops
Description of the practice	Selection of organic material such as tree leaves or weeds or straw, harvesting and transportation to the crop fields, spreading of the mulch on land or between crop rows Mulch for field crops is applied after land preparation
Quantity required	1.5 to 2.5 dry tons (or 7.5 to 10 fresh tons) of mulch per ha (tree leaves or crop residue)
Impact on crop yields	Crop yields are increased by 178% for green gram, 200% for the moth bean, 16% for the cluster bean, 57% for the cowpea, and 19% for pearl millet[1] Corn yield is doubled with application of 10 t/ha of dry mulch[2]
Impact on SOC	SOC is increased by 12% over the control plot on mulch application in corn[2]

Source: [1]Venkateswarlu 2010; [2]Laxminarayana *et al.* 2009.

The details of C-benefits for each of the activities are presented in Part B. The approach to and methods for estimating C-benefits of CEMs or project activities are described in Part C.

Approach to estimation and monitoring of C-benefits from CEMs and CEPs: C-benefits will have to be estimated *ex ante* at the time of preparing the project proposal as well as postimplementation.

In both the phases, there is a need to estimate the baseline (without a project scenario) carbon stock changes or CO_2 emissions for the base year as well as the period selected (such as 5, 10, or 20 years). Further, carbon stock enhancement/CO_2 emissions reduction achieved due to project implementation needs to be estimated. To obtain the net C-benefits due to project interventions, use the following equation:

Net C-benefit (in tC or tCO_2)
= [Gross carbon stock growth realized (or CO_2 emission reduced/avoided) due to project intervention] –[Baseline/reference carbon stock change or CO_2 emissions]

Methods of estimating the baseline and project scenario carbon stock changes/CO_2 emissions are presented in Part C.

Estimation of C-benefits in the project scenario requires the quantification of C-benefits realized for each of the CEMs or CEPs on a per-ha basis (tC per ha) and at the project level (tC) for the period selected. C-enhancement modules and practices are expected to provide C-benefits not envisaged in the project outputs or may enhance the C-benefits already envisaged in the project. C-benefits for different CEMs are explained in tables A.10 to A.12, and the methods of estimating and monitoring C-benefits are described in Part C. The approach to assessing the carbon implications of CEMs involves the following steps:

Step 1: Select the CEM/CEP for the identified region where the project is proposed to be implemented

Step 2: Identify the land categories relevant to the proposed project

Step 3: Identify and select the activities or practices for the chosen CEMs

Step 4: Understand how C-benefit would accrue from the activities incorporated in the module, such as soil organic matter improvement due to mulching or organic manure application

Step 5: During the *ex ante* phase, use the literature or default values to estimate the potential C-benefits per ha of each activity incorporated in the CEM and for the whole project area over different periods (refer to examples in tables A.10 to A.12)

Step 6: Monitor and estimate the C-benefits during the project implementation and postimplementation phases (refer to Part C for the estimation and monitoring methods)

TABLE A.14: Illustration of Outputs, Activities, and Implications for Carbon Under the Community Managed Sustainable Agriculture Project of the World Bank

OUTPUTS	ACTIVITIES OR PRACTICES	IMPLICATIONS FOR CARBON
Community-managed sustainable agriculture **Organic farming**	Conservative or deep furrows every four meters	Checks the erosion of fertile soil, conserving or enhancing soil carbon
	Trench around the field	Prevents soil erosion and improves groundwater recharge, leading to increased biomass production and litter turnover, enhancing SOC • Fruit-bearing trees planted in and around the trenches protect the natural fertility of soil and conserve water, leading to biomass and soil carbon accumulation
	Farm ponds	Moisture conservation, improved water availability for crop growth, and increased biomass growth
	Tank silt application	Improved soil fertility, increased crop biomass production leading to increased SOC stocks
	Raising fruit gardens	Improved biomass growth, residue turnover, and SOC improvement
	Increased diversity and cropping intensity	
	Appropriate cropping systems—intercropping, multiple cropping, and crop rotations	
	Enhancement and maintenance of soil health through mulching, green manuring, and vermicomposting	Improved soil fertility or soil organic matter status

Source: Authors.

A.3. IMPLICATIONS OF CEMs AND CEPs

Implications of C-enhancement modules for the project cycle, monitoring, cost of interventions, capacity required, socio-economic, and environmental aspects are presented in this section.

A.3.1. Implications for the Project Cycle

Incorporation of a C-enhancement goal, CEMs, and CEPs may happen largely at the project planning/designing stage and, in a few cases, at the project implementation stage. A project cycle involves conceptualizing the problem and identifying broad goals to address the identified problem, designing the interventions, implementing the activities, monitoring, evaluation, and reporting. Incorporation of additional activities related to C-enhancement in a project may have implications for different phases of the project cycle. It is likely that some of the proposed interventions have minimal or no additional implications—whether technical, institutional, or financial—for the project cycle. However, other project interventions may have incremental technical, institutional, and financial implications for the project. In the project cycle, after identifying the problem, project goals, and outputs to address the problem, the following steps are necessary.

The project design and planning phase: Appropriate CEMs/CEPs and any additional activities for the project may have to be identified and incorporated into the project design and plan. The proposed additional interventions may involve the following tasks:

- *Selection* of appropriate CEMs and package of practices, soil moisture conservation devices, land preparation practices, appropriate tree species, etc.
- *Seeking information* on the CEMs and practices from experts or from literature, such as selection of appropriate species for agro-forestry or shelterbelts and estimation of the quantity of mulch or organic manure to be added and the time of application
- *Estimation of the additional inputs* required, such as the number of seedlings of selected tree species, tons of organic manure or mulch material, labor required for incorporating the mulch or organic manure and for constructing any physical structures for soil and water conservation
- *Estimation of the incremental cost* of procuring the inputs, hiring labor, implementation, seeking technical expertise, etc., for securing additional C-benefits
- *Identification* of the additional human effort and capacity required for implementation of the proposed activities
    - Human labor for activities such as land preparation, organic manure preparation, planting, and soil sampling

- Access to technical experts such as agriculture extension officers or forest officers for assisting in the implementation of the proposed project activities
- Technical personnel for measurement and monitoring of the carbon stocks/CO_2 emissions

The project implementation phase: Implementing a project involves procuring the required inputs, engaging the labor to carry out the CEM and the package of practices based on the technical advice of experts or recommendations made for the region, and so on. These broad activities in turn involve establishing soil and water conservation structures, raising nurseries, preparing the land, preparing the compost, application of organic mulch, etc. The implications of incorporating CEMs and CEPs at the implementation phase may involve:

- No significant additional inputs or technical expertise, such as incorporating additional soil conservation and fertility enhancement activities in a watershed project
- Procurement of inputs and implementation of the practices
- Additional technical expertise to guide and supervise implementation and monitoring of the CEMs or activities

The project-monitoring phase: All projects aimed at enhancing C-benefit would require field and laboratory measurements, estimation, modeling, monitoring, and reporting of the carbon stock enhanced or CO_2 emissions avoided for the baseline scenario as well as for the project scenario. Further details of implications of incorporation of CEMs/CEPs for monitoring are discussed in the following section, and methods are given in Part C.

A.3.2. Implications for Monitoring of Carbon Stocks

Monitoring of C-benefits from land-based projects has been a subject of large scientific interest and debate under the climate convention, especially to arrive at a reliable and cost-effective monitoring process and methodology. A/R CDM projects require elaborate, rigorous, and expensive carbon-monitoring arrangements. Further, under the emerging REDD+ mechanism, MRV of C-benefits has been a contentious and complex issue. Monitoring is required for the following:

- To assess the carbon stock enhancement or CO_2 emissions reduction achieved under a project because of implementation of the CEM and relevant activities
- To estimate the net C-benefit due to the project interventions over no-project or baseline scenario conditions

Rigorous monitoring is essential if the project stakeholders are claiming financial incentives for the C-benefits derived due to project interventions. A/R CDM projects require intensive monitoring arrangements because of the payments for incremental carbon credits, and REDD+ projects are likely to demand even greater rigor in monitoring. There is limited debate on the methods of monitoring for agricultural soils and grasslands.

The monitoring process and activities: As evident in the following steps, monitoring involves field and laboratory measurements, modeling, calculations or estimation, recording, and reporting of the carbon stock changes and CO_2 emission reductions.

Step 1: Development of a monitoring plan involves the following tasks or activities:

- Selection of project area, activities implemented, and the land categories involved; stratification of the land categories; and marking of the project boundary and selection of the sample plots
- Identification of the carbon pools likely to be impacted by the project activities and selection of appropriate frequency for monitoring of each carbon pool
    - A biomass carbon pool is measured every 2 to 3 or even 5 years since biomass growth may not be large enough to be measured annually
    - A soil carbon pool is measured once every 5 to 10 years
- Identification of the methods of estimating the selected carbon pools, measurements in the field and laboratory analysis, and estimation of the carbon stocks or CO_2 emissions under the baseline or no-project scenario as well as during and after the implementation phase
- Estimation of the net C-benefits, considering the baseline as well as the project scenario carbon stock changes or CO_2 emission reductions

Step 2: Assessment of the technical expertise and instrumentation required for implementing the monitoring plan

(*continued*)

Step 3: Training and capacity building of the monitoring personnel

Step 4: Field measurements, laboratory estimations, calculations, and modeling of the carbon stock changes and CO_2 emission reductions

Step 5: Recording and reporting of the carbon stock changes and CO_2 emission reductions

The steps involved in monitoring are presented in figure A.4. For details of the methodology, refer to Ravindranath and Ostwald (2008) and GOFC-GOLD and IPCC GHG Inventory Guidelines (2006).

FIGURE A.4: Steps in Measurement and Estimation of Carbon Stocks

Step 1	Select a land-use category or project activity
Step 2	Define the project boundary and map the land-use category or project area
Step 3	Stratify the project area or land-use category
Step 4	Select the plot method or agricultural farms
Step 5	Select carbon pools and frequency of measurement
Step 6	Identify indicator parameters to be measured
Step 7	Select sampling method and sample size
Step 8	Prepare for field work and data recording
Step 9	Decide on sampling design
Step 10	Locate and lay sample plots
Step 11	Measure the indicator parameters in field and conduct laboratory analysis
Step 12	Analyze data and estimate C-stocks/CO_2 emissions

Source: Authors.

A.3.3. Cost Implications of C-Enhancement Interventions

Enhancement of C-benefits from a land-based project could involve modifications to the activities already included in the project or new activities and practices may have to be incorporated. These interventions may require additional inputs and technical and institutional capacity. This could include the cost of procurement of inputs such as organic manure, mulch material, or seedlings for planting or employment of labor and technical expertise for monitoring. Three scenarios of C-enhancement in land-based projects with cost implications could be considered:

- ***Projects in which no additional C-enhancement practices are required:*** Most watershed, afforestation, and biodiversity projects, such as biodiversity conservation or community forestry, include many activities that contribute to C-benefits without any incremental investment required; thus, the incorporation of CEMs/CEPs in many of the projects may not have any significant incremental cost implications except the costs of monitoring.
- ***Projects in which additional C-enhancement activities are required:*** In some projects, C-enhancement activities are an integral part of the project goals; however, these projects offer some opportunities to incorporate additional activities for advancing the project goals as well as for C-enhancement. These additional activities, such as agro-forestry, mulching, or low-tillage agriculture in watershed projects, have cost implications in addition to the cost of monitoring.
- ***Projects in which dedicated C-enhancement activities are to be incorporated:*** Projects that require incorporation of activities that will lead to C-benefits in addition to socio-economic goals of the project, such as those related to sustainable agriculture, will have significant cost implications for all the C-enhancement activities incorporated into the project including monitoring.

The cost of realizing enhanced C-benefits from a project would need to be assessed at the following stages and for different purposes:

- *Project design and planning phase:* Cost estimate of incremental activities for C-enhancement is required to seek budget allocation for the proposed CEM and activities. The incremental cost estimate would also assist in calculating the cost of C-benefit ($/$tCO_2$) *ex ante.*
- *Project implementation phase:* Cost estimates are required to seek the release of funds for different activities during the implementation phase.
- *Project monitoring and evaluation phase:* The project monitoring and evaluation phase is particularly critical to obtaining financial payments for the carbon credits obtained for the stakeholders such as farmers. The funding agency would also be interested in the cost-effectiveness ($/$tCO_2$) of the derived C-benefits in different land-based projects.

The additional activities and practices may or may not have a significant impact on the project costs. The potential costs of modules and activities for a few projects are given in table A.15 as an illustration. The following approach could be adopted for assessing cost implications at project preparation, implementation, and monitoring stages.

Step 1: Select the CEM and the associated activities including monitoring

Step 2: Identify the inputs, labor, and technical expertise required for the additional activities identified for C-enhancement, such as tons of organic manure, the number of seedlings of different tree species, labor for land preparation, and monitoring staff

Step 3: Determine the quantities of the inputs required for the project on a per-ha basis and for the whole project area and the number of technical staff for supervision and monitoring

Step 4: Estimate the cost of each of the inputs and staff for the total project along with the monitoring costs

A.3.4. Institutional and Technical Capacity Implications of CEMs/CEPs

The modules and activities aimed at enhancing C-benefits could have implications for institutional and technical capacity. Generally, any typical land-based NRM and developmental project would involve activities aimed at increasing crop production, conserving biodiversity, land reclamation, watershed protection, and afforestation of degraded lands.

TABLE A.15: Illustration of Potential Costs of CEMs/CEPs and Activities for an Afforestation and Watershed Project

ACTIVITY	COST/hA (INR): 1US$ = INR 45
Agro-forestry/social forestry	3,100
Silvi-pasture plantation	26,700
Shelterbelt	25,000 to 50,000
Grassland reclamation	35,000
Plantation, catchment treatment, and land preparation	22,000 to 25,000
Fuelwood plantation	36,500
Densification	30,800
Medicinal and aromatic plants	32,000
Afforestation	30,500

Source: Authors.

The incremental activities required for enhancing C-benefits may or may not be significantly different from the normal activities in any land-based project. All the proposed CEMs and CEPs described in the earlier sections are all generally part of different World Bank NRM and developmental projects related to forests, agriculture, biodiversity, watershed development, and livelihoods improvement. However, additional technical and institutional capacity may be required in a C-benefits enhancement project for the following:

- Identifying appropriate additional CEMs and activities to maximize C-benefits (such as agro-forestry for improving crop productivity and livelihoods) compatible with the project goal and agro-climatic conditions
- Promoting synergy between the project's developmental or environmental outputs and CEMs and practices (such as C-benefits in a watershed project)
- Designing a cost-effective package of practices to enhance C-benefits (such as land preparation, species choice, density of planting, etc., for an agro-forestry module)
- Assessing the technical capacity needed for supervision of implementation of the project activities according to technical specifications given in the package of practices
- Monitoring of carbon stock enhancement and CO_2 emission reductions under baseline and postproject implementation

The incremental technical and institutional capacity required for the above activities would generally be available for most NRM and agriculture development projects. However, the technical capacity required for rigorous and intensive monitoring may not be the norm in typical developmental and NRM projects, requiring significant additional technical expertise. If the required capacity is not available in-house for any project, experts could be hired for specific activities. The technical capacity required may be available at the local agricultural university or departments of agriculture, watershed, forests, etc.

A.3.5. Socio-Economic and Environmental Implications of C-Enhancement Interventions

All projects aim at delivering economic, environmental, or social benefits or a combination of these benefits. Most projects will have multiple goals. The main objective of these C-benefit enhancement guidelines is to promote C-benefits synergistically with the environmental or developmental goals of the projects. Two types of projects can benefit from the guidelines:

- Projects in which C-benefit is a cobenefit of socio-economic development or NRM, such as watershed development, biodiversity conservation, and agriculture development projects, which are the focus of these guidelines
- Projects in which carbon is the main benefit and socio-economic and environmental benefits are cobenefits, such as BioCarbon, A/R CDM projects, and REDD+ projects

All the CEMs and CEPs not only enhance C-benefits, but also have social, economic, and environmental aspects including the following:

- Increased crop yields through soil fertility improvement and water conservation or irrigation measures
- Supply of tree-based products through agro-forestry or afforestation
- Improved livestock productivity through grassland management and increased fodder production
- Enhanced resilience to climate change through agro-forestry, shelterbelts, and greater water-holding capacity of soils and improved soil fertility
- Employment generation for activities such as raising a nursery, building soil conservation structures, processing of increased food and tree biomass, etc.
- Increased and diversified income through agro-forestry, NTFP, and increased availability of grass

The following approach could be adopted for identifying and quantifying the potential economic, social, and environmental benefits:

Step 1: Identify the main focus or goals of the project, the focus of these guidelines:

- Social or economic development or natural resource management
- Climate change mitigation (such as BioCarbon, CDM and REDD+ projects)

Step 2: Identify the economic, environmental, and social benefits or outputs incorporated in the project that could include enhancing crop yields, increasing water availability, enhancing NTFP supply, and livelihood improvement

Step 3: Identify any new or additional economic, environmental, and social benefits that may accrue from activities leading to C-benefit enhancement in the proposed project, which could include enhanced soil fertility due to mulching or organic manure application, control of wind and water erosion due to shelterbelts, or agro-forestry practices

Step 4: Measure, monitor, and estimate the economic, environmental, and social impacts or benefits using standard methods in agriculture, forestry, or social sciences

A matrix of socio-economic and environmental benefits, including reduced vulnerability to climate change that could potentially accrue from incorporation of CEMs, is given in table A.16.

Table A.17 gives examples of potential economic, environmental, and social benefits from a BioCarbon project and from a sustainable land, water, and biodiversity management project. It can be observed that both types of projects funded by the World Bank offer multiple economic, social, and local environmental benefits apart from the C-enhancement benefits.

A.3.6. Implications of C-Enhancement to Climate Change Adaptation

This section assesses the implications of CEMs and CEPs for adaptation and discusses the opportunities for enhancing the resilience of socio-economic systems and natural ecosystems, both of which—as well as such environmental services as food production, water availability, and biodiversity—are likely to be affected by climate change (IPCC 2007).

TABLE A.16: Examples of Socio-Economic and Environmental Benefits of Activities Implemented for C-Enhancement with Potential Implications for Reducing Vulnerability

	BENEFITS		
C-ENHANCEMENT MODULES/ ACTIVITIES	**SOCIO-ECONOMIC**	**ENVIRONMENTAL**	**REDUCTION IN VULNERABILITY TO CLIMATE CHANGE**
Agro-forestry shelterbelts	Increased crop yield Fuelwood, timber, and NTFP supply Leaves as livestock fodder, mulch, or organic manure	Erosion control Greater moisture retention Biodiversity conservation	Supply of tree products (fodder and fruits) even during crop failures
Soil conservation **Water conservation** **Watershed protection**	Increased water availability for irrigation Increased crop yield Increased tree growth	Improved soil fertility Greater moisture retention	Stabilized crop yields even during water stress and droughts
Land reclamation	Increased crop yields Improved tree growth	Improved soil fertility Erosion control Greater soil moisture retention • Increased vegetation cover	Stable yields due to improved soil fertility and greater water-holding capacity
Sustainable agriculture	Increased and stabilized crop yield Substitution of high-cost fertilizers Improved tree growth and grass production		
Management of PA	Increased NTFP supply	Biodiversity conservation	Forests richer in biodiversity and therefore more resilient
Afforestation and forest regeneration **Community forestry**	Increased fuelwood and timber production Increased NTFP supply	Forest conservation Improved biodiversity Soil conservation	Increased availability of nontimber forest products to augment income
Biodiversity conservation	Increased supply of NTFP		Forests richer in biodiversity and therefore more resilient Increased availability of NTFP to augment income
Irrigation (minor or major)	Increased crop yield Increased fodder supply	Groundwater recharge Improved water availability	Stable crop yields despite moisture stress and deficit rainfall

Source: Authors.

Evidence exists to show that the observed climate change in the recent decades (warming and precipitation changes) have reduced the yields of global maize and wheat production by 3.8 and 5.5 percent, respectively, relative to a counterfactual without climate trends (Lobell 2011). Global efforts to address climate change include two basic responses—mitigation and adaptation; C-enhancement, the main objective of these guidelines, is aimed at mitigation.

Mitigation is defined as an anthropogenic intervention to reduce the sources and emissions of GHG or to enhance carbon sinks. Actions that stabilize CO_2 emissions or reduce net CO_2, the dominant GHG, reduce the projected magnitude and rate of climate change and thereby lessen the risk of climate change to natural and human systems. Therefore, mitigation actions are expected to delay and reduce damages caused by climate change, providing environmental and socio-economic benefits (IPCC 2002).

Adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli and their impacts on natural and socio-economic systems, which moderates harm or exploits beneficial opportunities. Various types of adaptation actions can be distinguished including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (IPCC 2002). Adaptation measures can occur at different levels: population, community, personal, or production system (food, forestry, and fisheries). It is very important to note, especially from a developing country perspective, that mitigation strategies will have a long-term global impact on greenhouse damage, whereas adaptation measures generally have a positive, direct, and immediate impact on countries and regions that implement them.

Implications of C-enhancement projects for adaptation: Land-based projects offer many opportunities to incorporate adaptation objectives. C-enhancement modules and practices provide or enhance multiple economic, environmental, and social benefits (table A.16). These benefits resulting from activities aimed at C-enhancement could make food production, water availability, biodiversity conservation, improvement of livelihoods, etc., more resilient to climate risks or impacts (table A.18).

TABLE A.17: Economic, Environmental, and Social Benefits from Selected World Bank Projects

PROJECT TITLE	ACTIVITIES/OUTCOME	ECONOMIC BENEFITS	ENVIRONMENTAL BENEFITS	SOCIAL BENEFITS
Mid Himalayan Watershed Development Project	60% of available treatable area of nonarable land is treated	Additional income from unproductive, nonagricultural, degraded lands through selling carbon credits	Reversal of land degradation through catchment treatment Increased availability of soil moisture and of water in sources such as springs and streams Carbon sequestration	Increased equity, inclusiveness of the vulnerable, the landless, and women
	4003 ha of carbon sink created through restoration, community and farm forestry	Availability of NTFP, fuelwood, and grass for livestock Carbon revenue from enhanced carbon sinks	Land reclamation Watershed protection Carbon sequestration	Increased access to fuelwood and grass for the poor
	60% of available treatable area of arable land is treated	Increased net income from farm production, retrieved lands, horticulture production, and farm forestry	Reversal of land degradation through catchment treatment Increased soil moisture	Increased incomes leading to reduction in poverty, greater buying power, and increased availability of food
Sustainable Land, Water and Biodiversity Conservation Management for Improved Livelihoods in Uttarakhand Watershed Sector	20 to 30% of the area in selected micro-watershed under improved sustainable land and ecosystem management techniques	Improved crop and grass production	Reduced watershed degradation Carbon sequestration	Reduction in poverty
	Increase in availability of water in dry season by 5% in the treated micro-watershed	Increased availability of water for agriculture resulting in higher crop yields and incomes	Increased biomass production and litter turnover leading to enhanced carbon sinks	Reduction in poverty
	10% increase in tree and other vegetative cover in 20 micro-watersheds	Increased availability of NTFP	Reduction in watershed degradation Carbon sequestration	Increased availability of fodder and firewood within the project area, thus reducing time and effort spent on collection

Source: Authors.

A.3.6.1. C-Enhancement and Reduction of Vulnerability to Climate Risks and Adaptation to Climate Change

Table A.18 shows that the majority of social, economic, and environmental benefits resulting from CEMs and relevant CEPs are likely to contribute to reducing the vulnerability of agriculture, forestry, and livelihood systems. The following approach could be adopted to recognize and enhance the adaptation benefits:

Step 1: Identify the appropriate CEMs and CEPs for enhancing C-benefits for a given project or given outputs

Step 2: Identify the climate risks and vulnerability of the project outputs and the region to current climate variability. This information could be obtained from reports of IPCC (2007), World Bank ADAPT studies, National Communications of the countries (http://www.unfccc.org/), and published literature

Step 3: Assess the implications of the CEMs and CEPs in the context of the identified climate risks and vulnerabilities

Step 4: Assess the social, economic, and environmental implications of the proposed CEMs and CEPs and their linkage with the identified climate risks

Step 5: Assess the potential of social, economic, and environmental impacts of CEMs and CEPs relevant to reducing vulnerability (table A.18):

- If the identified CEMs and CEPs and their implications or impacts are inadequate to address the identified climate risks and vulnerabilities, incorporate additional activities based on published literature or in consultation with agriculture, watershed, and forestry experts

Step 6: Incorporate the identified CEMs and CEPs into the proposed project

Step 7: Monitor the impacts of CEMs and CEPs with respect to the identified climate risks

TABLE A.18: Implications of Economic and Environmental Benefits of C-Enhancement Modules and Practices for Adaptation

CATEGORY OF BENEFITS	BENEFITS FROM CEMs AND CEPs	ADAPTATION IMPLICATIONS OR ENHANCEMENT OF RESILIENCE TO CLIMATE RISKS
Economic	Increased crop yields due to soil and water conservation and soil fertility improvement	Stabilized crop yields and greater drought tolerance
	Increased fuelwood, timber, and pole production from afforestation and agro-forestry	Additional and diversified sources of income
	Greater production of NTFP due to forest conservation, PA management, and reduction in deforestation	Additional and diversified sources of income and livelihoods Availability of nutritious fruits and vegetables
	Increased grass production due to soil and water conservation, soil fertility improvement, and grazing management	Increased milk and meat production as an additional diversified source of income
	Increased employment generation from afforestation and soil and water conservation measures	Additional income from diverse activities
Environmental	Increased soil fertility due to mulching, organic manure application, soil conservation, etc.	Stable and higher crop yields Multiple cropping ensures stable crop yield and income More stable crop yields Reduced moisture stress Enhanced resilience to moisture stress, crop failures, and droughts
	Reduced soil erosion due to shelterbelts	
	Improved water conservation due to mulching, shelterbelts, etc.	
	Groundwater recharge due to construction of water conservation structures	
	Forest and biodiversity conservation due to agro-forestry	Increased NTFP supply to supplement income from crop production and wages, increasing resilience to crop failures Forests richer in biodiversity and therefore more resilient

Source: Authors.

A.3.6.2. Mitigation and Adaptation Synergy and Trade-Offs in Land-Based Projects

The goal of UNFCCC is to achieve stabilization of GHG concentration in the atmosphere at levels that would prevent dangerous anthropogenic interference with climate and food production system. It is well known that even with the most ambitious mitigation policy, climate change seems likely to occur. Even under the most aggressive mitigation scenario, climate change is likely to leave an impact, particularly given the long life of different GHGs in the atmosphere (Bruce *et al.* 1996). Thus, adaptation is essential to complement mitigation efforts. The Cancun Agreement has suggested development of an adaptation framework and program, and the Cancun Green Fund has been established to promote adaptation and mitigation. Adaptation can complement mitigation cost-effectively in lowering the risks from climate change.

Mitigation and adaptation are generally considered separately in global negotiations, in the literature, and for project funding. However, both are intricately linked; many mitigation-driven actions could have positive (such as agro-forestry and biodiversity conservation) or negative (such as increase in pest and fires) consequences for adaptation. Similarly, adaptation-driven actions could also have positive or negative consequences for mitigation. To avoid trade-offs, it is important to explore options to adapt to new climatic circumstances at an early stage through anticipatory adaptation (Robledo *et al.* 2007). As the linkage between mitigation and adaptation becomes clearer (Ravindranath 2007), the implications of climate change for the mitigation potential need to be assessed, at national and subnational levels to assist policymakers.

Synergy between mitigation and adaptation: Opportunities to promote synergy between mitigation and adaptation need to be explored and recognized and any trade-off between mitigation and adaptation needs to be reduced or avoided, especially in land-based projects. Such an effort would lead to the following advantages:

- Adaptation becomes a cobenefit of a mitigation project and vice versa
- A single project can deliver the twin objectives of mitigation and adaptation
- The mitigation-adaptation synergy helps in convincing policymakers to promote both the strategies to address climate change, since adaptation provides local benefits, particularly for land-based projects

- Incorporation of an adaptation component in land-based mitigation projects through CEMs could improve the benefit-to-cost ratio of the project and the cost-effectiveness of obtaining mitigation and adaptation benefits
- Incorporation of an adaptation component in mitigation projects would assist in securing the participation of stakeholders, particularly farmers, agricultural labor, and forest dwellers, in the mitigation projects

Mitigation and adaptation trade-offs: Projects aimed at enhancing C-benefits or mitigation should not enhance vulnerability or reduce adaptive capacity. A few mitigation actions can potentially make systems such as agriculture and forestry more vulnerable. A few examples of trade-offs between mitigation and adaptation are as follows:

- Monoculture plantations for carbon stock enhancement could make them more vulnerable (through increased pest or fire incidence, for example)
- Promoting high-yielding varieties alone may make crop production more vulnerable

Approach to enhancing the mitigation–adaptation synergy: The approach to enhancing the synergy between mitigation and adaptation is the same as that described in section A.4.1 aimed at recognition and incorporation of an adaptation component in land-based mitigation projects in a cost-effective way. The approach involves the following components:

- Identifying the linkage between CEMs or CEPs and vulnerability reduction or adaptation potential
- Incorporating the CEMs and CEPs that provide social, economic, and environmental benefits, which, in turn, make the crop production or forestry systems less vulnerable (table A.16)
- Ensuring that the trade-offs, if any, are identified and addressed

Part B: CEMs, CEPs, AND C-ENHANCEMENT TECHNOLOGIES

The present guidelines focus on promoting the modules, practices, and technologies that enhance C-benefits (increasing carbon stocks or reducing CO_2 emissions) from land-based projects as cobenefits of environmental and developmental projects. The land-based projects encompass cropland, forest land, grassland, and wetlands. Part A presents the rationale, approach, methods, and impacts of these CEMs and CEPs, whereas Part B gives the details and features of each CEM and CEP as drawn from technical literature. Features of the CEM/CEPs are described briefly in this section; further details are available from standard texts on agronomy, soil science, forestry, and watershed management as well as from the packages of practices and extension literature available from departments or research institutes dealing with agriculture, forestry, grassland reclamation, and watershed management. An attempt is made to provide the C-enhancement benefits in quantitative terms. However, it should be noted that literature on the quantitative estimates of C-benefits from a large number of CEMs and CEPs is limited.

The following details are presented for each CEM/CEP:

- Explanation of the practice
- Benefits of the practice (economic, environmental, and carbon related)
- Applicability to a region (arid, semi-arid, and humid agro-ecological zones)
- Suitable land category (cropland, grassland, grazing land, catchment area, etc.)
- Steps involved in implementing the module or practice
- Inputs required (quantity of raw material, labor, or other inputs)
- Impact on crop or biomass productivity
- Impact on biomass and SOC

The explanation is provided for the following CEMs and CEPs:

CEMs

1. Shelterbelts
2. Agro-forestry
3. Soil conservation
4. Water conservation
5. Watershed
6. Sustainable agriculture
7. Land reclamation
8. Management of PAs
9. Afforestation and forest regeneration
10. Biodiversity conservation
11. Community forestry
12. Orchards and gardens
13. Irrigation (minor or major)
14. Fuelwood conservation devices

CEPs

1. Mulching
2. Organic manure/green manure/crop residue incorporation
3. Reduced tillage or no tillage
4. Contour bunding
5. Farm ponds
6. Tank silt application
7. Intercropping/ multiple cropping
8. Cover cropping
9. Silvi-pasture and horti-pasture

The following sections present the descriptions and details of each of the CEMs and CEPs and their implications for C-benefits. These technologies and practices may have to be adapted to local conditions depending on rainfall, soil, topography, land use, crop, plantation or forest types, cultivation practices, and socio-economic conditions.

FIGURE B.1: Low Plant Population in Any Agriculture Practice Will Not Give Desired Carbon Enhancement

Source: Authors.

B.1. DESCRIPTIONS OF CEMs

TABLE B.1: Shelterbelts

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Shelterbelts are wide strips of trees, shrubs, and grasses planted at right angles to the wind direction to deflect air currents, to reduce wind velocity, and generally to protect roads, canals, and agricultural fields (Singh 1997). Shelterbelts are generally established in agricultural fields in arid or desert areas to control erosion, particularly wind erosion.</td></tr>
<tr><td>Benefits of the practice</td><td>Shelterbelts provide the following direct and indirect benefits:
• Reduce wind velocity by 65 to 87% (Puri and Panwar 2007)
• Reduce soil erosion by as much as 50%
• Increase crop yields ranging from 10 to 74% (Pimentel <i>et al.</i> 1997)
• Increase carbon stocks in standing trees and SOC
• Provide fuelwood and fodder</td></tr>
<tr><td>Suitable regions</td><td>Mainly arid regions and some semi-arid regions with high-velocity winds</td></tr>
<tr><td>Land category</td><td>Desert areas, croplands, and grasslands</td></tr>
<tr><td>Description of practice</td><td>The practice involves the following steps:
• Step 1: Select the location and estimate the area required for establishing the shelterbelts
• Step 2: Select the type of shelterbelt
▪ Choose from tree rows, shrub rows, or both
▪ Fix the width of the shelterbelt
• Step 3: Select the tree and shrub species
• Step 4: Raise a nursery, prepare the land, and plant the seedlings
• Step 5: Protect and maintain the shelterbelt</td></tr>
<tr><td>Quantity required</td><td>• Number of plants of different tree and shrub species, depending on the area to be brought under shelterbelts and the distance between the belt and the field
• Number of rows and density of planting</td></tr>
<tr><td>Impact on crop yields</td><td>Crop yields could increase by 6 to 98% for different crops (Kort 1998). The response of different crops varies with the region.
<table>
<tr><th>CROP</th><th>INCREASE IN YIELD, % (WEIGHTED MEAN)</th></tr>
<tr><td>Spring wheat</td><td>8</td></tr>
<tr><td>Winter wheat</td><td>23</td></tr>
<tr><td>Barley</td><td>23</td></tr>
<tr><td>Oats</td><td>6</td></tr>
<tr><td>Rye</td><td>19</td></tr>
<tr><td>Millet</td><td>44</td></tr>
<tr><td>Corn</td><td>12</td></tr>
<tr><td>Alfalfa</td><td>99</td></tr>
</table>
</td></tr>
<tr><td>Impact on soil organic matter or SOC and biomass</td><td>Soil C-enhancement due to shelterbelt establishment occurs through:
• The ratio of biomass growth and stock of trees in the shelterbelt rows to root and shoot biomass
• Higher crop yield due to increased soil moisture conservation and incorporation of crop, root, and shoot biomass into soil
Shelterbelts also have a long-term impact on soil properties in a region. A study carried out by Prasad <i>et al.</i> (2009) in Western Rajasthan highlights the effect of a 15-year-old <i>Dalbergia sissoo</i> shelterbelt on soil properties.
<table>
<tr><th colspan="6">SOC (%) UNDER SHELTERBELTS INDICATING HIGHER SOC NEAR THE SHELTERBELT ROWS</th></tr>
<tr><th>SOIL DEPTH (CM)</th><th colspan="5">DISTANCE FROM SHELTERBELT AS A MULTIPLE OF ITS HEIGHT (H IN M)</th></tr>
<tr><td></td><td><i>0H</i></td><td><i>1H</i></td><td><i>2H</i></td><td><i>5H</i></td><td><i>10H</i></td></tr>
<tr><td>15</td><td>0.11</td><td>0.08</td><td>0.05</td><td>0.04</td><td>0.04</td></tr>
<tr><td>30</td><td>0.07</td><td>0.06</td><td>0.07</td><td>0.05</td><td>0.05</td></tr>
<tr><td>60</td><td>0.07</td><td>0.05</td><td>0.04</td><td>0.04</td><td>0.03</td></tr>
</table>
</td></tr>
</table>

Source: Authors.

TABLE B.2: Agro-Forestry

DESCRIPTION	FEATURES
Explanation of the practice	Agro-forestry, as the term implies, is a combination of agriculture and forestry; it is a collective name for land-use systems and technologies in which woody perennials (trees, shrubs, palms, bamboos, etc.) are grown on the same land-management unit as crops and/or animals in some form of spatial arrangement or temporal sequence. Agro-forestry is thus a land-use planning system following the principle of generating multiple resources from the same unit of land. The main method involves planting rows of trees and perennial shrubs interspersed with annual crop rows.
Benefits of the practice	Agro-forestry practice provides the following benefits: • Reduces soil erosion and enhances soil fertility and water-use efficiency • Reduces the chances of total crop failure and increases crop yield • Provides fodder and fuelwood • Provides greater and more diversified income to farmers • Reduces vulnerability to climate risks and rainfall failures • Maintains biodiversity • Acts as a means of biological pest control • Increases carbon stock in standing trees and SOC
Suitable regions	Agro-forestry is practiced in a variety of climatic locations although the species of trees and the crops vary from one region to another
Land category	The land categories suitable for agro-forestry involve annual crop land (crop fields)
Cropping or forestry system	Arid and semi-arid cropping systems
Description of practice	Agro-forestry practice includes the following steps: • Step 1: Identification of land area for agro-forestry • Step 2: Selection of the type of agro-forestry system—agri-silviculture, agri-horticulture, agri-silvi-pastoral, etc. • Step 3: Selection/identification of the crop and tree/shrub species to be grown in combination along with spacing and density • Step 4: Distribution and demarcation of land for different plant species • Step 5: Planting of trees, shrubs, crop, etc. • Step 6: Protection and maintenance of the agro-forestry system
Quantity required	The number of trees of different species depends on the tree species selected, spacing, and the total area being brought under agro-forestry bund or block plantation. Density of planting could be 50 to 100 trees (mango or coconut) per ha with 10-meter spacing.
Impact on crop yields	Agro-forestry systems could increase crop yield. For example, millet and sorghum varieties grown within a 5- to 10-meter radius around *Prosopis cineraria* doubled or tripled their yield.
Impact on soil organic matter or SOC	Agro-forestry systems lead to enhanced carbon stocks through standing tree biomass as well as enhanced SOC due to leaf production and turnover.

IMPACT OF AGRO-FORESTRY ON SOC

TREATMENT	SOC (g/kg OF SOIL)	
	0–15 cm	0–30 cm
Sole cropping	4.2	3.9
Agro-forestry	7.1	7.2
Agri-horticulture	7.3	7.3
Agri-siliviculture	3.8	4.7

Source: Authors; Nair 1993; Lungdrean and Raintree 1982; Sinha 1985; Puri and Panwar 2007; Tejwani 1994; Newaj and Dhayani 2010.

TABLE B.3: Soil Conservation

DESCRIPTION	FEATURES
Explanation of the practice	Soil conservation involves a set of management strategies that prevent soil erosion. Soil conservation thus implies reducing risks of soil erosion to an acceptable level and also means improving soil quality through controlling erosion, enhancing SOC content, improving soil structure, encouraging the activity of soil fauna, etc.
Benefits of the practice	Benefits of soil conservation include: • Increases water-holding capacity, thereby conserving water • Raises water table levels in the area • Increases crop yields • Increases biodiversity (soil biota, animal and plants) • Prevents land degradation
Region	Different soil conservation measures are applicable to different ecological zones and regions
Land category	Cropland, grassland, and degraded forest land
Description of practice	Various kinds of soil conservation measures are available including: • Cover cropping • Conservation tillage • Contour bunding • Terracing • Biological methods of soil conservation • Multiple cropping • Strip planting • Stubble planting Also refer to respective CEPs described in this section
Impact on crop yields	Refer to respective CEPs
Impact on soil organic matter or SOC	Reduction of soil erosion contributes to halting land degradation and conserving soil moisture, leading to increased biomass production and leaf litter turnover. This increases the soil organic matter and carbon stock in soils. Refer to different CEPs described in this section

Source: Authors; Lal 1998.

TABLE B.4: Water Conservation

DESCRIPTION	FEATURES
Explanation of the practice	Water conservation involves strategies to increase the water stored in the soil profile of an area. The water from rainfall or surface runoff can be conserved and used as a source of irrigation. Two broad methods of water conservation are: • Internal catchments, in which the catchment areas are within the cropped area • External catchments, in which the catchment areas are outside the cropped area Water conservation includes a package of practices including physical structures (such as contour bunding, check dams, and farm ponds), measures (such as plowing), and crop production practices (such as mulching, organic manuring, and agro-forestry). Most soil conservation practices also lead to moisture conservation.
Benefits of the practice	Benefits of water conservation include: • Higher water tables and increased water availability for crops and even irrigation • Enhanced soil fertility • Greater crop yields • Greater opportunities for crop diversification
Region	Arid and semi-arid regions
Land category	Cropland, grassland, and degraded forest land, but more frequently practiced in croplands
Description of practice	Several measures can be adopted for water conservation: • Mulching • Check dams • Contour furrows • Farm ponds
Quantity required (of raw material or input)	Refer to respective CEPs described in this section, watershed manuals, and agronomy textbooks
Impact on crop yields	
Impact on soil organic matter or SOC	All water conservation measures lead to increased crop and tree growth and crop residue turnover. Enhanced carbon stock in soil and standing trees contributes to C-benefit.

Source: Authors.

TABLE B.5: Watershed

DESCRIPTION	FEATURES
Explanation of the practice	A watershed can be described as a geo-hydrological unit bounded by a drainage divide within which the surface runoff collects and flows out of the watershed through a single outlet into a larger river or a lake. Watershed management involves the formulation and implementation of programs and strategies to ensure the sustenance and enhancement of watershed resources and functions. Watershed projects could involve multiple activities such as soil and moisture conservation, water harvesting, catchment area treatment, agro-forestry, and livestock management aimed at increasing and stabilizing agricultural production and incomes of the farmers.
Benefits of the practice	Benefits of a watershed include: • Soil and water conservation and water for irrigation • More irrigation for crops and therefore greater cropping intensity • Increased and stable crop yields due to improved cropping systems, soil conservation, and irrigation • Improved and diversified sources of farm income
Region	Suitable to all arid and particularly semi-arid regions
Land category	Multiple land categories such as water catchment area, cropland, and grassland
Description of practice	Generally, the following steps are involved in watershed management: • Step 1: Delineate the watershed boundary and prepare a map of the land components, land-use pattern, and cropping systems • Step 2: Identify soil and water conservation practices, water harvesting devices, and catchment area treatment practices • Step 3: Develop cropping systems, irrigation, and cultivation practices • Step 4: Assess the proposed watershed activities for their linkage with and implications for enhancing C-benefits and quantify the benefits • Step 5: Identify additional CEMS or CEPs for enhancing the C-benefits of the watershed project synergistically with the broad goals of the project, such as increasing crop yields sustainably • Step 6: Develop participatory institutions for managing water resources, forests, and grazing land and build institutional capacity to manage the resources • Step 7: Implement the land- and water-related activities in the watershed • Step 8: Monitor the environmental, social, and economic impacts, particularly carbon stock enhancement and CO_2 emission reduction
Quantity required	A watershed project would consist of multiple land categories and multiple practices, requiring diverse inputs.
Impact on crop yields	Refer to relevant CEPs described in this section: • Farm ponds • Soil conservation practices • Desilting • Catchment afforestation
Impact on SOC and biomass carbon stocks	Refer to relevant CEPs described in this section

Source: Authors.

FIGURE B.2: Cratewire Check Dam

Source: Authors.

FIGURE B.3: River Bank Protection

Source: Authors.

TABLE B.6: Sustainable Agriculture

DESCRIPTION	FEATURES
Explanation of the practice	Sustainable agriculture involves farming systems that are environmentally sound, profitable, productive, and compatible with socio-economic conditions. Sustainable agriculture production includes a package of practices: soil and water conservation, organic manuring, mulching, cover crops, agro-forestry, mixed and multiple cropping, etc.
Benefits of the practice	Sustainable agriculture can yield the following long-term benefits (FAO 1995): • Meet the nutritional requirements of present and future generations and in addition provide a number of other agricultural products • Increase crop productivity in a sustainable way by enhancing soil fertility • Provide steady employment, sufficient income, and decent living and working conditions for all those involved in agricultural production • Maintain and enhance the productive capacity of the natural resource base as a whole and the regenerative capacity of renewable resources without disrupting the functioning of basic ecological cycles and natural balances, destroying the socio-cultural attributes of rural communities, or contaminating the environment • Reduce vulnerability of the agricultural sector to adverse natural and socio-economic factors and climate risks
Region	Different sustainable agricultural practices can be followed in different regions based on the cropping systems and local climatic, ecological, and socio-economic conditions
Land category	Mostly in croplands
Description of practice	A package of practices, including those listed below, can be included under sustainable agriculture: • Organic farming/green manuring • Zero/reduced tillage • Mulching/cover crops • Intercropping/multiple cropping
Impact on crop productivity	Sustainable increase in crop productivity (refer to respective CEPs in this section and to land reclamation and watershed manuals)
Impact on biomass and soil carbon	Refer to respective CEPs in this section and to land reclamation and watershed manuals. Impacts include the following: • Organic manuring/cover crop/mulching/agro-forestry practices directly lead to increased SOC and biomass carbon • Soil and water conservation practices indirectly contribute to increased biomass and SOC due to increased crop biomass production and turnover

Source: Authors.

TABLE B.7: Land Reclamation

DESCRIPTION	FEATURES
Explanation of the practice	Land reclamation involves restoring its lost productivity and generally involves conversion of the unproductive land into arable land. Land reclamation includes a package of practices aimed at revegetation, soil and water conservation, and regulated grazing and biomass extraction.
Benefits of the practice	Benefits of land reclamation include the following: • Increases land availability for crop production • Enhances local natural resources and ecosystem services (water table, flood control, climate regulation, etc.) • Improves soil fertility • Increases crop, grass, and tree biomass productivity
Region	Arid and semi-arid
Land category	Cropland, grazing land, and degraded forest land
Description of practice	Refer to respective CEPs in this section and to land reclamation and watershed manuals. Different measures can be used for land reclamation, such as the following: • Revegetation (afforestation, grass cultivation, shelterbelts, and agro-forestry) • Soil and water conservation • Soil fertility improvement through mulching, organic manuring, etc.
Impact on biomass and SOC	Refer to respective CEPs in this section and to land reclamation and watershed manuals. Impacts include the following: • Reclamation of land results in improved soil fertility as well as increased biomass growth as a result of improved soil structure, status, and water-retention capacity • Increased vegetation cover, biomass growth, and turnover lead to increased tree biomass and SOC stocks

Source: Authors.

TABLE B.8: PA Management

DESCRIPTION	FEATURES
Explanation of the practice	A PA is defined as an area of land especially dedicated to the protection of biological diversity and of natural and associated cultural resources and managed through legal and other effective means. It can also be described as a "clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve long-term conservation of nature with associated ecosystem services and cultural values."[1] In the context of these guidelines, PA management includes improved management practices to conserve and enhance biodiversity of forests (and also of wetlands and grasslands), including halting (or regulating) biomass extraction and grazing and adopting sustainable forest management practices. The main aim is to conserve the flora and fauna of forests and other ecosystems.
Benefits of the practice	Benefits of PA management include the following: • Conserves biological and cultural diversity, particularly that of plants and animals • Regenerates native species • Protects watersheds, soil resources, and coastlines • Increases plant biomass accumulation and soil carbon stock • Increases availability of NTFP and livelihoods
Region and land category	Forests present in all ecological zones: evergreen forests to arid land forests to scrub forests. Wetlands and grasslands rich in biodiversity also need protection and management.
Description of practice	PA management involves a package of practices covering banning or regulating extraction of biomass and forest products, banning grazing and extraction of fuelwood and timber, promotion of natural regeneration and forest succession, and creation of alternative livelihoods.
Impact on livelihoods and biomass	Forest productivity increases with increased biomass accumulation through protection and sustainable management. Biodiversity-rich forests generate a range of NTFPs, which could be sustainably harvested creating livelihoods for local communities.
Impact on biomass and SOC	Increased plant biomass accumulation as a result of protection and conservation and litter turnover leads to conservation and enhancement of biomass soil carbon stock.

Source: Authors; IUCN 1994. [1]IUCN 2008.

TABLE B.9: Afforestation and Forest Regeneration

DESCRIPTION	FEATURES
Explanation of the practice	Afforestation is the process of converting wasteland, degraded forests, or marginal croplands into forests, plantations, or woodland and chiefly involves planting trees on nonforest land to transform it into a forest. Forest regeneration is the process of restoring the lost tree cover, mainly through protection and promotion of natural regeneration or forest succession.
Benefits of the practice	Benefits of afforestation include the following: • Land reclamation • Water and soil conservation • Biodiversity and natural resource conservation • Maintenance of local ecosystem services • Increased supply of fuelwood, timber, and NTFP • Increased biomass and soil carbon stocks
Region	All regions: humid, semi-arid, and arid
Land category	Wasteland, grazing land, marginal cropland, and other land categories
Description of practice	The practice of afforestation involves the following steps: • Step 1: Identification of location and total area • Step 2: Choice of species suitable for the land category, status, and biomass needs (fuelwood, timber, or NTFP or a combination of these) • Step 3: Establishment of a nursery • Step 4: Land preparation • Step 5: Decisions on spacing and density of planting • Step 6: Planting and establishment of the forest or plantation • Step 7: Protection, management, and aftercare
Quantity required	Depending on the total area, species chosen, and density of planting, the number of seedlings would vary; usually it is 1,000 to 4,000 seedlings per ha
Impact on biomass production	Impact includes increased biomass production, increased availability of NTFP including grass and fuelwood. Final reports of the IWDP in Kandy in Uttarakhand[1] indicate doubling of grass productivity with afforestation and protection. Similarly, studies by Ravindranath and Sudha (2004)[2] on the spread, performance, and impact of joint forest management in India report increased yields of fuelwood and grass in the areas afforested or regenerated and protected under the program.
Impact on biomass and soil carbon	The C-benefit depends on the agro-ecological zone, rainfall, and soil quality apart from the species and silvicultural practices (density, protection, etc.). The Greening India Mission document reports an increment of 0.84 t per ha per year under urban forestry to 3.56 t per ha per year when degraded open forests are afforested.

Source: Authors; [1]http://agriharyana.nic.in/kandi_iwdp.htm; [2]Ravindranath and Sudha 2004.

FIGURE B.4: Forest Plantation Being Raised

Source: Authors.

FIGURE B.5: Forest Nursery

11/09/2010 16:25

Source: Authors.

TABLE B.10: Biodiversity Conservation

DESCRIPTION	FEATURES
Explanation of the practice	Biodiversity (biological diversity) includes diversity of life in all its forms: plants, animals, and microorganisms. Biodiversity encompasses genetic diversity within and between species and of ecosystems, and biodiversity conservation involves formulating and implementing the methods, strategies, and plans to protect, prevent the depletion of, and enhance biodiversity.
Benefits of the practice	Benefits of biodiversity include the following: • Conservation of natural and genetic resources: plants, animals, and microorganisms present in the area • Provision of food and other natural products (fiber, timber, etc.) • Provision of different ecosystem services: ▪ Soil conservation ▪ Water conservation ▪ Waste recycling and disposal ▪ Climate regulation ▪ Buffering and prevention of such extreme events as floods and droughts
Region	All forests, particularly biodiversity-rich forests or those that harbor endemic or threatened species, and grasslands
Land category	Forests, grasslands, wetlands, and biodiversity hotspots
Description of practice	Biodiversity includes the following steps: • Step 1: Assess the biodiversity status • Step 2: Identify and quantify the dependence on biodiversity for the selected forests • Step 3: Identify the drivers of degradation or loss of biodiversity through household surveys and field ecological studies • Step 4: Develop alternative sources of livelihood, fuelwood, grass, timber, etc. • Step 5: Develop programs to reduce pressure on forest biodiversity • Step 6: Implement the plans after involving local communities in the protection and management of forests or other ecosystems • Step 7: Develop and enforce sustainable extraction and grazing practices • Step 8: Monitor the biodiversity status
Impact on biodiversity and NTFP	The biodiversity conserved depends on the original biodiversity of the land category, the rate of degradation, and the factors that are driving the degradation. Conservation of biodiversity leads to significantly enhanced availability of NTFP, leading to enhanced incomes and improved livelihoods.
Impact on biomass and SOC	Protection of forests, reduction in extraction and grazing, and sustainable harvest of products will all contribute to: • Conserving the existing stock of biomass carbon • Carbon sequestration in trees due to regeneration and growth of the degraded forests or grasslands Normally SOC is marginally impacted, unless soil was being disturbed during the preproject period

Source: Authors.

TABLE B.11: Community Forestry

DESCRIPTION	FEATURES
Explanation of the practice	Community forestry is a type of forest management that involves local communities in all decisions on forest planning, designing, planting, protection, and harvesting. Local communities receive socio-economic and ecological benefits in return. This kind of approach ensures ecological well-being of the forest and sustainability of local forest communities. An example of large-scale Community Forest Management (CFM) is the Joint Forest Management program implemented in India, in which local communities and the forest department jointly protect and manage the forests and derive economic and ecological benefits.
Benefits of the practice	Benefits of community forestry include the following: • Production of fuelwood, grass, and NTFP for the local communities • Socio-economic development and enhancement of self-reliance of local rural communities • Conservation of forest resources and maintenance of ecosystem services • Reduced pressure on natural forests and grasslands • Maintenance of watersheds and landscapes
Region	Applicable to all regions
Land category	Forests and degraded forests, community lands
Description of practice	Community forestry management includes the following steps: • Step 1: Identification of the location and area for community forestry • Step 2: Selection of natural regeneration or plantation approach • Step 3: Selection of species through public consultations taking into account the land category, community biomass needs, and soil status • Step 4: Establishment of a nursery • Step 5: Land preparation, decisions on spacing and density of planting, and planting • Step 6: Protection, management, and aftercare • Step 7: Adoption of sustainable harvesting and grazing practices
Quantity required	Depending on the total area, species chosen, and the density of planting, the number of seedlings would vary, but it is usually 500 to 2,000 seedlings per ha.
Impact on biomass production	Increased biomass production and increased availability of NTFP including grass and fuelwood The final reports of the IWDP in Kandi in Uttarakhand indicate a doubling of grass productivity with afforestation and protection. Similarly, studies by Ravindranath and Sudha (2004) on the spread, performance, and impact of Joint Forest Management in India report increased yields of fuelwood and grass in the areas afforested or regenerated and protected under the program.
Impact on biomass and SOC	The C-benefit depends on the agro-ecological zone, rainfall, and soil quality apart from the species and silvicultural practices (density, protection, etc.). Illustrative examples are provided below

PRACTICE	BIOMASS (t/ha/YEAR)	SOC (tC/ha/YEAR)
Planting short-rotation species	6	0.22
Planting long-rotation species	3.56	
Natural regeneration	1.5	

Source: Authors; Ravindranath and Sudha 2004; Greening Mission document 2010.

TABLE B.12: Orchards and Gardens

DESCRIPTION	FEATURES
Explanation of the practice	Traditionally, farmers grow fruit trees along the borders or dedicate a small patch of land for growing fruit trees for home consumption as well as for generating marketable surplus. Some of the common fruit trees grown in orchards include coconut, mango, tamarind, sapota, guava, and pomegranate. These fruit orchards could be grown as block orchards on small patches of cropland belonging to the farmers to supplement their income as well as an insurance against crop failures. Orchards present a large opportunity to enhance C-benefits synergistically with increasing incomes.
Benefits of the practice	Fruit orchards provide fruits more or less throughout the year as a supplementary source of income. Fruit trees act as an insurance against crop failures, providing fruits for marketing. If grown on marginal croplands, such trees may contribute to soil and water conservation. The standing trees contribute to biomass carbon accumulation along with increased SOC.
Region	In all agro-ecological or rainfall zones
Land category	Mainly croplands of farmers but can also be grown on grassland or degraded forest lands
Description of practice	Establishing orchards and gardens requires the following steps: • Step 1: Select the area to be devoted to fruit orchards, preferably marginal croplands • Step 2: Select suitable fruit tree species • Step 3: Estimate the required number of seedlings of the selected fruit tree species and either raise a nursery or procure the seedlings from elsewhere • Step 4: Prepare the land incorporating soil and water conservation measures, plant the trees, and look after them
Quantity required	The number of seedlings of the selected tree species depends on the spacing and the density of planting, e.g., 150 to 200 trees per ha for coconut and 80 to 100 trees per ha for mango
Impact on incomes	All fruit orchards are potentially commercial ventures that provide significant income to farmers
Impact on biomass and SOC	Orchards raised on marginal lands or croplands lead to: • Enhanced biomass carbon stock in the standing perennial trees compared to marginal lands or croplands without trees • Enhanced SOC due to protection, root biomass accumulation, litter, and root biomass turnover SOC enhancement due to fruit orchards in the Uttara Kannada district in the Western Ghats and in Tamil Nadu are provided below

LAND CATEGORY	SOC (%)
WESTERN GHATS	
Marginal cropland	1.1
Agriculture (paddy)	0.7
Coconut	1.8
Cashew	1.4
TAMIL NADU	
Marginal cropland	0.71
Paddy	0.83
Sugarcane	0.66
Corn as fodder	0.54
Coconut	1.74

Source: Authors.

TABLE B.13: Irrigation (Minor or Major)

DESCRIPTION	FEATURES
Explanation of the practice	Irrigation involves supplying water to land (cropland, grassland, etc.) by artificial means in case adequate water is not available naturally. Minor irrigation projects involve conserving, collecting, storing, and providing water for irrigating crops and are generally small-scale projects extending from a few ha up to perhaps a few hundred ha. The techniques deployed for irrigation include digging small storage tanks, pumping water from flowing rivers and streams, farm ponds, desilting of water storage bodies to increase water storage, etc.
Benefits of the practice	Benefits of irrigation include the following: • Increased agricultural production • Increased utilization of land for cropping • Reduced risk of crop failure • Greater crop diversification • Soil and water conservation
Region	Arid and semi-arid regions
Land category	Croplands
Description of practice	The implementation of irrigation includes the following steps: • Step 1: Select the approach and technology /practices • Step 2: Consult civil or agricultural engineers, prepare a design, and plan the relevant activities • Step 3: Implement the practices • Step 4: Develop a management system for sharing water • Step 5: Suggest cropping and cultivation practices to maximize water-use efficiency (grain yield per unit of water)
Impact on crop yields	Irrigation could double or triple the crop yield in arid and semi-arid regions; in some situations, irrigation stands between total crop failure and high yields
Impact on soil and biomass carbon	Generally, increased biomass production and root and crop residue turnover would lead to increased SOC

Source: Authors.

FIGURE B.6: Irrigation Tank

Source: Authors.

TABLE B.14: Fuelwood Conservation Devices (Biogas and Efficient Cookstoves)

DESCRIPTION	FEATURES
Explanation of the practice	Biogas is chiefly methane and carbon dioxide with small amounts of carbon monoxide and nitrogen. Biogas is produced by microbial conversion of biomass or organic matter into methane involving anaerobic digestion. The biomass includes the following kinds of material: • Animal dung, industrial and municipal wastes • Mill and farm residues • Fast-growing trees and other leaf litter **Biogas** is produced, especially in rural India, for meeting the energy needs of local people and is primarily used as a cooking fuel. Biogas replaces fuelwood or cattle dung as fuel and improves the quality of life of women. **Efficient cookstoves or chulhas** are two to three times as efficient (conversion efficiencies of 20 to 30% and 8 to 15%, respectively) as traditional stoves, which have low thermal efficiencies, requiring more fuelwood for cooking.
Benefits of the practice (economic, environmental, and carbon)	Benefits of using biogas: • Clean fuel with high calorific value • Renewable source of energy • Recycling of waste material (agricultural, municipal, livestock) • The waste residue produced from biogas plants is good manure • Substitution and conservation of fuelwood and trees • Improved quality of life for women Benefits of using efficient cookstoves: • Conservation of fuelwood and trees • Reduction of smoke in rural kitchens, enhancing women's health
Region	All regions
Description of practice	Using **biogas** depends on the availability of cattle dung, space for the plant, access to biogas builders, and the capacity to invest. Only families with adequate cattle (sheep and goats; normally one cow/bullock/buffalo per person is the norm, but the number depends on dung yield) have this option. It is necessary to consult the biogas builder and determine the feasibility of the biogas option for the family depending on the number of cattle, dung yield, size of the family, land available for the plant, etc. Using an improved **cookstove** is recommended only if biogas is not feasible, as biogas is the first option. The design of the improved cookstove is based on the cooking practice. The cookstoves are either built at the site or bought from the market.
Impact on CO_2 emissions	**Biogas:** The shift to biogas leads to total substitution of fuelwood combustion, thereby avoiding the emissions of CO_2 and other GHGs. The level of CO_2 emission avoided depends on the quantity of fuelwood and the proportion coming from nonsustainable extraction of wood or felling of trees. Quantity of CO_2 emission avoided in kg/household/year = [(Quantity of fuelwood consumed in kg/household/day) × 365 days × (fraction of fuelwood saved by shifting to biogas)] × proportion of fuelwood obtained from felling of trees × 0.5 × 3.667 Ravindranath *et al.* (2000) estimated the fuelwood conservation potential of 17 million biogas plants (at 80% capacity utilization) at 25 million tons, which is equivalent to conserving 79,365 ha of forests or plantations **Efficient cookstoves:** When efficient cookstoves are considered, normally the saving in fuelwood ranges from 10 to 50%. The CO_2 emission avoided depends on the quantity of fuelwood saved and the proportion of nonsustainable extraction of wood or felling of trees. The following formula can be used to calculate the CO_2 emission avoided. Quantity of CO_2 emission avoided in kg/household/year = [(Quantity of fuelwood consumed in kg/household/day) × 365 days × (fraction of fuelwood saved by using efficient stove)] × proportion of fuelwood obtained from felling of trees × 0.5 × 3.667 Ravindranath *et al.* (2000) estimated the fuelwood conservation potential of 70 million stoves at 99 million tons, which is equivalent to conserving 314,275 ha of forests and plantations

Source: Authors; Ravindranath *et al.* 2000.

FIGURE B.7: Biogas Plant

Source: Authors.

B.2. DESCRIPTIONS OF CEPs

TABLE B.15: Mulching

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Mulching is a moisture conservation practice for croplands. It involves spreading organic matter or other materials on the soil surface to reduce the loss of soil moisture and also to prevent soil erosion. Mulches could be of various kinds, such as crop residue, leaf litter, weeds, and tank silt.</td></tr>
<tr><td>Benefits of the practice</td><td>The benefits of mulching include the following:
• Soil moisture conservation and reduction of soil erosion
• Increased infiltration
• Enhanced germination of seedlings
• Greater root density in the top layer due to favorable soil moisture
• Moderation of soil temperature
• Weed control
• Improved crop growth and higher yields
• Increased carbon stock due to the addition of organic mulches</td></tr>
<tr><td>Suitable regions</td><td>Mulching is particularly suitable for arid and semi-arid regions</td></tr>
<tr><td>Land category</td><td>The land categories suitable for mulching are those that support annual crops, horticultural crops, or plantations</td></tr>
<tr><td>Description of practice</td><td>Mulching involves the following steps:
• Step 1: Selection of area and estimation of the quantity of mulch required
• Step 2: Identification of the source of mulch (e.g., crop residue, tree leaves, organic manure, and tank silt)
• Step 3: Procurement of the mulch and transportation to the field
• Step 4: Application of mulch at the appropriate stage of crop production such as after sowing or after transplanting</td></tr>
<tr><td>Quantity required</td><td>Varies from 5 to 10 tons per ha</td></tr>
<tr><td>Impact on crop yields</td><td>Mulching, by reducing soil erosion and increasing infiltration, causes increased moisture retention, thereby enhancing germination of seedlings and deeper rooting and ultimately better growth and crop yield.
Impact of mulch application on yield of a few crops under rain-fed conditions is shown below[1]
<table>
<tr><th></th><th colspan="2">GRAIN YIELD (t/ha)</th></tr>
<tr><th>CROP</th><th>NO MULCH</th><th>MULCH</th></tr>
<tr><td>Green gram</td><td>0.14</td><td>0.39</td></tr>
<tr><td>Moth bean</td><td>0.21</td><td>0.4</td></tr>
<tr><td>Cluster bean</td><td>0.56</td><td>0.65</td></tr>
<tr><td>Cowpea</td><td>0.42</td><td>0.66</td></tr>
<tr><td>Pearl millet</td><td>1.39</td><td>1.66</td></tr>
<tr><td>Wheat</td><td>2.33–2.86</td><td>2.93–3.51</td></tr>
<tr><td>Tobacco</td><td>1.33</td><td>1.84</td></tr>
<tr><td>Sorghum</td><td>0.53</td><td>0.94</td></tr>
<tr><td>Barley</td><td>1.75</td><td>1.91</td></tr>
</table></td></tr>
<tr><td>Impact on SOC</td><td>Application of mulch leads to increased crop or plantation biomass production, including root biomass production. This increased root and shoot biomass production and incorporation into soil leads to increased SOC.[2]
<table>
<tr><th>QUANTITY OF MULCH (t/ha)</th><th>SOIL ORGANIC C (g/kg OF SOIL)</th></tr>
<tr><td>0 (control or no mulch)</td><td>19.7</td></tr>
<tr><td>2.5</td><td>28.7</td></tr>
<tr><td>5</td><td>29.6</td></tr>
<tr><td>10</td><td>32.1</td></tr>
</table></td></tr>
</table>

Source: Authors; [1]Venkateswarlu 2004; [2]Blanco Canqui *et al.* 2006.

TABLE B.16: Organic Manure/Green Manure/Crop Residue Incorporation

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Organic manuring involves application of organic matter such as FYM or compost or leaf litter into the soil in annual cropland and orchards to increase nutrient supply as well as soil moisture.
Green manuring includes cultivation of short-duration green manuring crops such as <i>Sesbania</i>, horse gram, or sun hemp and incorporating the standing crop into soil before sowing or transplanting the main crop.
Residue of the previous crop is also incorporated into the soil before raising the next crop to increase crop yields, particularly in rain-fed agriculture.</td></tr>
<tr><td>Benefits of the practice</td><td>Application of organic/green manure leads to increased availability of nitrogen as well as other nutrients to crops and increases soil moisture availability in rain-fed croplands, enhancing crop productivity</td></tr>
<tr><td>Suitable regions</td><td>Suitable for all regions: arid, semi-arid, and humid</td></tr>
<tr><td>Land category</td><td>Annual croplands, perennial croplands, orchards, and plantations</td></tr>
<tr><td>Description of practice</td><td>Implementation of organic manuring includes the following steps:
• Step 1: Preparation of compost or FYM, which involves collection of livestock dung, kitchen waste, weeds, and crop residue regularly and storing the material in compost pits for decomposition
• Step 2: Transportation of manure to the fields
• Step 3: Incorporation of organic manure into soil during plowing prior to sowing or transplanting the main crop

Implementation of green manuring includes the following steps:
• Step 1: Sowing a green manure crop such as <i>Sesbania</i>, sun hemp, or horse gram a few weeks before transplanting the main crop such as rice
• Step 2: Plowing the green manure crop at a tender stage into the soil before sowing or transplanting the main crop
In some regions, leaves of trees such as <i>Gliricidia</i> and <i>Pongamia</i> are harvested while they are still green and worked into the soil during plowing.</td></tr>
<tr><td>Quantity required</td><td>Organic manure application could be in the range of 2 to 10 t per ha</td></tr>
<tr><td>Impact on crop yields</td><td>Application of organic or green manure contributes to increased soil fertility as well as availability of nutrients in addition to enhancing the moisture-holding capacity of soil, thereby contributing to increased crop productivity

The impact of organic manuring on production of maize and chickpea is described below
<table>
<tr><th>MANURE AND QUANTITY/ha</th><th colspan="2">GRAIN YIELD (kg/ha)</th></tr>
<tr><th></th><th>CORN</th><th>CHICKPEA</th></tr>
<tr><td>Control (no manure)</td><td>1389</td><td>540</td></tr>
<tr><td>FYM, 10 t</td><td>2037</td><td>1,173</td></tr>
<tr><td>Vermicompost, 3 t</td><td>2006</td><td>1,018</td></tr>
<tr><td>FYM, 5 t</td><td>2253</td><td>926</td></tr>
</table></td></tr>
<tr><td>Impact on SOC</td><td>Incorporation of organic or green manure leads to increased stock of soil organic matter or SOC directly as well as indirectly through increased crop and root biomass production and turnover.
<table>
<tr><th>TREATMENT</th><th>SOC (%)</th></tr>
<tr><td colspan="2">GREEN MANURING</td></tr>
<tr><td>Before treatment</td><td>0.50</td></tr>
<tr><td>Incorporation of sun hemp (green manuring crop)</td><td>0.60</td></tr>
<tr><td colspan="2">ORGANIC MANURING</td></tr>
<tr><td>Control (no organic manure application)</td><td>0.10</td></tr>
<tr><td>50% of nutrients from crop residue, rest from fertilizers</td><td>0.26</td></tr>
<tr><td>50% of nutrients from FYM, rest from fertilizers</td><td>0.29</td></tr>
</table></td></tr>
</table>

Source: Authors; Annual Report 2009/10.

FIGURE B.8: Crop Residue Shredded (top photo) and applied (bottom photo) as mulch in Adilabad, Andhra Pradesh

Source: Authors.

TABLE B.17: Reduced Tillage or No Tillage

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Reduced tillage or no tillage is one of a set of techniques used in conservation agriculture that aims to enhance and sustain farm production by conserving and improving soil, water, and biological resources. Essentially, it maintains a permanent or semipermanent organic soil cover (e.g., a growing crop or dead mulch) that protects the soil from the sun, rain, and wind and allows soil microorganisms and other fauna to take on the task of “tilling” and balancing soil nutrients through natural processes disturbed by mechanical tillage. Reduced tillage is more relevant to tropical regions.</td></tr>
<tr><td>Benefits of the practice</td><td>Benefits of reduced or no tillage include the following:
• Reduction in soil erosion (to as much as 1/15 of that under normal tillage)
• Fuel saving since land preparation is greatly reduced
• Flexibility in planting and harvest
• Reduced requirement of labor and equipment
• Improved water retention and reduced evaporation
• Improved nutrient cycling
• Increased availability of plant nutrients
• Improved soil organic matter status and increased carbon sequestration</td></tr>
<tr><td>Suitable regions</td><td>Arid and semi-arid regions</td></tr>
<tr><td>Land category</td><td>Cropland, rain fed</td></tr>
<tr><td>Description of practice</td><td>With no tillage, there is little or no preparation of land before sowing. The practice is also called slot planting, zero tillage, or direct drilling. It often involves the use of herbicides to kill weeds.</td></tr>
<tr><td>Impact on crop yields</td><td>Reduced tillage or no tillage helps to increase the amount of water in the soil and decrease soil erosion and may also increase the number and variety of life forms in and on the soil, which increases soil fertility and thereby crop yields
The impact of conventional and no tillage on wheat is described below
<table>
<tr><th>TILLAGE SYSTEM</th><th>CROP RESIDUE (t/ha)</th><th>GRAIN YIELD (t/ha)</th></tr>
<tr><td>Conventional</td><td>1.65</td><td>1.18</td></tr>
<tr><td>No tillage</td><td>2.85</td><td>1.42</td></tr>
</table></td></tr>
<tr><td>Impact on SOC</td><td>Conventional farming practices that rely on tillage remove carbon from the soil ecosystem by removing crop residues. Further tillage disturbs topsoil and exposes it to heat, leading to enhanced oxidation of soil organic matter and loss of CO_2. By eliminating tillage, crop residues are left to decompose in the field and carbon loss can be slowed and eventually reversed. Soil carbon sinks are increased by the increased biomass due to increased yields as well as by decreased losses of organic carbon from soil erosion.
Stocks and accumulation rates of carbon and carbon sequestration rates in conventional tillage and no-tillage systems in the 0- to 30-cm and 0- to 100-cm soil layers are shown below
<table>
<tr><th>TREATMENT</th><th>SOC (g/kg)</th></tr>
<tr><td>Conventional tillage</td><td>5.8</td></tr>
<tr><td>Zero tillage</td><td>5.7</td></tr>
<tr><td>Zero tillage + residue incorporation</td><td>6.7</td></tr>
</table></td></tr>
</table>

Source: Authors; Saha *et al.* 2010.

TABLE B.18: Contour Bunding

DESCRIPTION	FEATURES
Explanation of the practice	Contour bunding is one of the most common methods of soil and water conservation and involves the construction of trapezoidal bunds with a narrow base along the contour lines to impound runoff water, so that all the water stored is absorbed gradually in the soil profile for crop use.
Benefits of the practice	Benefits of contour bunding include the following: • Soil and water conservation • Increased crop yields • Carbon sequestration in soils
Suitable regions	Contour bunding is recommended for low-rainfall areas (less than 600 mm) and for permeable soils up to slopes of about 6% in agricultural lands
Land category	Agricultural lands, plantations, and afforestation sites
Cropping system	Rain-fed crops
Description of practice	Building contour bunds involves the following steps: • Step 1: Determining the cross-section and spacing between the bunds (height and width of bunds) • Step 2: Marking the contour lines • Step 3: Constructing the bunds along the contours
Impact on crop yields	Conservation of soil and moisture leading to increased crop yields
Impact on soil organic matter or SOC	Reduced water erosion and increased availability of soil moisture for crops, leading to increased biomass production and root biomass and crop residue turnover, which in turn contribute to enhanced SOC

Source: Authors; Narayana 2002.

FIGURE B.9: *In Situ* Rainwater Harvesting Along the Bunds in Trenches (left) and in a Field (right) Ploughed by a Ridger in Mahabubnagar, Andhra Pradesh

Source: Authors.

TABLE B.19: Farm Ponds

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Farm ponds are constructed to hold the runoff water from cropland or other catchment areas. The water collected is used for providing supplemental irrigation to crops at critical periods of crop growth. Farm ponds are usually small, constructed to provide water for areas ranging from a fraction of a ha to a few ha.</td></tr>
<tr><td>Benefits of the practice</td><td>Benefits of farm ponds include the following:
• Conservation of water
• A water supply as supplementary or life-saving irrigation to rain-fed crops
• Overcoming moisture stress due to droughts or delayed rains
Farm ponds can save a crop from total failure or increase and stabilize crop yields.</td></tr>
<tr><td>Region</td><td>Arid and semi-arid</td></tr>
<tr><td>Land category</td><td>Cropland</td></tr>
<tr><td>Description of practice</td><td>Establishing a farm pond includes the following steps:
• Step 1: Estimate the catchment area
• Step 2: Estimate the runoff based on the pattern of rainfall
• Step 3: Estimate the capacity of the pond
  ▪ The depth of the pond should be 5 m or less to avoid seepage losses
  ▪ The length and the breadth depend on the volume of runoff water
• Step 4: Estimate the area to be irrigated
• Step 5: Modify the land to facilitate water flow into the ponds naturally
  ▪ Select low-lying areas to minimize the cost of excavation
  ▪ Ensure that the soil at the selected site is impermeable so as to minimize percolation losses
• Step 6: Provide proper inlet and outlet to the farm pond
• Step 7: Construct a silt trap (pit) in the inlet region
• Step 8: Line the insides with impervious material to control seepage loss
• Step 9: Use the stored water for life-saving or critical irrigation</td></tr>
<tr><td>Farm pond capacity</td><td>Farm pond capacity is determined based on the steps mentioned above. Usually, a farm pond for one ha of land is 250 cubic meters.</td></tr>
<tr><td>Impact on crop yields</td><td>Farm ponds can supply critical life-saving irrigation to overcome moisture stress in rain-fed agriculture and increase yields by 15 to 40%.
The impact of farm pond on productivity of major crops is described below
<table>
<tr><th rowspan="2">CROP</th><th colspan="2">YIELD (kg/ha)</th><th rowspan="2">% CHANGE IN YIELD</th></tr>
<tr><th>WITH FARM POND</th><th>WITHOUT FARM POND</th></tr>
<tr><td>Paddy</td><td>2,482</td><td>2,022</td><td>22.74</td></tr>
<tr><td>Cotton</td><td>1,195</td><td>988</td><td>20.95</td></tr>
<tr><td>Sorghum</td><td>1,168</td><td>953</td><td>22.56</td></tr>
<tr><td>Corn</td><td>3,203</td><td>2,460</td><td>30.20</td></tr>
<tr><td>Soybean</td><td>1,575</td><td>1,312</td><td>20.04</td></tr>
<tr><td>Peanut</td><td>1,722</td><td>1,492</td><td>16.15</td></tr>
<tr><td>Winter sorghum</td><td>1,017</td><td>832</td><td>22.23</td></tr>
<tr><td>Green gram</td><td>380</td><td>269</td><td>41.26</td></tr>
</table></td></tr>
<tr><td>Impact on SOC</td><td>Irrigating rain-fed croplands leads to increased biomass production, root biomass and turnover, all contributing to increased SOC</td></tr>
</table>

Source: Authors; Rajeshwari *et al.* 2007.

FIGURE B.10: Farm Ponds for Harvesting Runoff and Recycling During Midterm Droughts in Adilabad, Andhra Pradesh, and a Village Pond in Uttaranchal

Source: Authors.

TABLE B.20: Application of Tank Silt

DESCRIPTION	FEATURES
Explanation of the practice	Poor management of catchment areas has resulted in silting of most water bodies and significant reduction in their storage capacity. Good practices such as desilting of water storage bodies and application of silt to agricultural fields provides a win-win situation by restoring the lost storage capacity as well as by improving soil health. This is traditionally practiced in irrigation tanks or minor irrigation water storage systems.
Benefits of the practice	**Desilting** increases the storage capacity of tanks, leading to increased water availability for irrigation, thereby contributing to increased crop yields. The **application of tank silt** improves the water-holding capacity, cation exchange capacity, and fertility of the soil as the silt contains both major nutrients and micronutrients, which boost crop growth and yield.
Region	Arid and semi-arid
Land category	Cropland
Description of practice	Desilting involves the following steps: • Step 1: Identify the tank to be desilted • Step 2: Desilt the tank by removing the accumulated silt from the floor of the tank either manually or by using appropriate machinery • Step 3: Determine the quantity of silt to be applied per ha • Step 4: Use the silt thus extracted as a soil amendment, especially for rain-fed cropland subjected to topsoil erosion
Impact on biomass and SOC	With silt application, moisture retention capacity of soil goes up by 4 to 7 days, which plays an important role during the period of prolonged dry spells. It was confirmed through gravimetric studies that the available water content in the root zone increased from its normal level of 6 to 7 percent after addition of 100 trolley loads of silt per ha. Further, the physical and chemical properties of soil changed permanently (the clay content in the root zone went up from 20 to 40 percent and sand and fine sand was decreased). Such an increase in clay content helps retain more moisture and also reduces the loss of nutrients through leaching because of improved cation exchange capacity. All these lead to improved soil fertility and increased crop growth and litter turnover, contributing to increased SOC. The impact of tank silt application on SOC of croplands of Chitradurga, Karnataka is decribed below

TREATMENT	SOC (%)
Wasteland	0.22–0.56
Cropland	0.58–1.07
Cropland+silt	1.02–3.18

Source: Authors; Tiwari *et al.* 2010.

FIGURE B.11: Tank Silt Applied to Enhance Soil Fertility and Increase Water Harvesting Capacity of Tanks in Kadapa, Andhra Pradesh

Source: Authors.

TABLE B.21: Cropping Systems: Intercropping, Multiple Cropping, Mixed Cropping, and Relay Cropping

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Intercropping involves growing two or more crops on the same piece of land. Multiple cropping involves growing multiple crops in a year (three crops in a year instead of one). Mixed cropping involves mixing seeds of several crop species and sowing the mix in the same plot. Intercropping includes several subcategories such as strip cropping and relay cropping.
Multiple cropping is one such common form of intercropping and can be described as the intensification of land use by increasing the number of crops grown on the same piece of land, thus ensuring more efficient use of time and other resources. Normally, cereals or millets are mixed with pulses, oil seeds, and vegetables.</td></tr>
<tr><td>Benefits of the practice</td><td>Benefits of cropping systems include the following:
• Reduced risk of crop failure: The risk that all crops will fail is rare; if one crop fails, the other could survive and yield
• Variety of produce: A variety of produce could be obtained from a single piece of land to meet the varied requirements of a family for cereals, pulses, vegetables, etc.
• Increased yield: Component crops could have a complementary effect on one another (e.g., legume crops, by fixing nitrogen in the soil, have a beneficial effect on cereals and other nonlegume crops)
• Improved soil fertility: Cereal crops deplete the soil of nutrients, whereas growing legumes will help increase the nitrogen content of the soil. Thus, soil fertility is improved by the right choice of component crops
• Reduced pest damage: Crops of a particular species are more prone to particular types of pests (weed, insects, and diseases); when different types of crops are grown together, chances of pest infestation are reduced
• Greater biodiversity: Floral and faunal biodiversity in the field is enriched by the presence of a range of crops
• Weed control: Since the land is under crop cover for longer periods, weeds are kept in check</td></tr>
<tr><td>Suitable regions</td><td>Arid and semi-arid regions</td></tr>
<tr><td>Land category</td><td>Cropland</td></tr>
<tr><td>Description of practice</td><td>There following criteria and steps could be adopted for intercropping or mixed cropping:
• Step 1: Decide on the form of intercropping (multiple cropping, mixed cropping, etc.)
• Step 2: Identify the appropriate combination of crops:
▪ Long and short duration
▪ Different height and spread (tall/short and spreading/nonspreading)
▪ Different products (cereals or millets and pulses or vegetables)
• Step 3: Identify the appropriate cultivation practices—density, spacing, number of rows of different crops or the mixing pattern for different crops, land preparation, time of sowing, manure or fertilizer application, etc.
• Step 4: Implement the selected crop combination and cultivation practices</td></tr>
<tr><td>Impact on crop yields</td><td>Intercropping helps in matching crop demands to available sunlight, water, nutrients, and labor. The advantage of intercropping over sole cropping is that competition for resources between species is less than that within the same species, thus resulting in better yields.
The effect of mixed cropping on the yield of wheat and gram at Kota is described below[1]
<table>
<tr><th>CROPPING SYSTEM</th><th>MEAN YIELD (kg/ha)</th></tr>
<tr><td>Wheat (pure crop)</td><td>315</td></tr>
<tr><td>Gram (pure crop)</td><td>315</td></tr>
<tr><td>Wheat + gram (in alternate rows)</td><td>440</td></tr>
</table>
The impact of intercropping with different crops on coconut yield is decribed below[2]
<table>
<tr><th>INTERCROP</th><th>YIELD (NO. OF COCONUTS/ha/YEAR)</th></tr>
<tr><td>Control (no intercrop)</td><td>5,172</td></tr>
<tr><td>Clove</td><td>5,549</td></tr>
<tr><td>Black pepper</td><td>5,466</td></tr>
<tr><td>Cinnamon</td><td>7,080</td></tr>
<tr><td>Coffee</td><td>7,318</td></tr>
<tr><td>Annuals in rotation</td><td>6,825</td></tr>
</table></td></tr>
<tr><td>Impact on SOC</td><td>Continued cultivation of a single crop results in depletion of certain soil nutrients. With intercropping and crop rotation, soil fertility is promoted through alternate planting of crops having different nutrient needs, which prevents depletion of any one essential element present in the soil. Leguminous plants, because of their ability to accumulate nitrogen by fixing it from the air in association with <i>Rhizobium</i> bacteria, also improve soil fertility.
SOC would increase due to increased biomass production and root or residue turnover.</td></tr>
</table>

Source: Authors; [1]Aryan 2002; [2]Singh 1997.

TABLE B.22: Cover Cropping

DESCRIPTION	FEATURES
Explanation of the practice	Cover crops contribute to restoration and maintenance of SOC and soil fertility, leading to improved crop yields. Cover crops provide an onsite source of plant biomass for incorporation into soil to restore and increase SOC and density.
Benefits of the practice	Cover crop incorporation into soil improves soil aggregation and infiltration capacity and maintains the physical and chemical properties of soil. Cover crops also reduce land degradation by wind and water erosion. Biological measures of erosion control involving use of cover crops provide ground cover to protect the soil from the impact of raindrops and decrease the velocity and carrying capacity of overland flow. Incorporation of cover crops enhances SOC.
Region	Irrigated crops (such as wheat and rice) and semi-arid croplands
Land category	Cropland
Description of practice	Planting cover crops involves the following steps: • Step 1: Select the main crop and the season in which the main crop is to be grown • Step 2: Select a cover crop, preferably a leguminous crop with low lignin content, for cultivation and incorporation into the soil ▪ Dedicated manure crop (e.g., *Sesbania*) ▪ Grain and manure crops (e.g., cowpea, horse gram, and pigeon pea) • Step 3: Cultivate the cover crop before sowing or transplanting the main crop; in some cases, cover crops could also be grown after the harvest of the main crop using the residual soil moisture • Step 4: Harvest the grain of the cover crop at maturity and then incorporate the crop residue into soil; if a dedicated cover crop is grown, the whole plant is plowed and incorporated into soil a few weeks before transplanting the main crop
Impact on crop yields and soil fertility	Incorporation of a large quantity of plant biomass, especially of leguminous crops, leads to increased soil fertility, leading to decreased use of inorganic fertilizers and increased yield of the crop. If a gain-yielding crop is grown as the additional crop, the grain yield will contribute to the income.
Impact on biomass and SOC	Cultivation and incorporation of leaves or whole-plant biomass, particularly of leguminous crops, lead to increased SOC. Further, the increased soil fertility leads to increased main crop biomass, and its turnover leads to enhanced SOC.

COVER CROP	SOC (%)
Control (no cover crop)	0.530
Stylosanthes hamata	0.720
Lucerne	0.740
Centrosema	0.695
Calapagonium	0.720

Source: Authors.

TABLE B.23: Silvi-pasture and Horti-pasture

<table>
<tr><th>DESCRIPTION</th><th>FEATURES</th></tr>
<tr><td>Explanation of the practice</td><td>Silvi-pasture is when woody perennials, preferably of fodder value, are planted and raised on grazing lands to optimize land productivity, conserving species, soils, and nutrients and producing mainly forage along with timber and fuelwood. The main purpose of silvi-pasture is to produce grass and fodder through annuals as well as perennials (fodder-yielding trees).
Horti-pasture is when perennial horticultural crops such as mango, tamarind, guava, and sapota are cultivated. The main purpose of horti-pasture is to produce economically valuable fruits in addition to grass or fodder.</td></tr>
<tr><td>Benefits of the practice</td><td>The benefits of a good silvi-pasture system include the following:
• Could increase land productivity from about 1 t per ha per year to about 10 t per ha per year (for a 10-year rotation)
• Produces additional tree-based fodder for livestock and fuelwood for households
• Tree leaves as fodder are available year round
• Has potential for grassland reclamation and biodiversity conservation
The benefits of a horti-pasture system include the following:
• Fruits are produced in addition to grass
• Fruit production acts as a hedge against crop failures
Both silvi- and horti-pasture contribute to soil conservation. Biomass carbon stocks would increase due to planting of trees (forage or fruit). In addition, with improved management of land and growth of trees, SOC stock could increase due to leaf litter and root biomass turnover.</td></tr>
<tr><td>Region</td><td>Arid and semi-arid</td></tr>
<tr><td>Land category</td><td>Grassland, grazing land, degraded forest, or community land</td></tr>
<tr><td>Description of practice</td><td>Establishment of a silvi- or horti-pasture system includes the following steps:
• Step 1: Selection of location (e.g., degraded grassland or grazing land)
• Step 2: Selection of fodder-yielding or horticultural tree species
• Step 3: Development of planting design including the number of rows, distance between the rows, and spacing of trees within rows
• Step 4: Raising the seedlings of the tree species or procuring them from elsewhere
• Step 5: Land preparation and planting
• Step 6: Aftercare, regulated grazing, and grass harvesting</td></tr>
<tr><td>Quantity required</td><td>The number of trees of different species depends on the tree species selected, which in turn governs the spacing, both between rows and within a row.</td></tr>
<tr><td>Impact on grass production and leaf, fodder, fruit production</td><td>Leaf production as fodder and fruit production depends on the tree species, density per ha, and soil and water conditions. A good silvi-pasture system could increase land productivity from about 1 t per ha per year to about 10 t per ha per year (for a 10-year rotation).</td></tr>
<tr><td>Impact on biomass and SOC</td><td>Biomass carbon stock is enhanced because of planting and growth of perennial trees and shrubs since only leaves or fruits are extracted.
SOC stock is enhanced due to growth of tree root biomass and litter turnover as well as improved grass production.
<table>
<tr><th>LAND CATEGORY</th><th>SOC (%)</th></tr>
<tr><td>Control</td><td>0.29</td></tr>
<tr><td><i>Leucaena leucocephala</i> and <i>Stylosanthes hamata</i></td><td>0.68 (after 5 years)</td></tr>
<tr><td><i>Leucaena leucocephala</i> and <i>Cenchrus ciliaris</i></td><td>0.52 (after 5 years)</td></tr>
</table></td></tr>
</table>

Source: Authors.

FIGURE B.12: Promotion of Horti-Pastures in Degraded Lands in Kadapa, Andhra Pradesh

Source: Authors.

Part C: CARBON ESTIMATION AND MONITORING METHODS

C.1. CARBON-MONITORING METHODS AND PRACTICAL GUIDANCE

There is need for methods and guidance on estimation and monitoring of carbon benefits at different phases.

C.1.1. Monitoring of C-Benefits

Land-use sectors, particularly forest lands and agricultural lands, play a critical role in addressing climate change mitigation. Addressing climate change through land-use sectors involves reducing CO_2 emissions from forest and agricultural land use and land-use change as well as enhancing the carbon stocks of both the land categories. According to FAO (2010), carbon stocks in forests are declining, and according to IPCC (2007), land use and land-use change contributed to approximately 17.4 percent of the global CO_2 equivalent of GHG emissions in 2004. Further, IPCC (2007) has shown the large mitigation potential available in the land-use sectors for stabilizing CO_2 concentration in the atmosphere. Many efforts are under way from the global to the local level to explore the land-use sectors for mitigating climate change. These efforts include A/R under the CDM, the REDD+ mechanism under the Cancun Agreement, and bilateral and multilateral programs as well as efforts at the national level to reduce deforestation and degradation and promote A/R. The potential of agricultural soils to mitigate climate change is very high; it is being recognized and may become a part of future UNFCCC mechanisms.

In addition to the traditional approaches of REDD and A/R, agricultural land, grassland, and degraded forest land offer many opportunities to enhance carbon stocks and reduce CO_2 emissions. A variety of NRM, agricultural development, land reclamation, and livelihood improvement programs are being implemented in developing countries. These programs provide opportunities to generate C-benefits synergistically with the socio-economic goals of the programs, and the present guidelines describe approaches to and methods of enhancing C-benefits from all land-based NRM and developmental projects.

Monitoring C-benefits includes measurement, estimation, and projection of carbon stock changes or CO_2 emissions reduction resulting from project implementation: Estimation of net C-benefits requires estimation and projection of baseline or reference-scenario carbon stocks and changes (or CO_2 emissions) as well as of changes in carbon stocks or CO_2 emissions resulting from project implementation. C-benefit estimation is required during two phases:

- *The ex ante or project proposal preparation phase:* During the phase of preparing a project proposal, C-benefits from the proposed project interventions need to be estimated. *Ex ante* estimates, including projections of potential C-benefits, are required by the project developer to assess the potential C-benefits and by project evaluators and funding agencies to decide on funding C-enhancement activities or interventions. The proposal preparation phase involves identifying project interventions or activities, determining the area under each activity, estimating the likely C-benefits per unit area, and modeling those benefits.
- *Ex post or project implementation phase:* Periodical and long-term monitoring of C-benefits is required during the postimplementation phase, and guidelines are required for project managers to develop and implement carbon-monitoring arrangements. The postimplementation phase involves laying out permanent plots for long-term monitoring, field and laboratory studies, calculations, and modeling of carbon stock changes.

To estimate the incremental carbon stocks due to project activities, carbon stocks or CO_2 emissions have to be measured and estimated for two scenarios:

- *Baseline scenario (or control plots):* The parameters required for estimating carbon stocks are measured in plots that are not subjected to project activities but have land and soil features similar to those plots proposed to be subjected to project activities.
- *Project scenario:* The parameters required for estimating carbon stocks are measured in representative sample plots subjected to project activities.

Reasons for estimating or monitoring carbon in land-based projects: Project developers, managers, evaluators, and funding agencies require the estimation, projection, and monitoring of C-benefits to decide on funding C-enhancement projects, evaluating the impacts of the projects, making payments for the C-benefits derived from projects, and reporting carbon mitigation at the national level. Quantitative estimates of C-benefits also assist in quantifying the cost-effectiveness of different land-based project interventions in mitigating climate change. Such estimates are also useful while deciding on whether to incorporate any additional activities or to modify the implementation arrangements to enhance C-benefits.

Scope of the guidance: Monitoring of C-benefits involves estimating changes in carbon stocks of or CO_2 emissions from five carbon pools: AGB, below-ground biomass (BGB), deadwood, litter, and soil carbon. Measurement, estimation, and projection of C-benefits require methods, models, and field and laboratory studies to estimate changes in all these five carbon pools or a subset of these pools periodically.

These guidelines provide practical methods applicable to all land-based projects focusing on biomass and soil carbon. The importance of these two pools varies from agriculture to forest to grassland categories.

- In agriculture, watershed, and grassland development projects, the focus is on soil carbon. Projects in these three sectors could also include tree-based interventions such as agro-forestry, orchards, cultivation of green manuring trees, silvi-pasture, and shelterbelts. Thus, agriculture and watershed projects also require monitoring tree biomass carbon pools and require methods for measuring trees.
- Biomass and soil carbon pools are important in forestry projects, requiring monitoring of both.

Thus, the methods described for measuring trees in forests and plantations are also applicable to agriculture and watershed projects with tree-based interventions. Further, the methods described for measuring soil carbon in forestry or tree-based projects can be applied to agriculture and watershed projects.

A number of approaches to and methods of measuring, estimating, monitoring, and reporting C-benefits at the project level as well as at the national level are available. Sources of such methods and guidelines include the following, which provide detailed steps, procedures, and explanations: **the IPCC Good Practice Guidance 2003, the IPCC 2006 AFOLU Guidelines, CDM methodologies, Verified Carbon Standards (VCS) methodologies, GOFC Gold 2009, Winrock 2006, Ravindranath and Ostwald 2008, and CIFOR 2010.**

This part of the guidelines provides practical guidance and simplified methods of carbon estimation and monitoring, applicable mainly to typical land-based agriculture and NRM projects. For more detailed description of methods and models, one could refer to the sources mentioned above. **The present guidelines focus on projects aimed at mainstreaming C-benefit enhancement in agriculture and NRM projects and not on projects dedicated to climate change mitigation such as A/R under CDM and REDD mechanisms,** although the basic methods can be applied for these projects as well.

Categories of projects requiring carbon estimation and monitoring:

- Watershed projects including soil and water conservation and tree planting components
- Agriculture development projects including sustainable agriculture, crop intensification, irrigation, etc.
- Grassland, arid land, and wasteland reclamation projects
- Land-based livelihood improvement and poverty alleviation projects
- Forest regeneration, forest conservation, and afforestation projects
- REDD and CDM projects as well as VCS (not the focus of these guidelines)

C.1.1.1. Comparison of Different Methods and Guidelines Available for Estimating and Monitoring C-Benefits

Several methods and guidelines are available for estimation and monitoring of C-benefits from land-based projects. Table C.1 presents the features of a few key guidelines. The handbook by Ravindranath and Ostwald (2008) provides detailed step-by-step procedures and methods for developing baseline carbon stock estimates, *ex ante* estimation, and *ex post* monitoring of C-benefits; field and laboratory guidance on measurement of different carbon pools; modeling; calculation; and estimation of uncertainty.

C.1.2. Broad Approaches to and Methods of Estimating and Monitoring C-Benefits

The approach to estimating and monitoring C-benefits is presented in figure C.1. It can be observed that both baseline and project-scenario estimates are required, first during the project proposal preparation phase to make and project

TABLE C.1: Features of Key Guidelines for Estimating and Monitoring C-Benefits

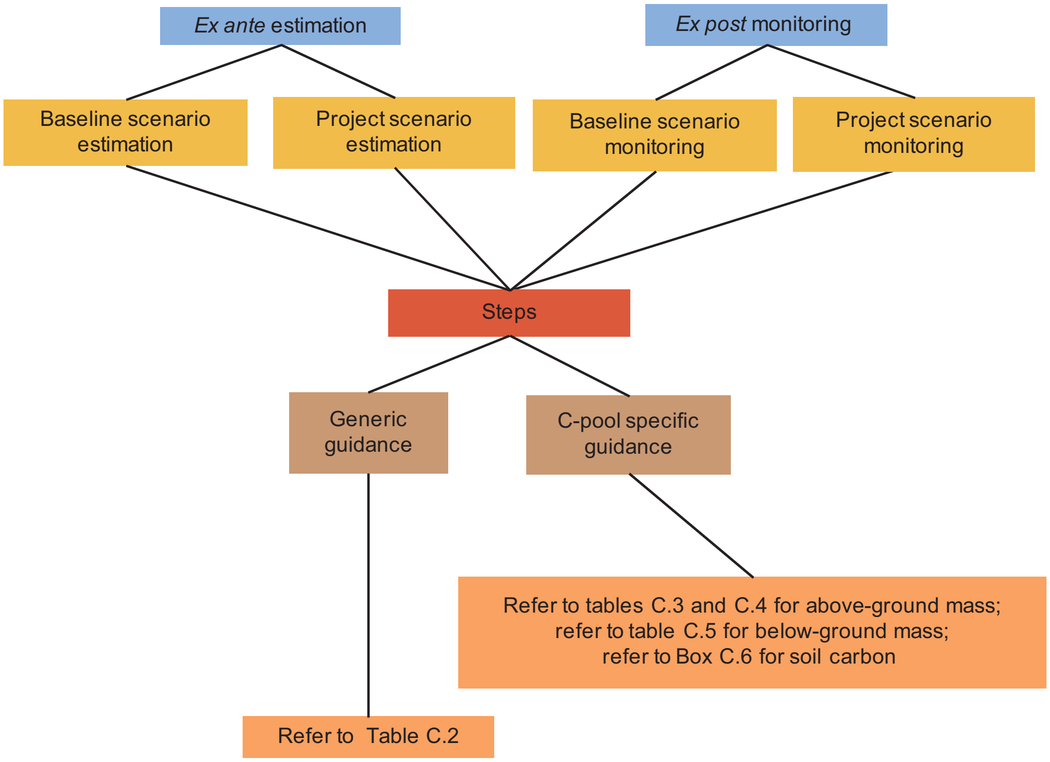
GUIDELINES	C-POOLS	UTILITY FOR *EX ANTE* CARBON ESTIMATION	UTILITY FOR *EX POST* CARBON MONITORING	BASELINE METHODS	MODELING	PRACTICAL GUIDANCE FOR FIELD AND LABORATORY METHODS
IPCC GPG 2003	All 5 pools	Yes	Yes	No	Yes	No
IPCC AFOLU 2006	All 5 pools	Yes	Yes	Yes	No	No
Consolidated CDM methodologies	All 5 pools, optional	Yes	Yes	Yes	No	No
GOFC-GOLD	AGB, BGB, SOC	Yes	Yes	Yes	Yes	No
Ravindranath and Ostwald 2008	All 5 pools	Yes	Yes	Yes	Yes	Yes
Winrock sourcebook 2005	All 5 pools	Yes	Yes	Yes	No	Yes
VCS—REDD	All 5 pools	Yes	Yes	Yes	No	No
Nicholas Institute	All 5 pools	Yes	Yes	Yes	No	Yes

Source: Authors.

the assessment of C-benefits likely to accrue from project activities and secondly during the postproject implementation phase to periodically monitor the net C-benefits. The approach involves some generic steps as well as some carbon-pool-specific steps; both are presented in figure C.1.

IPCC methods for estimating carbon stock changes: The IPCC provides two methods of carbon inventory, Gain-Loss and Stock-Difference. Making a carbon inventory requires estimation of carbon stocks at two points in time or of carbon gain and loss for a given year. Carbon stock change is the sum of changes in stocks of all the carbon pools in a given area over time, which could be averaged to annual stock changes. The methods are described as follows (Ravindranath and Ostwald 2008, IPCC 2006).

FIGURE C.1: Steps in Carbon Estimation and Monitoring



Source: Authors.

A generic equation for estimating the changes in carbon stock for a given land-use category or project is given below.

Annual carbon stock change for a land-use category is the sum of changes in all carbon pools

$$\Delta C_{LUi} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SC}$$

where

ΔC_{LUi} = carbon stock change for a land-use category, AB = above-ground biomass, BB = below-ground biomass, DW = deadwood, LI = litter, and SC = soil carbon.

The Gain-Loss method involves estimating gains in carbon stock of the pools due to growth and transfer of carbon from one pool to another, such as transfer of carbon from the live-biomass pool to the dead organic matter pool due to harvest or disturbance. The method also involves deducting losses in carbon stocks due to harvest, decay, burning, and transfer from one pool to another as described in the following equation:

Annual carbon stock change in a given pool as a function of gains and losses

$$\Delta C = \Delta C_G - \Delta C_L$$

where

ΔC is annual carbon stock change in the pool and ΔC_G and ΔC_L are the annual gain and loss of carbon, respectively.

The Gain-Loss method requires estimation of gain in the stock of each relevant carbon pool during the year or over a period under consideration in a given area. Similarly, losses in the stock of each pool need to be separately estimated and aggregated for a given area over a given period. The difference between carbon gain and loss will give an estimate of net carbon emission or removal.

The Stock-Difference method includes all processes that bring about changes in a given carbon pool. Carbon stocks are estimated for each pool at two points in time, t_1 and t_2. The duration between the two points could be 1 year or several years, such as 5, 7, or 10 years.

Carbon stock change in a given pool as an annual average difference between estimates at two points in time

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$$

where

ΔC is the annual carbon stock change in the pool,

C_{t_1} is the carbon stock in the pool at time t_1, and

C_{t_2} is the carbon stock in the same pool at time t_2.

As discussed in section A.3.2.1, the frequency of measurement of most of the carbon pools is once in several years—5 years, for example, for soil carbon. Thus, the estimated stock at t_2 needs to be deducted from the estimated stock at t_1, and the difference needs to be divided by the number of years between the two periods ($t_2 - t_1$). The stock difference must be estimated separately for each carbon pool.

Changes in carbon stock using this method are estimated for a given land-use category or project area as follows.

Step 1: Estimate the stock of a pool at time t_1 and repeat the measurement to estimate the stock at time t_2

Step 2: Estimate the change in the stock of the selected carbon pool by deducting the stock at time t_1 from that at t_2

Step 3: Divide the difference in stocks by the duration ($t_2 - t_1$) in years to obtain the annual change in stock

Step 4: Extrapolate to a per-ha basis if the estimates were made for sample plots

Step 5: Extrapolate the per-ha estimate to the total project or land-use category area to obtain the total for the project area

C.1.3. Generic Steps for Estimating and Monitoring C-Benefits

Generic steps include the methods to be adopted for estimation and monitoring of C-benefits during the *ex ante* and *ex post* phases of a project for the selected carbon pools. The broad generic steps and approach for both the phases are presented in table C.2.

C.1.4. Project Typology for Estimating Carbon Pools

The carbon pools to be estimated or monitored and the method to be adopted for field measurements will depend on the feature or type of the project activity or CEMs and CEPs. For example, afforestation would require the plot method for measuring tree biomass, whereas soil conservation on cropland may require selection of farms to estimate the stocks of SOC. A broad typology of project activities (CEMs and CEPs), which may require different methods for sampling and measurement of parameters relevant to the carbon pools selected, is presented in table C.3.

TABLE C.2: Generic Steps and Description of Methods Common to All the Carbon Pools for *Ex Ante* and *Ex Post* Phases

STEP	METHOD
Selection of project area	Select the project area including the types of land and extent. • The land categories could include agricultural land, grazing land, community lands, degraded forestland, forestland, etc.
Selection of project activities	Select the project activities included in the project. • The activities are selected according to the land category and objectives of the project • Activities could include CEMs (agro-forestry, watershed management, sustainable agriculture, etc.) and CEPs (mulching, reduced tillage, organic or green manuring, etc.)
Stratify the project area based on project activities and land features	Stratify the project area according to activities (CEMs/CEPs) and land category and features of the land category (refer to figure D.1). • *Activities:* according to CEMs/CEPs • *Land category:* according to land type (grazing land, cropland, catchment area for water body, degraded forestland, etc.) • *Features of land category:* based on slope or topography of the land, extent of degradation, soil fertility status, irrigation, etc.
Estimation of area under different project activities	Estimate the area according to land stratification and project activities. • Area according to CEM/CEP and any other land feature such as slope, soil fertility, irrigation, or cropping system
Define project boundary	• Select the land category and project activity along with the area for different land parcels or plots since the total area under an activity could be in multiple parcels or plots, with area ranging from a few ha to hundreds of ha • Prepare a map of the project area, clearly demarcating the land category, project activity (CEM/CEP), and features of the land • Record the GPS coordinates of each parcel of land and provide an ID to each plot/parcel
Select carbon pools	Identify the carbon pools likely to be impacted the most by the project activities. Among the pools to be impacted, select the pools that would be impacted the most. • *AGB* is the most important pool for all project activities; that is, CEMs and CEPs involving planting, protection, or management of trees (such as agro-forestry, shelterbelts, afforestation, and PA management). • *BGB* is the pool relevant to all activities (CEMs and CEPs) that impact the AGB involving trees as mentioned above. The BGB can be measured only through destructive sampling involving uprooting of the trees and is therefore normally not measured. • *SOC* is the pool relevant to all activities involving both tree-based and, particularly, nontree-based interventions. Tree-based interventions such as agro-forestry, shelterbelts, and PA management and nontree-based or soil-based interventions or activities such as mulching, reduced tillage, organic manuring, soil conservation, and sustainable agriculture would impact this pool. • *Deadwood and litter* are the pools relevant only to tree-based project activities. Even for tree-based project activities, the magnitude of impact is marginal on a per-ha basis compared to the other three pools and involves significant additional cost and efforts. Therefore, these two pools need not be measured in majority of land-based projects.
Determining the frequency of monitoring of carbon pools	The frequency of monitoring of different carbon pools is determined by the rate of change in the stock of a carbon pool as well as the effort required. Normally, in tree-based projects, the AGB is the pool subjected to higher rate of growth on an annual basis compared to SOC. The rate of change of soil carbon is very low on an annual basis. • The *AGB* for tree-based projects could be monitored once in 3 to 5 years, depending on the rate of growth of the tree biomass • The *BGB* can be measured only through a destructive method involving felling or uprooting of trees and is therefore estimated, using a default value, as a proportion of the AGB • *SOC is* normally measured once in 5 to 10 years since the rate of change of SOC is very slow

Source: Authors.

C.2. METHODS FOR DIFFERENT CARBON POOLS

This section describes the methods to estimate SOC, AGB, and BGB. Among the carbon pools, SOC is relevant to all land-based projects, in particular agricultural projects. Only the key steps and features of the methods are presented in tables C.4 to C.7; for more details, refer to guidelines such as Ravindranath and Ostwald (2008), Nicholas Institute (2009), Winrock (2005), and GOFC GOLD (2009). The order of presentation of methods is as follows, considering the pools as well as C-enhancement activities and practices.

PRESENTATION OF METHODS FOR ESTIMATION AND MONITORING OF DIFFERENT CARBON POOLS

1. **Generic steps for forestry and tree-based agricultural projects**
   - AGB: Tree-based projects including agro-forestry, shelterbelt, watershed, and forestry
   - *BGB:* Tree-based projects including agro-forestry, shelterbelt, watersheds and forestry
   - *SOC:* Agriculture, watershed, and forestry

(*continued*)

TABLE C.3: Project Typology, Features, and Project Activities for Measuring and Monitoring C-Benefits

PROJECT TYPOLOGY	FEATURES	PROJECT ACTIVITIES (CEMs/CEPs)	CARBON POOLS	
			MEASURED	ESTIMATED
Soil-based projects	Interventions aimed at improving soil fertility, reducing soil erosion, improving water-holding capacity of soils, moisture conservation, etc.	Mulching, reduced tillage, soil conservation, contour bunding, tank silt application, cover cropping, multiple cropping, etc.	SOC	–
Agro-forestry	Row planting of trees interspersed with annual crops	Agro-forestry, shelterbelts, silvi-pasture, horti-pasture, orchards	AGB, SOC	BGB
Watershed or multi-component projects	Multiple types of project activities; e.g., a watershed project could include afforestation in water catchment area, agro-forestry, and soil/water conservation measures Such projects may require estimation of carbon pools separately for the forest or plantation component, agro-forestry, and soil-based components	Watershed, land reclamation, sustainable agriculture, agriculture intensification	AGB for activities involving trees, SOC for all other activities	BGB
Forest and tree-plantation	Tree planting as a primary activity carried out following the block method – captive plantations	Afforestation, community forestry, management of PA, orchards, watershed catchment area planting, silvi-horti and silvi-pasture	AGB, litter and deadwood, SOC	BGB

Source*: Authors.*

2. **CEM/CEP-specific steps**
    - Agro-forestry
    - Shelterbelt
    - Soil and water conservation practices
    - Grassland management

AGB consists of trees and shrubs—the two categories are differentiated based on how thick their stems are, measured typically at a point 130 cm from the ground, a measurement usually referred to as diameter at breast height (DBH):

- Trees: DBH greater than 5 cm
- Shrubs: DBH of 5 cm or less and all perennial shrubs

Table C.4 provides the steps for measuring and monitoring trees in forestry, agro-forestry, silvi-pasture, shelterbelt, and other projects with tree-based interventions. The field procedures for measuring trees are given in Part D.

Shrub biomass is relevant only for forest-based projects, and the steps are described in table C.5. Field measurement procedures for shrubs are given in Part D.

Root biomass is estimated for all interventions involving tree planting in all land categories. Table C.6 provides the steps for estimating root biomass of trees in forestry, agriculture, agro-forestry, silvi-pasture, and other projects with tree-based interventions.

SOC estimation for agricultural soils and forestry projects: **SOC** is relevant to all land-based projects, particularly to agriculture and watershed development projects. Table C.7 describes methods for measuring soil carbon for agriculture, forestry, watershed, and grassland development projects.

C.3. CARBON INVENTORY FOR WATERSHED AND AGRICULTURE PROJECTS

This section presents the sampling methods and procedures for field measurements for watershed and agriculture projects incorporating agro-forestry, shelterbelts, and soil and water conservation measures and activities.

TABLE C.4: Summary of Steps and Procedures for Estimating/Monitoring Carbon in a Tree AGB Pool

TASK/STEP	DETAILS/PROCEDURE
Selection of the method	**The plot method for tree-based project activities** involves selecting adequate number of plots of appropriate size at random within the selected strata, measuring the indicator parameters such as tree height and diameter, calculating the biomass, and extrapolating the values to per-ha estimates and for the entire project area. Normally rectangular or square plots are used. Tree-based projects such as afforestation, management of PA, and community forestry require the plot method, which is therefore suitable for forests, degraded forests, and block plantations of timber, fuelwood, and fruit trees. **Agro-forestry and shelterbelts** involve planting of trees in single or multiple rows along the boundary or interspersed with annual crops (such as cereals). Suitable methods for these types of projects involve selecting whole farms after categorizing them as large or small farms and irrigated or rain-fed farms. If the farms are very large, one-ha plots could be selected as samples.
Sampling	The number of plots and their size should be determined with statistical rigor to get a valid assessment of the carbon stocks and changes. • *The number of plots* depends on the desired precision, size of the project area, variation in the vegetation parameters (heterogeneity), budget available, and the cost of measurement. Standard statistical equations are available for estimating the size of the sample (or number of plots). These equations require data on the desired precision level, an estimate of the variance, the cost of monitoring, the confidence interval, and the number of strata and could be used to arrive at an appropriate sample size.[1, 2, 3] More detail is provided in Part D, section D.1.2.
	Plot size for tree-based activities: The larger the plot, the lower the variability between two samples. Plot size depends on the extent of variation among plots and the cost of measurement. Statistical equations are available for estimating the size of the plots (refer to Part D for details). **Standard sample size:** If the required data as inputs for the sampling equations are not available, project managers could, as a rule of thumb, use the following recommendations on plot size and the number of plots for each stratum.
	1. A/R, PA, community forestry projects • If project activity includes heterogeneous vegetation with multiple tree species, ▪ Size of the plots: 50 m × 40 m ▪ Number of sample plots: 5 (equivalent to 10,000 m^2 each) • If the project activity includes homogeneous vegetation or monoculture or is dominated by single tree species, ▪ Size of the plots: 25 m × 20 m ▪ Number of sample plots: 5 (equivalent to 2500 m^2 each)
	2. *Agro-forestry/shelterbelts* • For activities involving row planting of trees in crop lands, whole farms could be selected. If the farms are very large, a 1-ha plot could be sampled. • Sample size for farm-based activities such as agro-forestry and shelterbelts could also be determined using the sampling equation suggested for estimating the sample size for tree biomass estimation. • Sample size for each project activity (refer to Part D, section D.1.2): As a rule of thumb, a minimum of 30 farms could be selected. However, if the farm is larger than about 2 ha, select a 0.5 to 1 ha plot as a subplot for each farm.
Permanent plots	Permanent plots enable changes in carbon stocks in biomass as well as soil carbon to be measured periodically. Permanent plots are required because trees grow for decades and soil carbon accumulation occurs over decades and because they are also suitable for most land-based projects such as afforestation, community forestry, agro-forestry, and shelterbelts.
Selection/laying of plots	The selected number of plots is to be located and laid in an unbiased manner in the project area. Laying of plots could be through simple random sampling or stratified random sampling or systematic sampling (for details, refer to Ravindranath and Ostwald 2008 or Winrock 2005). **Marking permanent plots in the field for tree-based activities** • Using project area maps with sample plots marked along with geographic coordinates, locate sample plots on the ground using GPS points from the map • Mark the corners of the sample plots on ground with stones or pegs for long-term periodic monitoring **Agro-forestry and shelterbelts** • The number of farms for the sample should be selected randomly for each stratum of project activity and land features. If one-ha plots are selected from each farm, they could be randomly located within the farm.
Measure indicator parameters	Estimating AGB in land-based projects involves the following preparatory steps: • Locate sample plots on the ground • Select parameters for measurement and measure the parameters for trees, namely species, girth, height, and other features (further details of measuring the above parameters are provided in Ravindranath and Ostwald 2008 and Winrock 2005) • Identify the species with the help of local community members; record both local names and the botanical names (seeking help from plant taxonomists) • Procure the material required for field studies such as GPS devices, ropes, measuring tapes, slide calipers, and pegs; refer to Part D for details of procedures for measuring the parameters

(*continued*)

TABLE C.4: Summary of Steps and Procedures for Estimating/Monitoring Carbon in a Tree AGB Pool (*continued*)

TASK/STEP	DETAILS/PROCEDURE
Record and compile data	• Standard formats are available for recording the parameters measured in the field • The data recorded in the standard formats in the field are fed into a computer to make a database • Care should be taken to ensure the units, the plot number, location, date of measurement, and other strata features are recorded
Analyze the data	• The objective of field measurements of trees is to estimate the AGB stocks in terms of tons per ha. • Parameters such as girth and height recorded in the field could be used in allometric equations for estimating the biomass of each tree. Allometric equations are available for a large number of tree species. If not available for a given species, use generic biomass equations available for the region. • Volume (m^3/ha) of a tree also could be calculated using girth, height, and the tree form factor. The volume could be converted to biomass (t per ha) using species-specific wood density values available.

Source: Authors; [1]IPCC 2003; [2]Ravindranath and Ostwald 2008; [3]Winrock 2005.

TABLE C.5: Summary Steps for Nontree or Shrub Biomass Pool

TASK/STEP	PROCEDURE/DETAILS
Select and mark the shrub plots	Mark the shrub quadrats within each of the tree quadrats, normally at two opposite corners, keeping two shrub plots per tree quadrat or plot.
Measure indicator parameters	Step 1: Locate the shrub plots in each of the tree plots Step 2: Start from one corner of the shrub plot and record indicator parameters Step 3: Record the species and the number of shrub plants under each species Step 4: Measure the height of the shrub (include all stems less than 5 cm DBH as well as perennial shrubs) Step 5: Measure the DBH of all stems taller than 1.5 m in the shrub plot; if multiple shoots are present, record DBH for all the shoots. Refer to Part D for the measurement procedure.
Record and compile data	Record the name, height, DBH, and other features for each shrub plant in the format provided. Refer to Part D for the format.
Analyze the data	The objective of field measurements of trees is to estimate the AGB stocks in terms of tons per ha. • Parameters such as girth and height recorded in the field could be used in allometric equations for estimating the biomass of each tree. Allometric equations are available for a large number of tree species. If not available for a given species, use generic biomass equations available for the region. • Volume (m^3 per ha) of a tree also could be calculated using girth, height, and the tree form factor. The volume could be converted to biomass (t per ha) using species-specific wood density values available.

Source: Authors.

TABLE C.6: Summary Steps for BGB or Root Biomass Pool

TASK/STEP	PROCEDURE/DETAILS
Estimate AGB	• Use the methods described in tables C.2 and C.3 and express the mass in terms of tons of dry biomass per ha • BGB could be estimated on per ha basis or per tree basis (kg per tree)
Selection of root-to-shoot ratio	• There is an established relationship between the volume or weight of the AGB of forests/plantations and BGB or root biomass • The root-to-shoot ratios or conversion factors are available in the literature for many forest and plantation types as well as for a few tree species • Due to the limitations of data as well as low variability across forest types and species, a generic default value of 0.26 could be used, based on the recommendation of IPCC (2006)
Calculate BGB	BGB (tons per ha) could be calculated by multiplying the AGB (in t per ha) with the root-to-shoot ratio (0.26)

Source: Authors; IPCC 2006.

C.3.1. Agro-Forestry

Agro-forestry activity is often a component of watershed projects, involving a large number of farms. Agro-forestry projects aim to enhance the density and diversity of trees and carbon stock in soil and vegetation, flow of tree-based products and incomes, and crop productivity. Crop production will remain the dominant activity, with rows of trees in the middle or along the bunds or boundaries.

Carbon pools to be monitored: Above-ground tree biomass is the most important carbon pool. In some situations, soil carbon and BGB may also be estimated.

Tree biomass: The following sampling procedure can be adopted for agro-forestry projects for the baseline and project scenarios:

TABLE C.7: Summary Steps for Soil Organic Pool

TASK/STEP	PROCEDURE/DETAILS
Selection of project area	Refer to table C.4 for approach and methods
Selection of project activities	
Stratification of project area based on project activities and land features	
Estimation of area under different project activities	
Definition of project boundary	
Sample size	Tree-based activities: • The number of plots selected for tree biomass estimation could also be adopted for estimating the SOC for each of the project activity stratum • The sample size would be the same as the number of tree plots selected
	Agro-forestry and shelterbelts: Select the farms subjected to the project activity randomly from the list of farms where a particular project activity is to be implemented.
	Nontree-based activities—agriculture and watershed: • SOC estimation is critical to all interventions on grasslands and croplands • Obtain a list of farms subjected to the project activity in a given project area • Select the number of farms using equation suggested for tree biomass estimation
Selection of plots	Tree-based activities: • Select plots marked for nontree biomass (shrub plots of 5 × 5 m) • Mark any point in the shrub plot of 5 × 5 m at random
	Farm-based and nontree-based activities—agriculture and watershed: • Select at random the required number of sample farms from the list of farms subjected to a project activity using simple random sampling, stratified random sampling, or systematic sampling • Mark any point randomly within the selected farm plot subjected to the project activity for collecting soil samples. The sample plot can remain constant for future measurements
Depth for soil sampling	• SOC is largely concentrated in the top 30 cm for most land categories • Normally, soil carbon stock is estimated for two depths, 0 to 15 cm and 15 to 30 cm, and the carbon stock values from both the depths are aggregated to obtain the SOC stock per ha
Collection of soil samples	• Using a soil auger, drill soil to a depth of 0 to 15 and 15 to 30 cm and collect samples • To reduce variability, collect and aggregate the samples from multiple points after removing plant debris, if any • Collect about 0.5 kg of fresh soil into a plastic bag for laboratory analysis • Clearly label the samples giving details of the land category, project activity, stratum, and depth • Air-dry the soil samples prior to laboratory analysis
Laboratory analysis	• SOC can be estimated using several methods ranging from simple laboratory estimation to diffuse reflectance spectroscopy • The most widely used and cost-effective method is wet digestion or titrimetric determination (the Walkley and Black method). For details, refer to any standard soil science or soil chemistry textbook.[1]
Calculation procedure	Calculate the SOC in terms of Tc per ha with the following two equations using data on SOC concentration (as a percentage) estimated from laboratory analysis and bulk density for the two depths: • SOC (tons/ha) = [Soil mass in 0–30 cm layer × SOC concentration (%)] / 100 • Soil mass (tons/ha) = [area (10,000 m^2/ha) × depth (0.3 m) × bulk density (t/m^3)]
Bulk density estimation	Multiple methods are available for estimating bulk density. A simplified procedure is given as follows: Step 1: Weigh an empty bottle or a metal can Step 2: Collect soil into this container from one of the marked plots; fill the container to the brim but tap it often to compact the soil (the degree of compaction should be comparable to that in the field) Step 3: Weigh the container filled with soil Step 4: Empty the container and fill it to the brim (or to the same level as that used while filling the soil) with water Step 5: Note the volume of water using a measuring cylinder $\text{Bulkdensity}\,(g/cc) = \frac{\text{Weight of soil in can}}{\text{Volume of water in can}}$ Step 6: Using multiple samples, calculate the mean bulk density

Source: Authors; [1]Ravindranath and Ostwald 2008.

Step 1: Obtain a map of the project area where the agroforestry activity is planned

Step 2: Mark the boundaries of all the farms where agroforestry is proposed and number each farm

Step 3: Obtain the area of each farm subjected to agroforestry activity

Step 4: Tabulate the farms according to size (0 to 5 ha, 5 to 10 ha, etc.)

Step 5: Further stratify the farms if necessary and if clear variations can be observed with respect to soil type, availability of irrigation, etc.

- Determine the sample size using the equation given for the tree plots. If the use of equations is not feasible, use the following guideline of sampling at least 30 farms for each project activity stratum

Step 6: Select five whole farms in each class of farm size (depending on the total number of farms) and if necessary from substrata of the farms to represent different conditions as mentioned in Step 5

- If the number of farms is less than 100, select 5 sample farms
- If the number is from 100 to 200, select 10 sample farms
- If the number is greater than 200, select 20 sample farms
- The total should be more than 30 farms

Step 7: Measure the DBH and height of all trees using the format given in Part D

- Consider the whole farm as a "tree plot" and measure all trees
- Shrub and herb plots are not needed

Step 8: Estimate the AGB and BGB using the procedure given for tree biomass

Soil carbon estimation: SOC needs to be measured only if the agro-forestry activity involves planting a large number of trees or rows of trees spaced densely. Although it is difficult to specify an exact number, generally if fewer than 250 trees are planted per ha, the impact on soil carbon stock is likely to be small and difficult to measure and hence could be ignored. The agency developing or implementing the project could decide to measure soil carbon only if the agro-forestry activity is likely to make a significant and, more important, measurable impact on soil carbon stock (tC per ha). In most agro-forestry situations, soil carbon need not estimated. However, if agro-forestry is combined with soil and water conservation measures, measure or monitor soil carbon using the following steps:

Step 1: Select the farms that have been selected for AGB measurement or those treated for soil improvement

Step 2: Locate sampling points

- Obtain the proposed tree planting pattern, in most cases rows of trees with annual crops between the rows
- Select two rows of trees, preferably in the middle of the farm
- Locate two points in the middle of the plot dedicated to crops between the rows of trees, and two points along the tree rows

Step 3**:** Collect soil samples, estimate bulk density in the field and soil carbon content (percentage) in the laboratory, and calculate carbon density per ha as described in table C.7

C.3.2. Shelterbelts

Shelterbelts involve planting rows of trees at the boundary of a village or boundary of a block of farms to prevent wind erosion, to halt desertification, enhance carbon stock, possibly increase biomass (fuelwood and nonwood tree products) supply, and ultimately increase crop productivity.

Carbon pools to be monitored: Tree AGB is the only critical carbon pool to be measured or monitored. BGB can be estimated using the appropriate root-to-shoot ratio. Due to the low planting density of trees, other carbon pools may not be relevant.

Sampling for tree biomass estimation: Trees are planted in multiple rows closely spaced along the boundary of a block of farms or of the village ecosystems to reduce soil erosion. Sampling and biomass estimation procedure involve the following steps:

Step 1: Obtain a map of the project area

Step 2: Mark the shelterbelt proposed or planted

Step 3: Measure the length and breadth of the shelterbelt

(*continued*)

Step 4: Calculate the land area under the shelterbelt using the length and breadth data

Step 5: Divide the shelterbelt length into, for example, 20 or 40 blocks depending on the length and mark them on the map

Step 6: Select 4 or 5 blocks or belt-transects systematically, such as the 4th, 8th, 12th, and 16th block out of 20 blocks or the 8th, 16th, 24th, and 32nd out of 40 blocks

Step 7: Measure and record the height and DBH of trees using the format given for trees (Part D)

Step 8: Estimate AGB using the methods given in Part D, using tree-specific or generic biomass equations and using the DBH and height data

Step 9: Extrapolate the estimated AGB from sample belt blocks to the whole shelterbelt area

Step 10: Estimate root or BGB of trees by using the root-to-shoot ratio.

Step 11: Estimate the total biomass of the shelterbelt

A similar procedure can be adopted for the baseline and project scenarios.

C.3.3. Soil and Water Conservation Practices

Soil and water conservation is one of the critical objectives of most watershed projects. Watershed protection is achieved by soil and water conservation practices such as mulching, cover cropping, multiple cropping, contour bunding, gully plugging, and check dams. Soil conservation measures also increase the soil organic matter concentration and crop or grass productivity.

Carbon pools to be monitored: The only carbon pool that will be impacted is soil carbon.

Soil sampling and carbon estimation procedure: The following steps could be adopted for sampling and carbon estimation:

Step 1: Mark the area or land-use systems or farms subjected to soil or water conservation practices on a map of the project area

Step 2: Stratify the project area subjected to soil conservation practices into

- Farm and nonfarm land, irrigated or rain-fed
- Different soil types
- Different levels of degradation or topography

Step 3: Overlay the substrata on a grid map of the project area

Step 4: Select four to five grids randomly for each substratum of the project intervention and land-use system and mark a point randomly in the grid or cell for soil sample collection

Step 5: Select control plots adjacent to the treated plots with similar soil and topography

Step 6: Collect soil samples from control plots

Step 7: Estimate the SOC using the procedure given in table C.7

Estimate soil carbon for *control plots* in areas not subjected to soil conservation practices under the baseline scenario using the same approach as that used for the project scenario.

C.3.4. Grassland Management Practices

Management practices for grassland, pastures, or rangeland involving soil and water conservation, planting grasses, regulation of grazing or harvesting, and fire control could lead to increased grass productivity and increased soil carbon density. The most important carbon pool to be measured or monitored is soil carbon, which will be impacted most by grassland management practices. The procedure for estimating soil carbon and root biomass is as follows:

Step 1: Obtain a map of the project area

Step 2: Mark the areas of grasslands subjected to improved management practice on the grid map

Step 3: Stratify the areas if any visible variation exists, such as that in soil type, grazing pressure (high or low), topography, and levels of degradation

Step 4**:** Overlay the substrata subjected to project activity on the grid map

Step 5: Mark on the map four to five grids at random for each strata and mark a point at random for soil sampling

Step 6: Select control plots adjacent to the treated plots for sampling

Step 7: Adopt the procedure given in table C.7 to collect soil samples, estimate bulk density, estimate SOC concentration, and calculate soil carbon density (tC per ha)

The same procedure can be adopted for *control plots* under the baseline scenario as well as for lands subjected to grassland management practices.

C.4. DATA RECORDING, COMPILATION, AND CALCULATION

The data on biomass and soil carbon–related parameters obtained from field and laboratory studies need to be fed into a computerized database, compiled, synthesized, and analyzed for generating the estimates of changes in biomass and soil carbon stock. Data verification and quality control are very critical to ensuring that data are properly collected and fed into the analytical procedures and models. The data gathered from the field and from the laboratory should also be archived since monitoring of carbon stock changes could happen over a project life or over decades. Some critical measures to ensure data quality are as follows:

- Use the appropriate formats for recording data in the field
- Record such information as the name of the location, GPS readings, strata features, project activity, date, and the investigator's name
- Ensure that correct units are used, especially while feeding the data into the database

Formats for data recording in the field for trees, shrubs, and soil carbon are given in Part D.

Calculation and estimation of carbon stocks and CO_2 emissions: Methods for measuring different indicator parameters from which carbon stocks in different carbon pools can be estimated are described in the previous sections. The next step is to estimate carbon stocks and changes using the parameters measured and monitored in the field and in the laboratory. The analysis and calculation of carbon stocks and changes involve conversion of field and laboratory estimates of various parameters from sample plots, such as DBH, height, and soil organic matter into tC per ha per year or over several years using different methods and models. The carbon pools for which the stocks are to be estimated are:

- AGB
- BGB
- SOC

Deadwood and litter: The majority of the project activities considered in these guidelines, apart from forestry projects, may not require monitoring of deadwood and litter since these projects deal with enhancing soil carbon and conserving soil and moisture for increasing crop or grass or tree productivity. Therefore, these guidelines focus on the above three pools and do not consider deadwood and litter. The transaction costs of measurement and monitoring of these two pools are also very high. However, if any project manager requires estimation of deadwood and litter, several studies are available that provide methods and guidelines for estimating these pools (Ravindranath and Ostwald 2008, Winrock 2005, Nicholas Institute 2010).

Estimating AGB of trees—agriculture, watershed, and forestry projects: AGB of trees includes commercial (or merchantable) timber and total tree biomass, which includes not only commercial timber, but also twigs, branches, and bark, expressed as tons of oven-dried biomass. The two commonly used methods for estimating AGB for trees in forests or in agro-forestry plots are as follows:

- Estimating tree volume using height and DBH values and the tree form factor
- Estimating tree biomass using allometric equations where biomass of a tree is estimated using the DBH and height values

Estimating tree volume and biomass: The plot method provides values for tree parameters such as DBH and height. These values could be used to estimate the volume of the trees, which can be converted into weight using wood density. This method involves the following steps:

Step 1: Measure the height and DBH of all the trees in the sample plots (as described in Part D)

Step 2: Tabulate the values of height and DBH by species and by plot

Step 3: Estimate the volume of each tree in the sample plots using the following formulae depending on the shape of the tree, whether cylindrical or conical:

$$V = \pi \times r^2 \times H \text{ (for cylindrical trees)}$$
$$V = (\pi \times r^2 \times H)/3 \text{ (for conical trees)}$$

where

V = volume of the tree in cubic centimeters or cubic meters

r = radius of the tree at a point 130 cm above the ground = DBH/2

H = height of the tree in centimeters or meters

Step 4: Obtain the wood density value for each of the tree species from literature, at least for the dominant species (IPCC, 2003-GPG):

- if the density value for any dominant tree species is not available in the literature, select the species most closely related to the species present on the site

Step 5: Multiply the volume of the tree with the respective wood density to obtain the dry weight of that tree and convert the weight from grams to kilograms or tons.

- Weight of tree (in grams) = volume of the tree (in cm^3) × density (g/cm^3)

Step 6: Add up the weights of all trees of each species in the selected sample plots or farms in case of agro-forestry or shelterbelts (in kilograms or tons for each species)

Step 7: Add up the weight of all the trees of all tree species for all the sample plots or farms, based on the weight calculated for each plot (in kilograms or tons)

Step 8: Extrapolate the weight of each species from the total sample area (sum of all the plots or farms) to a per-ha value (tons of biomass per ha for each species)

Step 9: Add up the biomass of each species to obtain the total biomass of all the trees in tons per ha (dry matter)

Estimation of biomass using equations: Biomass of a tree can be estimated using the DBH and height data of trees. Biomass equations can be linear, quadratic, cubic, logarithmic, and exponential. Species-specific and generic biomass estimation equations are available in the literature. Often generic biomass equations are used for estimating the AGB. In addition to biomass equations for individual trees, they are also available for estimating biomass in per-ha terms. Usually only the volume of a tree is measured, since measuring the weight, particularly of large trees, in the field is difficult. Many biomass equations are indeed biomass volume equations. Tree volume is related to parameters such as DBH and height. The volume (m^3) estimated using the equations needs to be converted to biomass in tons per tree or per ha using the density of the species. The following steps are adopted for estimating the volume as well as the biomass of the trees:

Step 1: Select the project area, activities, and sample plots, and measure the DBH and height of all the trees in the sample plots

Step 2: Select the biomass volume estimation equation for the dominant tree species or for all the species for which species-specific equations are available

- If no species-specific equations (table C.8) are available, use generic equations or those specific to a given forest or plantation type (table C.9)

Step 3: Enter the DBH, height, and the biomass volume equation into a software package such as Excel

Step 4: Calculate the volume of each tree based on the DBH and height using the software

Step 5: Aggregate the volume of all the sample trees by species if species-specific equations are used to obtain the total volume of the trees (m^3)

Step 6: Convert the volume of the trees in the sample plots or farms to biomass in tons using the density of biomass for the selected species

- If species-specific density values are not available or cannot be derived for all the species, use the density of the dominant tree species for converting the whole forest or plantation volume to biomass
- If the equation provides only the merchantable volume, use the biomass conversion and expansion factor (BCEF) to obtain total biomass in kg per ha or tons per ha

Step 7: Extrapolate the biomass from the sample plot or farm area to tons of biomass per ha

BCEF: The data on biomass volume and the default biomass stock as well as growth rates are often estimated considering only the merchantable or commercial volume. Estimating only the commercial component of the tree biomass, which is largely the main tree trunk, may be adequate for estimating industrial roundwood. However, for estimating carbon stocks and changes, all the AGB, including twigs and branches and even leaves, needs to be estimated. To convert the merchantable tree volume into total biomass, BCEF are used (IPCC 2006). Biomass expansion factors (BEF) could be used if a biomass equation provides the merchantable biomass (tons per ha) directly. BEF expands the dry weight of the merchantable volume of the growing stock to account for nonmerchantable components of trees. Total biomass can be estimated in two ways depending on the units of merchantable biomass estimates (as volume in m^3 or in tons per ha):

TABLE C.8: Some Generic Equations for Estimating Biomass

FOREST TYPE	EQUATION	R^2/ SAMPLE SIZE	DBH RANGE (CM)
Tropical moist hardwoods	Y = EXP{–2.289 + 2.694 LN [DBH] – 0.021 [LN (DBH)]}	0.98/226	5–148
Tropical wet hardwoods	Y = 21.297 – 6.953 (DBH) + 0.740 (DBH)	0.92/176	4–112
Temperate/tropical pines	Y = 0.887 + [10486 (DBH) 2.84/(DBH 2.84) + 376907]	0.98/137	0.6–56
Temperate U.S. Eastern hardwoods	Y = 0.5 + [(25000 (DBH) 2.5/(DBH 2.5) + 246872	0.99/454	1.3–83.2

Y = dry biomass in kg/tree, DBH = diameter at breast height, LN = natural log; EXP = "e raised to the power of."

Source: Brown 1997; Brown and Schroeder 1999; Schroeder *et al.* 1997; Delaney *et al.* 1999.

TABLE C.9: Some Species-Specific Biomass Equations Based on Girth-at-Breast Height (GBH) Values

SPECIES	MODEL	A	B	R^2	STANDARD ERROR (SE)
Bauhinia racemosa	Y = a + b*X (X = GBH2*height)	0.0431	0.0025	0.97	3.17
Zizyphus xylopyra	log10 Y = a + b*logX(X = GBH)	–3.20	2.87	0.94	0.12
Tectona grandis	Log Y = a + b*logX(X = GBH)	–2.85	2.655	0.98	0.075
Lannea coromandelica	Y = a + b*X (X = GBH2*height)	–1.84	0.002	0.98	14.49
Miliusa tomentosa	Y= a + b*X (X = GBH2*height)	–0.68	0.0024	0.99	1.33

Source: Kale *et al.* 2004.

Total biomass (t/ha) = Total merchantable biomass (t/ha) × BEF

Total biomass (t/ha) = volume of merchantable biomass (m^3/ha) × BCEF (t/m^3)

Estimating AGB of young trees or shrubs: Shrub biomass is relevant only for forestry projects or activities such as afforestation, management of PA, and biodiversity conservation projects. Shrub biomass could be ignored if the quantities involved are small compared to tree biomass. Shrub biomass is expressed as tons of dry biomass production per ha per year and is estimated separately, since the sample plot size as well as the form of the plants is different. Biomass for shrubs is estimated through the harvest method:

Step 1: Record the fresh and dry weight of the shrub biomass harvested from sample plots (kilograms per plot)

- If there are young regenerating valuable tree plants and any economically valuable perennial shrubs, harvesting such plants may not be desirable
- A few representative plants could be harvested and weighed and the height and spread of each of these plants recorded along with the name of the species
- These data could be used for estimating the weight of plants that cannot be harvested
- Alternatively, some of the perennial or economically valuable shrub species could be ignored if they cover only a small proportion of the ground area (less than 10%, for example)

Step 2: Estimate the biomass of young trees (less than 5 cm DBH) using the steps described for estimating tree AGB

Step 3: Pool all the biomass harvested from different shrub plots to obtain the total dry shrub biomass for the total area of the sample plots

Step 4: Extrapolate the sample area biomass to a per-ha value (dry tons per ha)

Estimating BGB or root biomass: Methods for measuring root biomass are not practical in most situations because of high cost and the difficulty in uprooting or digging within a forest, a plantation, or agro-forestry plots. Therefore, the two most common and feasible approaches for root biomass estimation are:

- Standard root-to-shoot ratios
- Allometric equations

Root-to-shoot ratio: Using root-to-shoot ratios to estimate root biomass involves the following steps:

Step 1: Estimate the tree AGB in terms of tons of dry biomass per ha as explained in earlier sections

Step 2: Select the appropriate root-to-shoot ratio from the literature. A review by Cairns *et al.* (1997), covering more than 160 studies from tropical, temperate, and boreal forests, estimated a mean root-to-shoot ratio of 0.26 with a range of 0.18 to 0.30. Thus, for most projects, a root-to-shoot ratio of 0.26 could be used

Step 3: Calculate the root biomass using the data on tree AGB and the root-to-shoot ratio selected with the following formula:

Root biomass (in dry tons/ha) = 0.26 ×
above-ground tree biomass
(dry tons/ha)

Allometric equations for root biomass estimation: Biomass equations have been developed to estimate root biomass using data on AGB. The method involves estimating the AGB using the methods described in earlier sections, selecting the appropriate biomass equation, and substituting the AGB value in the equation to obtain root biomass in tons of dry root biomass per ha. Allometric equations for estimating root biomass using AGB are given in table C.10.

Calculation of SOC: Estimation of soil carbon density (tC per ha) involves estimation of bulk density of the soil and soil organic matter content (percentage). The steps involved in calculating soil carbon density are as follows:

Step 1: Select the land-use category, project activity, and stratum

Step 2: Conduct field and laboratory studies and estimate the bulk density and soil organic matter or carbon content (as described earlier)

Bulk density: Estimate bulk density using the steps described earlier and using the following formula:

Bulk density (g/ml) = (weight of soil and the container –
weight of the empty container)/
volume of the container

or

Weight of soil clod/volume of the soil clod

TABLE C.10: Regression Equations for Estimating Root Biomass of Forests

CONDITIONS AND INDEPENDENT VARIABLES	EQUATION Y = ROOT BIOMASS (IN TONS)	SAMPLE SIZE	R^2
All forests, AGB	Y = Exp[–1.085 + 0.9256*LN (AGB)]	151	0.83
All forests, AGB and age (years)	Y = Exp[–1.3267 + 0.8877*LN(AGB) + 0.1045*LN(AGE)]	109	0.84
Tropical forests, AGB	Y = Exp[–1.0587 + 0.8836*LN(AGB)]	151	0.84
Temperate forests, AGB	Y = Exp[–1.0587 + 0.8836*LN(AGB) + 0.2840]	151	0.84
Boreal forests, AGB	Y = Exp[–1.0587 + 0.8836*LN(AGB) + 0.1874]	151	0.84

LN = natural log, Exp = "e to the power of," AGB = AGB in tons, R^2 = coefficient of determination.

Source: Cairns *et al.* 1997.

An illustrative example of the calculation procedure for SOC is given below.

LAND-USE SYSTEM	PROJECT ACTIVITY	BULK DENSITY (GR/CC)	SOC % IN 2002	SOC % IN 2012	WEIGHT OF SOIL (t/ha)	SOC (tC/ha)	
						2002	2012
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Moderately degraded	Assisted natural regeneration	1.39	1.29	2.29	4,170	54	95
Highly degraded	Mixed-species forestry	1.25	0.9	1.90	3,750	34	71
Cropland	Agro-forestry	1.48	0.4	0.87	4,440	18	39
Grassland	Improved grassland management	1.22	1.05	2.05	3,660	38	75

Column (3): Bulk density in grams/cc of soil, estimated by using data on weight / volume of soil.
Columns (4) and (5): SOC in % from laboratory analysis.
Column (6): Weight of soil (t/ha) = [Bulk density (in gr/cc)] × [Volume of soil (Area × Depth)]. E.g., (1.39 (gr/cc) × 10000 (m^2) × 0.3 (m)) / 1000,000 gr/t = t of soil/ha.
Columns (7) and (8): SOC (tC/ha) = [SOC (%)] × [Weight of soil (t/ha)]. E.g., 1.29/100 × 4170 = 54 tC/ha.

Soil carbon density: The content of organic carbon in soil estimated in percentage terms needs to be converted to tons per ha using bulk density, depth of the soil, and area (10,000 m^2):

$$\text{SOC (tons/ha)} = [\text{Soil mass In 0–30 cm layer} \times \text{SOC concentration (\%)}]/100$$

$$\text{Soil mass (tons/ha)} = [\text{Area } (10{,}000\ m^2/\text{ha}) \times \text{depth } (0.3\ m) \times \text{bulk density } (t/m^3)]$$

C.5. MODELING FOR ESTIMATION AND PROJECTION OF CARBON STOCKS

The methods for estimating the stocks of different carbon pools described in section C.2 provide estimates of carbon stocks at a given point of time or for a given year. If the period of intervention or activity is known, annual rates of change could be calculated. Projections of carbon stocks over 5 to 30 or 60 years will be required for land-based projects. Projections will be required during two phases:

- The project proposal preparation phase to estimate and project potential C-benefits from the proposed interventions for dedicated C-enhancement projects as well as projects with carbon as a cobenefit.
- The postproject implementation phase where C-benefits may have to be projected periodically to plan for release of carbon revenue payments or advance payments and to assess the projected carbon implications of project activities.

Models are simplified versions of a system used to estimate and project certain features or functions or outputs of a system. Models are used to make projections of carbon stocks in forests, plantations, grasslands, and cropping systems. Models could be used to make separate projections for biomass and soil carbon stocks. Further, models are also available to project AGB and BGB separately. Models are often based on several assumptions about data and quantitative relationship between input variables and output values. Thus, model outputs are often characterized by uncertainty due to the assumptions made about the relationships between variables.

Types of models: Several categories of models are available for projecting C-benefits. These models can project carbon stocks for the next 5 to 60 years using input data on diameter, height, density, rotation period, biomass productivity, and rates of change in soil carbon, baseline carbon stocks, etc. Some of the models used for making projections are as follows (Ravindranath and Ostwald 2008):

- PROCOMAP for project-level carbon stock projections for forestry projects
- TARAM for project-level carbon stock projections for forestry projects
- CATIE for project-level carbon stock projections for forestry projects
- CO_2FIX for estimating biomass and changes in soil carbon stocks for forestry and agriculture projects
- CENTURY and ROTH for dynamics of soil carbon stocks for agriculture and forestry projects

These models vary in data requirements, process adopted, outputs generated, and their application. In general, all the following models can be used for determining the stocks

TABLE C.11: Comparative Features and Application of Three Carbon Estimation and Projection Models for Forestry Projects

MODEL	KEY INPUTS	KEY OUTPUTS	APPLICATION
PROCOMAP	• Area dedicated to activity • Planting rate and vegetation carbon stock in base year • Rotation period • Mean annual increment (MAI) in biomass and soil carbon	• Total carbon stock per ha and total project area • Biomass and SOC stock • Incremental carbon stocks • Cost effectiveness	• Projection of carbon stocks in forestry mitigation: A/R and avoided deforestation projects
TARAM*	• Species to be planted • Wood density of species • BEF • Root-to-shoot ratio • Existing vegetation and its volume • Area planted under different strata • Phasing of planting • Growth rate of species	• Net anthropogenic CO_2 removal by sinks • Leakage estimates • Average net anthropogenic CO_2 removal by sinks over the crediting period • Average net anthropogenic CO_2 removal by sinks per ha and per year • Cost-to-benefit analysis	• Projection of carbon stocks in A/R projects including leakage for A/R under CDM
CATIE*	• Baseline information of stratum • Project details such as area planted, phasing, rotation period, woody biomass per stratum, root-to-shoot ratio, carbon fraction, and wood density • Leakage-related information • Project management details	• Total carbon stocks in planted trees and pre-existing trees • Sum of changes in carbon stocks • Total anthropogenic sum of carbon changes in carbon stocks • Actual net CO_2 removals by sinks	• CO_2 accounting tool that follows the CDM approach to CO_2 accounting of afforestation and reforestation projects

** TARAM and CATIE include CO_2 and other GHGs such as N_2O and CH_4.*
Source: Authors.

of carbon pools. Three of the models, namely PROCOMAP, TARAM, and CATIE, are already in use for projecting C-benefits, and their features and applications are summarized in table C.11. CENTURY, CO_2FIX, and ROTH models are highly data intensive and require modeling capability and therefore are not generally applied for project-level carbon stock projections, which is why they have been excluded from table C.11.

Selection and steps in applying the models: The models estimate the changes in carbon stock annually under baseline and mitigation scenarios. Projection of C-benefits for a given future year would require estimates of carbon stocks under the baseline scenario in the absence of project activities and under the project scenario for the same year selected.

The selection of a carbon estimation model or tool is determined by many factors including technical expertise and skills available within a team. Some of the determining factors in selection of models include the following:

- Objective of the program, such as estimation or projection of changes in carbon stock due to project activities, estimation of CO_2 emissions and removals due to project activities, and assessment of the carbon dynamics
- Access to model and suitability of the model to the location, land category, or project activity
- Input data available and needed for the model

Once a model is chosen, the broad steps to be adopted for estimating carbon stock changes in the baseline and mitigation scenarios and the incremental carbon stocks are as follows:

Step 1: Define land-use categories relevant to the baseline and project scenarios

Step 2: Define the baseline area under different land categories for a selected base year and project the area under this category annually for future years up to, for example, 2020, 2030, or 2050

Step 3: Identify and estimate the area proposed to be brought or already brought under different project activities over different years

Step 4: Generate the data needed for the model to project carbon stocks under the baseline and project scenarios for each activity

Step 5: Run the model and generate outputs of carbon stocks for the baseline and project scenarios and incremental C-benefits

Application of models for projecting C-benefits: All the CDM A/R and BioCarbon projects as well as all carbon mitigation projects currently use one of the models for projecting incremental C-benefits as well as carbon revenues. The three models presented in table C.11 are largely applicable to forestry projects incorporating methods for estimating changes in biomass stocks:

- PROCOMAP: biomass and soil carbon estimates for afforestation and reforestation (including natural regeneration), agro-forestry, and shelterbelt projects (for soil C-enhancement practices, the change in biomass carbon stocks could be assumed to be zero)
- TARAM: biomass estimates for A/R (including natural regeneration) projects and soil carbon stock changes
- CATIE: biomass estimates for A/R (including natural regeneration) projects

Thus, there is a need for developing simplified models for estimation and projection of biomass as well as soil C-benefits from different categories of land-based projects, particularly those aimed at enhancing soil carbon stocks alone.

C.6. REPORTING OF C-BENEFITS

C-benefits can be estimated *ex ante* during the preparation of a project proposal as well as *ex post*; that is, after a project is implemented. C-benefits could be estimated for different carbon pools over different periods. The quantity of C-benefits estimated for different pools, through direct measurements or derived indirectly using equations and conversion factors available, could be aggregated and expressed as tC at a given age or as a MAI. C-benefits in terms of tC per ha can be estimated and presented in terms of gross or net carbon stock changes. Generally, most project managers would prefer an estimate of the incremental carbon stock change or benefits. C-benefits could be presented in terms of tC or tons of CO_2 per ha or for the whole project area. C-benefits can also be modeled to make a projection over different periods such as 20, 50, and 100 years. The baseline and project scenario carbon stocks and changes need to be reported periodically to all the stakeholders.

Part D: PRACTICAL GUIDANCE ON SAMPLING, FIELD STUDIES, BASELINE DEVELOPMENT, AND MODELING

In Part D, practical guidance is provided first on the approaches to and methods of stratification of project area, sampling design, and field measurements, secondly on developing baseline scenario carbon stocks and changes, and thirdly on the application of models for estimating and projecting C-benefits. Methods and models are described only briefly; for further details, refer to IPCC (2003 and 2006), Ravindranath and Ostwald (2008), GOFC GOLD (2009), Nicholas Institute (2010), and Winrock (2007). Practical guidance is provided along the following lines:

- D.1. Field studies on C-benefits in land-based projects
- D.2. Estimation of baseline or reference carbon stocks and CO_2 emissions
- D.3. Application of models for projecting C-benefits (carbon stock changes and CO_2 emissions)

D.1. FIELD METHODS FOR ESTIMATING CARBON STOCKS IN LAND-BASED PROJECTS—PRACTICAL GUIDANCE

Section D.2 provides guidelines on selecting CEMs and CEPs and incorporating them into projects, estimating C-benefits, and monitoring carbon pools. This section offers practical step-by-step guidance on measuring and monitoring C-benefits and on conducting field studies.

D.1.1. Stratification

Stratification is required because of variations or heterogeneity in soil, topography, water availability, project activities, and management practices. Stratification makes measurements more accurate and estimates more reliable and involves dividing land area into homogeneous subunits. Stratification reduces sampling error and sampling effort by aggregating those spatial components that are homogeneous. Multistage stratification may be required to account for variations in land categories, topography, soil fertility, and project activities. The stratum to be sampled is the last stage in disaggregating a large area and represents a homogeneous land area or project activity (figure D.1).

Stratification is required for the baseline as well as project scenario and involves the following steps (Ravindranath and Ostwald 2008):

Step 1: Define the project boundary

Step 2: Obtain a map of the project area and overlay on it the different maps of the same area, each representing, for example, land-use systems, soil, and topography under the baseline scenario

Step 3: Overlay on the land-use systems in the baseline scenario a map showing areas of project activities, such as agro-forestry plus soil conservation on rain-fed cropland, silvi-pasture on grazing land, and afforestation of catchment area

Step 4: Identify the key differentiating features for stratification of land-use systems in the baseline scenario that are likely to impact carbon stocks:

- Current land-use such as open access grazing, controlled grazing, fuelwood extraction, or rain-fed cropping
- Soil quality: good, moderate, or poor
- Topography: level land, slope, or hilly terrain

Step 5: Collect all the information available from secondary sources as well as through participatory rural appraisal

Step 6: Stratify the area under the baseline scenario:

- Delineate areas under different project activities
- Overlay the delineated areas with key features of land-use systems that are critical to estimating baseline carbon stocks

(*continued*)

- Mark the strata to be brought under different project activities spatially on the project map

Step 7: Stratify the area under the project scenario:

- Locate the project activities on the baseline scenario strata spatially
- Mark spatially the different strata representing different project activities, land-use systems, and other features; however, ensure that each stratum is homogeneous within itself

The sampling strategy will be different for each of the stratum depending on the land category to which it belongs. The spatial maps of the stratification adopted should be maintained with the project. Sampling plots will be laid separately in each of the strata.

D.1.2. Sampling Design

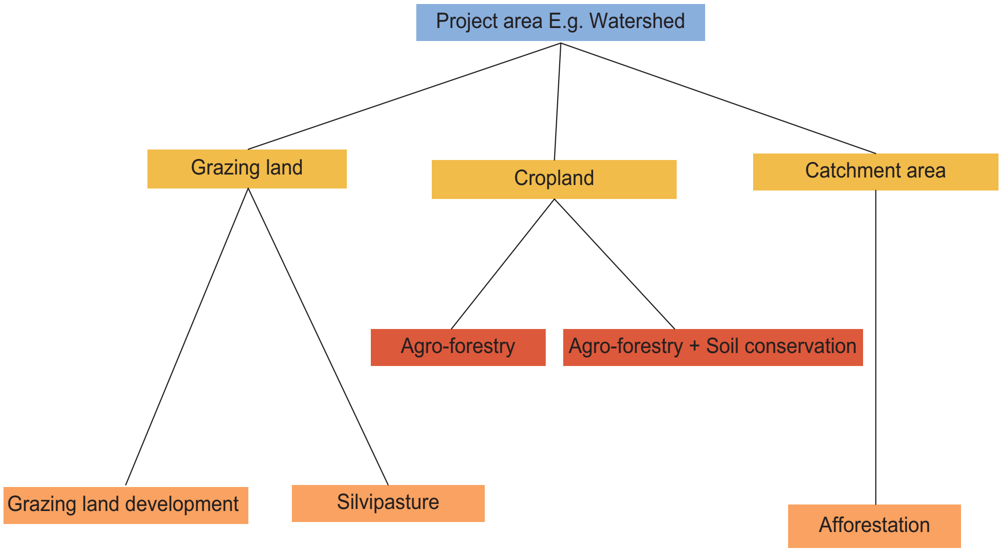
Sampling is a strategy for collecting information about an entire project area by observing only a part of it. A sampling strategy specifies the size of a sample plot, the number of such plots to be selected, and the location of the sampling plots in the project area. Sampling is critical to obtaining reliable estimates of carbon stocks under different project activities at different periods in the project area although project managers tend to ignore a statistically valid sampling strategy. Stratified random sampling is the most commonly adopted strategy. Sampling involves two common statistical concepts, namely accuracy and precision. Accuracy is a measure of how close the sample measurements are to actual values, whereas precision is a measure of how well a value has been defined. Decisions on the type, shape, and number of plots need to be made while sampling.

Permanent plots: For long-term monitoring of biomass growth in perennial vegetation, permanent plots are required and are suitable for all land-based projects on cropland, forest land, and grassland.

Shape of the plots: Rectangular, square, circular, or long-strip plots are adopted for monitoring carbon stock changes. Rectangular or square plots are largely adopted for most land-based projects.

Number of plots: The number of plots to be sampled determines the reliability of the estimates of carbon stocks and is determined by various factors such as heterogeneity of land, topography, soil fertility, project activity, management practices, cost of sampling, and the desired precision level. The following steps could be adopted to determine the size of the sample (Ravindranath and Ostwald 2008):

FIGURE D.1: Stratification Procedure for a Multi-Activity Project



Step 1: Define the desired precision level; typically, to estimate the number of plots needed for measuring and monitoring at a given confidence level, it is necessary to first estimate the variance of the variable (such as carbon stock of the main pools, trees in an afforestation or reforestation project, or soil in a cropland management project) in each stratum (IPCC 2003):

- This can be accomplished either by using existing data from a project similar to the one yet to be implemented (such as a forest or soil inventory in an area representative of the proposed project) or by conducting a pilot study in an area representative of the proposed project.
- Carbon inventory requires reliable estimates, which means the values are both precise and accurate; the higher the level of precision, the larger the sample size and the higher the cost.
- The level of precision should be determined at the beginning of a project and could vary from plus-or-minus 5 to 20 percent of the population mean. A precision level within plus-or-minus 10 percent of the true value of the mean at a confidence interval of 95 percent is normally adequate, although a range of plus-or-minus 5 or even 20 percent is also often employed.

Step 2: Estimate the variance; an estimate of variance of the carbon stocks is required for each stratum, which could be obtained from studies conducted in a region with conditions similar to those for each proposed project activity

- If such estimates are not available, pilot studies may be required in locations close to the project area
- Such a study involves the following steps:
    - Identify an area near the project area with conditions similar to those for the proposed project activities (such as tree plantation, agro-forestry, soil conservation, or water conservation)
    - Conduct field studies by selecting a few small sample plots in the selected land-use category and measure the relevant tree or nontree parameters such as DBH, tree height, weight of shrub biomass, and soil carbon content
    - Calculate the mean and variance from the data collected from the pilot study using methods described for estimating tree biomass and soil carbon

Step 3: Obtain cost estimates for monitoring; data on the cost of conducting field studies are necessary, which could include travel, laying plots, labor for making measurements, laboratory soil analysis and calculations, and any other expenses (the cost of sampling a plot can be determined based on pilot studies or could be obtained from similar studies)

Step 4: Estimate the permissible error in the mean carbon stock value estimates, which is usually taken as plus-or-minus 10 percent of the expected mean value

Step 5: Choose a confidence interval of 95 percent

Step 6: Select the number of strata for the project activity

Step 7: Calculate the number of plots required using the following statistical sampling formula:

$$n\left(\frac{t_{\alpha/2}}{A}\right)^2\left(\sum_{i=1}^{N_i} W_i\sqrt{S_i}\right)\left(\sum_{i=1}^{N_s} W_i\sqrt{S_i}\right)$$

where

n = sample size (the number of sample plots required for monitoring)

t_α = value of student's t statistic for alpha = 0.05 (implying a 95% confidence level)

N_s = total number of strata designed

N_i = number of potential sample units (permanent sample plots in the stratum level)

S_i = standard deviation in stratum i

A = permissible error in the mean

C_i = cost of selecting a sample plot in stratum i

$W_i = N_i / N_s$

The number of plots shall be allocated among the strata.

$$n_i = n - p_i \quad p_i = \left(W_i S_i \sqrt{C_i}\right) \Big/ \left(\sum_{i=1}^{N_s} W_i S_i \sqrt{C_i}\right)$$

where n_i is the number of samples to be allocated in stratum i.

TABLE D.1: Sampling Strategy for Different Project Types and Activities

PROJECT TYPOLOGY	PROJECT ACTIVITIES	SAMPLING METHOD AND SIZE
Soil and moisture conservation	Mulching, reduced tillage, soil conservation, contour bunding, tank silt application, cover cropping, etc.	Statistical sampling formulae used to determine the sample size.
Watershed or multi-land component	Watershed, land reclamation, Sustainable agriculture	• Statistical sampling formulae for forest and plantation-based activities as well as soil-based project activities • Farm-based sampling for agro-forestry and shelterbelts
Agro-forestry	Agro-forestry, shelterbelts	Size of the sample *For agro-forestry/shelter belts:* For activities involving row planting of trees on cropland, whole farms could be selected. If the farms are very large, a one-ha plot could be sampled. *For farms:* For farm-based agro-forestry and shelterbelts, use the same equation as that suggested for estimating forest tree biomass
Forest and plantations	Afforestation, community forestry, management of PA, orchards, watershed catchment area planting, silvi-horti and silvi-pasture	Plot method and statistical sampling formulae

Source: Authors.

D.1.3. Plot Size

The plot size is relevant only for the project activities that involve planting trees. The size of the sample plot is a trade-off between accuracy, precision, and the cost of measurement (IPCC GPG 2003). The size of a plot is also related to the type of activity (for example, agro-forestry or afforestation), the number of trees, their diameter, and variance of the carbon stock among plots. The size typical for different project activities is determined as follows:

- Heterogeneous tree vegetation or soil features: 50 × 40 m or 50 × 50 m or 100 × 100 m
- Homogeneous tree vegetation or soil features: 25 × 20 m or 20 × 20 m
- Agro-forestry and shelterbelts: the number of farms is determined using statistical sampling formulae or, as a rule of thumb, by selecting more than 30 sample farms for each stratum

D.1.4. Applicability of Sampling Methods

The category of projects considered for C-enhancement in these guidelines includes a large diversity of C-enhancement modules and practices with diverse features. The project activities could include soil and water conservation, cropping systems, tillage practices, planting trees in blocks or in rows, etc., and are therefore too diverse to be amenable to a generic sampling strategy applicable to all categories of CEMs/CEPs. However, the following general guidelines could be considered while drawing up a sampling strategy (table D.1).

D.1.5. Field Measurements

Preparation for field work: Efficient planning is essential to reduce unnecessary labor costs, avoid safety risks, and ensure reliable carbon estimates. The equipment used for fieldwork should be accurate, rugged, and durable to withstand the rigors of use under adverse conditions. The type of equipment required will depend on the type of measurements, but the following list covers most of what is typically used.

Soil studies: The following items are needed for soil sampling in the field for estimating soil carbon content and bulk density:

- Auger or core sampler for taking soil sample at 0- to 15-cm and 15- to 30-cm depths
- Containers (usually tins or bottles) for bulk density measurement
- Polythene and cloth bags for soil samples

Biomass studies: Some of the materials needed for biomass carbon inventory are listed below:

- Long measuring tape (30 m or 50 m long)
- Fine measuring tape (1 to 1.5 m long) for DBH measurements
- Rope and pegs for marking boundary and corner points
- Paint and brush for marking the point at which to measure the DBH
- Instrument for measuring the height of a tree
- Slide calipers
- Balance for weighing shrub and woody litter biomass
- Cloth bags for samples of harvested biomass or litter biomass for dry weight estimation
- Data-recording formats and pencil

Preliminary information: It is very important to collect and record all the past and current information available for the project area, each land-use system, and each sample plot. This information includes the following items:

- Map of the project location with latitude and longitude, topographic map, soil map, etc.
- Names of land-use systems, location, and area
- Elevation, topography, and broad soil type
- Proximity to road and human settlements (village, urban center, market, etc.)
- Land tenure or ownership
- Livestock population and grazing locations
- Past land-use changes and features
- Data on A/R, soil and water conservation, etc., activities implemented and proposed
- Socio-economic and demographic features

Field measurements

Trees: A tree plot includes all trees taller than 1.5 m and with the DBH above 5 cm (or a girth of approximately 15 cm or larger); in arid zones, where trees grow slowly, the minimum DBH can be as small as 2.5 cm (or a girth of approximately 8 cm). The parameters to be measured and recorded include DBH, height, mode of regeneration, damage to the tree if any and, if dead, whether standing or fallen, etc.

DBH: This is the most critical parameter as an indicator of biomass of a standing tree, its growth rate, and even the height of a tree. The parameter is also easy to measure and verify and requires only a measuring tape, paint, and a brush. To measure the DBH, first paint a ring around the trunk 1.3 m above the ground. Place the tape along the painted circle to measure the GBH to calculate the DBH. If a tree has multiple shoots, measure the GBH for all of them. The format for recording such data is given in section D.1.6, and figure D.2 shows how to record the measurements under a variety of circumstances (the trunk growing at an angle, trees on a slope, and so on).

Height: Measuring the height of a tree is difficult, unlike measuring the DBH, especially in a dense forest or plantation with dense tree stems and overlapping tree crowns. The height is an indicator of biomass and growth rate and can be measured in several ways: (1) using an instrument, which gives very precise measurements; (2) using height classes, which gives an approximate estimate wherein trees are observed and categorized into height classes such as less than 5 m to 10 m, 10 m to 15 m, 15 m to 20 m, 20 m to 30 m, and greater than 30 m (with a little practice and experience, field investigators can produce fairly reliable estimates); or (3) using an equation based on the DBH. Appropriate equations can be developed by actually measuring the two parameters for, say, at least 30 trees of the dominant tree species. Although placing a tree in its appropriate height class based on visual observation is adequate at the project development phase, the other two methods may also be used in that phase.

Periodic monitoring of the DBH and height: Periodic monitoring of tree biomass requires permanent plots. Height, DBH, and other data should be recorded from the same permanent plot marked on the ground, using the same data format periodically, such as once in 2 or 3 years. The trees could be numbered for repeated measurements.

Biomass measurement and monitoring for shrubs and tree saplings: Shrubs and younger trees or saplings shorter than 1.5 m with a DBH smaller than 5 cm are included in shrub plots. The DBH of young trees and perennial shrubs is measured as described for tree plots, and height could be measured using a 5-m-long graduated pole. If the shrub vegetation is bushy with no clear stems and dominates the plot, the vegetation could be harvested, especially if the shrub species are not ecologically or economically valuable (rare or threatened species), and the fresh weight recorded in the field and a small sample kept aside for dry weight estimation in the laboratory later. Using the weight of dry matter as a percentage of fresh weight from the sample plots, total dry biomass of shrubs can be estimated per plot and per ha.

Periodic monitoring of shrub-tree biomass: Periodic monitoring of shrub biomass could be through the harvest approach described above, collecting the sample from the permanent plot. However, select plots adjacent to the previously harvested plot for harvesting in successive years to avoid the impact of previous harvest so that the measurements are comparable.

Woody litter biomass including fallen deadwood: Woody litter biomass includes coarse and fine woody litter fallen on the ground and dead trees and branches lying on the ground. The standing dead trees will be measured as part of the tree biomass inventory in the data-recording format for trees. Estimating annual woody litter biomass production is a complex process and involves fixing litter traps in all the shrub plots and collecting and weighing litter every month. This requires protecting the litter traps and preventing the removal of litter in the field. A practical method of estimating standing woody litter biomass is as follows:

Step 1: Select and use the shrub plots marked in the field

Step 2: Based on local experience, determine the month in which litter fall is maximum

Step 3: Collect all the woody litter from all the shrub plots and pool it into a single heap

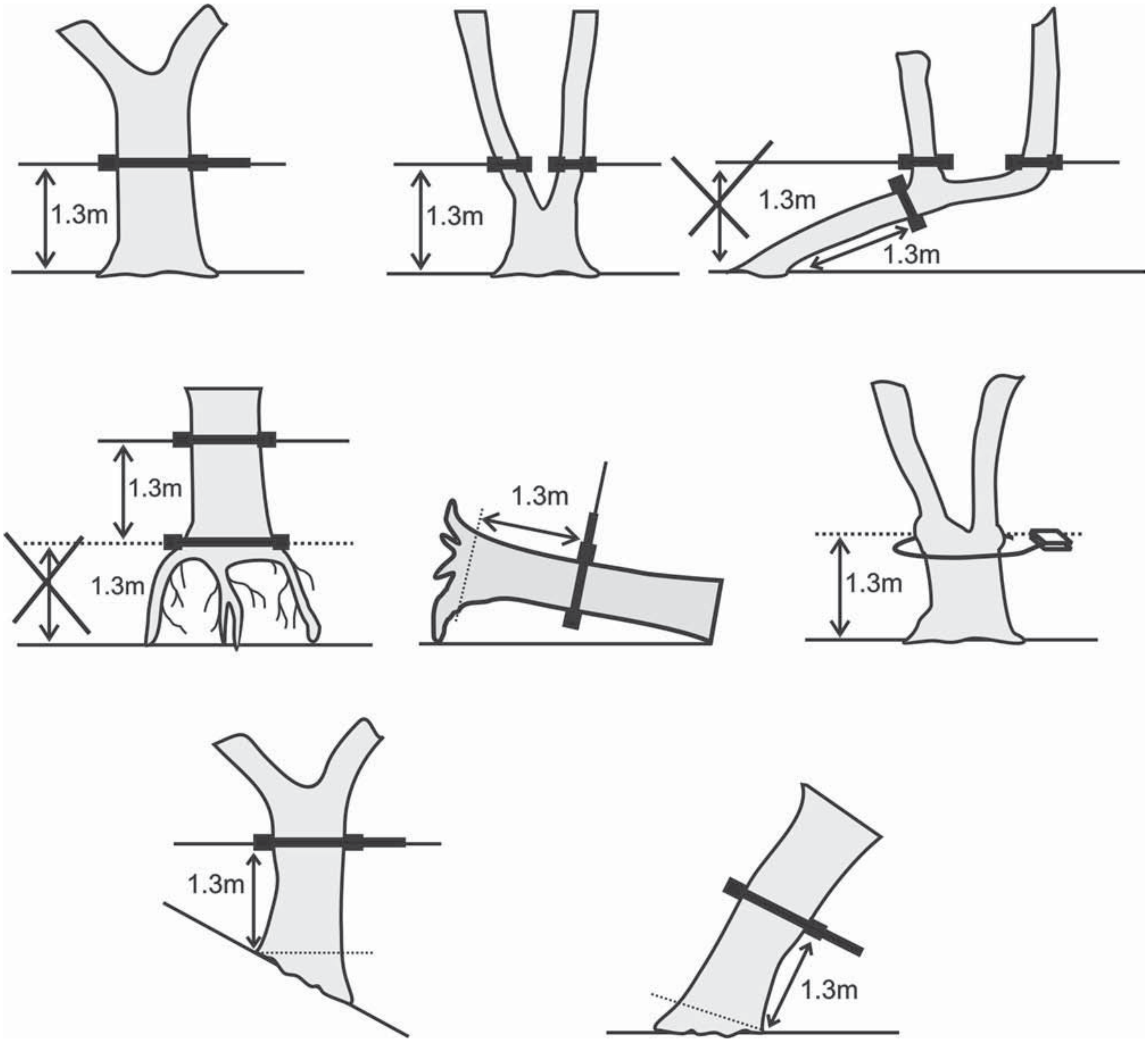
Step 4: Estimate the fresh weight of the woody litter

Step 5: Take a sample, such as 1 kg, for dry weight estimation later in the laboratory

Step 6: Record the dry weight as a percentage of fresh weight

Step 7: Calculate the weight of the dry woody litter per ha using the data on fresh and dry weight and the area of the shrub plots

FIGURE D.2: Methods to Measure GBH for Different Shapes and Types of Trees



Source: Authors.

Format for Recording Tree Data: Applicable for Agro-Forestry, Shelterbelts, Orchards, Silvi-pasture, Plantations, and Forests

LOCATION: **GPS READING:**		**LAND-USE SYSTEM:** **STRATUM:**						**PLOT NO.:** **SIZE OF THE PLOT:**	**INVESTIGATORS:** **DATE:**	
			GBH OF STEM (CM)							
SERIAL NO.	**SPECIES NAME**	**TREE NUMBER**	**1**	**2**	**3**	**4**	**5**	**PLANTED OR REGENERATED**	**HEIGHT (M)**	**STATUS OF CROWN**[1]
1										

[1] *Indicate the percentage crown cover present or damaged.*

Format for Recording Shrub Data for Forests and Plantations

LOCATION: **GPS READING:**		**LAND-USE SYSTEM:** **STRATUM:**			**TREE PLOT NO.:** **SHRUB PLOT NO.:** **SIZE OF THE PLOT:**	**INVESTIGATORS:** **DATE:**
		DIAMETER (CM)				
SERIAL NO.	**SPECIES**	**DBH1**	**DBH2**	**DBH3**	**HEIGHT (M)**	**BIOMASS: FRESH WEIGHT (KG)**
1						

Format for Recording Soil Data: Applicable for all Agriculture, Soil Conservation, Watershed, Land Reclamation, and Forestry Projects

Dimensions of the core	Length (cm): Diameter (cm):
Weight of the empty container	kg
Weight of the tin filled with dried soil	kg
Above-ground vegetation/land use	Status
Location	Latitude and longitude

D.1.6. Data Entry Formats for Trees, Shrubs, and Soil Sampling

A format for recording the data in the field for trees, shrubs, and soil is provided in this section. It is very important to collect and record the data, check the entries for the units; location and, if feasible, the GPS coordinates; and archive the data.

D.2. ESTIMATION OF BASELINE OR REFERENCE CARBON STOCKS AND CO_2 EMISSIONS

A baseline is defined as "the scenario that reasonably represents anthropogenic emissions by sources and removal by sinks that would occur in the absence of the proposed project activity" (UNFCCC 2002). The baseline scenario is also often referred to as the reference scenario or *business-as-usual* scenario. Development of baseline is one of the critical and complex steps in estimating net C-benefits from land-based projects involving CEMs/CEPs. Thus, additional guidance is presented in this section on baseline scenario development. Specific methodologies are available for A/R CDM projects and will become available for REDD+ projects.

Why baseline carbon stock or emission estimates: Baseline or reference-level carbon stocks and projected baseline changes in carbon stocks or CO_2 emissions for the project period are necessary for estimating the incremental or additional C-benefits that are the result of project interventions.

D.2.1. Types of Baselines

A carbon inventory for developing a baseline scenario involves estimation and projection of changes in stocks of different carbon pools (or emission of CO_2) in the project area at the project proposal phase, project development phase, and project-monitoring phase. It is possible to visualize three situations with respect to baseline carbon stock changes with implications for the carbon inventory:

- The carbon stock may decline (or CO_2 emissions may increase) under the baseline scenario *or*
- The carbon stock (or CO_2 emissions) may remain stable over the period under consideration *or*
- The carbon stock may increase (or CO_2 emissions may decline) marginally over the period under consideration

Fixed carbon stocks under baseline scenario: The carbon stock in the baseline scenario may have stabilized over the years and is unlikely to change significantly during the project period. For example, the land use or management practices on degraded forests, grasslands, and croplands may not have changed over the years, leading to stabilization of carbon stocks. Thus, the carbon stock needs to be measured only for the project base-year, the assumption being that the stocks would remain stable or decline marginally over a given period in the future. Adoption of this approach reduces the cost of measuring carbon stock changes periodically over the years. The change, particularly in the soil carbon stock, may also be negligible for a given period of 5 or 10 years. Many CDM A/R methodologies make this assumption. Even the *IPCC GHG Inventory Methodology Guidelines* for land-use sectors under Tier-1 methodology make this assumption (IPCC 2006).

Dynamic or adjustable carbon stocks or CO_2 emissions under the baseline scenario: Carbon stocks or CO_2 emission rates could change over the years because of changes in land-use or management practices or even in the intensity of use and management practices (grazing, fuelwood extraction, and land preparation). Carbon stocks or CO_2 emissions could change drastically because of practices such as land preparation that disturb the topsoil.

D.2.2. Selection of a Baseline

Selecting a baseline is the first step in estimating carbon stocks or CO_2 emissions and projecting changes in them under the baseline scenario. The selection of the type of baseline has implications for carbon inventory estimation methods and the costs. The selection could be based on expert judgment of the likely changes in carbon stocks in the future under baseline scenario conditions. If land-use or management practices are expected to change, impacting carbon stocks, an adjustable baseline should be adopted. If an adjustable baseline is selected, the carbon stocks or CO_2 emissions will have to be measured or estimated periodically. If the land-use system or management practices have stabilized or if the land is so degraded that no changes in carbon stocks are likely in the future, adopt a fixed baseline, requiring estimation only once at the beginning of the project. A fixed baseline may be adequate for most projects, especially since changes in soil carbon stocks are slow and small and therefore difficult to detect through measurements for short periods of 5 or 10 years.

Broad steps in developing a baseline for land-based projects: The methods for estimating baseline carbon stocks or CO_2 emissions may vary for different climate change mitigation mechanisms such as CDM and REDD. For example, CDM in A/R projects has different methods recommended by the CDM Executive Board (http://www.unfccc.int/CDM), and the emerging REDD+ mechanism may stipulate specific and multiple methods to be adopted. Therefore, only a generic approach is presented here:

Step 1: Define the project area, identify the current land uses and management practices, demarcate the boundary, and stratify the project area into homogenous strata

Step 2: Select the method for establishing the baseline carbon stocks or CO_2 emissions

Step 3: Select the carbon pools to be impacted under baseline scenario

Step 4: Estimate carbon stocks in all the land-use strata for the base year and for at least one more point prior to the base year based on cross-sectional field studies; if

(*continued*)

data on carbon stocks from any previous study or measurements are available for similar land conditions, such data could also be used to estimate the rate of change over a period

Step 5: Project the future land-use scenario and carbon stocks or CO_2 emissions using models or simple linear projections

Project boundary: The project boundary is a geographically delineated area dedicated to the project activity. Projects can vary in size from hundreds of ha to hundreds of thousands of ha, either as a contiguous unit or distributed as multiple parcels under a single project management. The spatial boundaries of the land parcels need to be clearly defined and properly documented for measurements and monitoring. A project area can have a primary boundary and a secondary boundary.

A primary project boundary is the geographic boundary restricted to areas, locations, and land-use systems directly proposed to be subjected to project interventions or activities.

A secondary project boundary may have to be delineated and marked to include locations and land-use systems outside the project boundary that are projected to be impacted or likely to experience leakage because of shifting land conversion, biomass extraction, livestock grazing, etc.

Scale of the project: The size of a project determines the methods to be used for carbon inventory. Carbon stock changes in small-scale projects could be monitored using field measurements, whereas large-scale projects may require adoption of remote sensing and modeling techniques. Small-scale projects are likely to be more homogeneous with respect to soil, topography, and agricultural practices than large-scale projects, which are likely to be heterogeneous, requiring multistage stratification. The heterogeneity or homogeneity of a project also determines the methods to be adopted for boundary determination, stratification, sampling, and selection of carbon pools.

D.2.3. Method for Estimating Carbon Stocks

Three broad approaches to estimating carbon stocks or CO_2 emission and changes under baseline and project scenarios during *ex ante* stage are as follows (Ravindranath and Ostwald 2008):

- Default value
- Cross-sectional field studies
- Modeling

Approach based on default values: The approach based on default values is relevant at the project development phase. Default values for carbon stocks or CO_2 emissions available in literature for the selected land categories and land-use practices could be used. IPCC (2006 and 2003) provides exhaustive default values. The Emission Factor Database (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php) of IPCC also provides the default values. The steps to be adopted for *ex ante* calculation of changes in carbon stock or CO_2 emission in the baseline scenario are as follows:

Step 1: Define the project boundary covering all the parcels of land to be brought under different project activities

Step 2: Stratify the project area into homogeneous land classes based on tenure, soil, topography, and baseline agricultural or forestry practices prior to the implementation of the project, representing the baseline scenario conditions

Step 3: Stratify the project area by overlaying the homogeneous land classes obtained in Step 2 with the proposed project activities (such as crop cultivation practices, planting of different species, improved grazing practices and new forest management practices)

Step 4: Define and demarcate the strata dedicated to different project activities based on Step 3 for the base year (t_0), incorporating the current land-use status (Step 2) and proposed project activities (Step 3), and estimate the area under each stratum, such as:

- Stratum 1 comprising cropland proposed for agro-forestry
- Stratum 2 comprising cropland proposed for soil conservation measures
- Stratum 3 comprising cropland proposed for organic manure application

Step 5: Select the carbon pools relevant to each of the land stratum defined in Step 4

Step 6: Estimate the carbon stocks for all the selected strata under the baseline conditions for the base year t_0 based on field measurements or using default values available from other studies, reports, and programs in the region or from a published database

Step 7: Select one of the following two approaches for estimation and projection of carbon stock change under the baseline scenario, namely

(*continued*)

- Fixed carbon stock
- Adjustable carbon stock

Step 8:

- If the fixed-carbon-stock approach is used, estimate the stocks of different carbon pools only once for the base year t_0, assuming that the stocks may not change or change only marginally over the project period

or

- If the adjustable-carbon-stock approach is used, estimate the carbon stocks at different selected periods for different pools using default values for changes in carbon stocks from literature

Step 9: Based on current and historical land-use data and any ongoing or proposed programs for the project area, project future land-use systems for different periods; for example 5, 10, 15, and 20 years for each stratum

Step 10: Use the future land-use pattern for a selected year (for example, t_5, t_{10}, and t_{15}) and use the default values for carbon stocks

Step 11: Estimate the carbon stocks for a future period of 5 or 10 or 20 years (t_5, t_{10}, or $t_{20,}$ respectively) for all the land strata defined in Step 4 using default data for the soil carbon and AGB carbon pools.

Step 12: Calculate the difference between the carbon stocks, taking into consideration all project land-use systems and areas for year t_n (projected period) and year t_0 (base year, the project starting date) using the following formula:

Change in carbon stock in the baseline or without-project scenario (ΔC)

$$\Delta C = Ct_n - Ct_0$$

where

ΔC = change in carbon stock in tC/ha

Ct_n = carbon stock in year t_n (tC/ha)

Ct_0 = carbon stock in base year t_0 (tC/ha)

ΔC could be positive or negative but is likely to be negative for most projects, indicating marginal reduction in carbon stocks or increased CO_2 emissions, especially SOC

Approach based on cross-sectional studies: The approach based on cross-sectional studies can be used during the project development phase to estimate baseline carbon stocks or CO_2 emissions and for making projections. The approach is likely to provide more reliable estimates of carbon stocks or CO_2 emissions than those provided by the default-value–based approach. Carbon stocks for the base year as well as future years could be estimated using this approach.

Base year estimates: Carbon stocks for the base year t_0 could be estimated using the following steps during the project development or *ex ante* phase:

Steps 1 to 5 are identical to those described earlier in the default value method to identify and demarcate different land strata

Step 6: Estimate the total carbon stock for year t_0 for each land stratum for different carbon pools in the project area based on measurements using the plot method

Future year estimates: Carbon stocks for the future year t_n could be estimated using the following steps during the project development phase. This approach is necessary only if changes in land use or management practices are projected under the baseline scenario, which may include degraded forest or grassland converted to cropland or cropland left fallow.

Step 1: Derive the future land-use system and areas for each of the stratum under the baseline scenario based on historical data, participatory rural appraisal, and any ongoing or proposed program for the time period selected (t_5, t_{10}, t_{15}, t_n)

Step 2: Select the relevant carbon pools for the future land-use systems, which may be similar to or different from the pools for the current land-use system strata

Step 3: Obtain future carbon stock data for each projected land-use system by identifying land areas subjected to conditions leading to the new land-use system for the period t_n:

- Locate areas that have experienced the projected land-use changes (such as forest land converted to grassland or cropland) or changes in

(*continued*)

management practices (such as grazing) within the project boundary or nearby areas outside the project boundary

- Estimate carbon stocks in areas subjected to the changes in land-use or management practices
- Calculate total carbon stocks taking into account the projected land-use systems and area

Step 4: Estimate the change in carbon stocks using the following procedure:

- Estimate the total carbon stock for base year (t_0)
- Estimate the total carbon stock for a future project-year such as t_5, $t_{10,}$ or t_{20} using the steps described above
- Estimate the change in carbon stock between the future project year and the base year using the equation provided in the previous section for the approach using default values

Approach based on modeling: Models are particularly relevant to making projections during the project development phase for the project activities. Adoption of models such as PRO-COMAP, CO_2-FIX, TARAM, and CATIE requires generation of input data for making the projections using default data or those obtained from cross-sectional studies. Select the model and adopt the following steps to make projections of carbon stock changes (refer to section C.5 for details of the models and application).

Step 1: Select the baseline land strata and land-use systems

Step 2: Select a model suitable for the project activities

Step 3: Identify the input parameters required for making projections, such as baseline biomass and soil carbon stock, rate of change under the baseline conditions, and area of the stratum

Step 4: Generate the input parameters by adopting the default value approach or conducting cross-sectional field studies

Step 5: Input the parameters into the model and generate future carbon stocks or incremental gain or loss for a given project activity and area

Table D.2 outlines the relevant carbon pools and baseline features for broad project types. Refer to section C.5 for details of models and procedures for adopting the models. Table D.3 provides biomass and soil carbon values for degraded forests, community lands, and abandoned private

TABLE D.2: Project Type, Relevant Carbon Pools, and Baseline Features

PROJECT TYPE	CARBON POOLS	BASELINE FEATURES
Agriculture	SOC	Soil carbon in agricultural lands in the absence of project interventions may be subjected to increment or reduction due to agricultural practices such as plowing or fertilizer application or organic manuring. In most project scenarios, baseline SOC stock may have stabilized or may change only marginally.
	AGB	Croplands may support perennials, which, in the absence of project intervention, may be subjected to growth or extraction, leading to increment or reduction in biomass stock, respectively. Generally, very limited tree biomass or AGB stock may exist, and it may have stabilized, except in a few agro-forestry systems.
Forestry	AGB	In the proposed project area, AGB carbon stocks may increase or decrease without project interventions. Existing forests proposed for a PA project where significant carbon stock exists may be declining due to extraction, grazing, fire, etc. Degraded lands proposed for afforestation are characterized by low carbon density: a few trees and shrubs may be subjected to loss of carbon due to biomass extraction and grazing or marginal increase in carbon density as a result of increase in AGB due to growth.
	SOC	In the absence of project interventions, soil carbon could be subjected to marginal increment or reduction. Generally, in most situations under the baseline, SOC stock may not change significantly or change only marginally over short periods (5 years or 10 years).
Degraded or fallow lands (forest land, cropland, or grassland)	AGB	These lands may support low perennial plant biomass stock where the AGB could be subjected to extraction and decline in the absence of project intervention. Generally, very limited tree biomass stock or AGB may exist, and it may have stabilized under most baseline scenarios.
	SOC	Soil carbon in the absence of project activities may be subjected to increment or reduction due to soil disturbance and grazing. Generally, in most baseline scenarios SOC stock may be low and may have stabilized.

Source: Authors.

TABLE D.3: Average AGB and BGB (Dry Tons) and SOC Stocks Under Baseline Condition in Different Land Categories of Himachal Pradesh, India

BASELINE LAND STRATUM	ALTITUDE	AGB (t/ha)	BGB (t/ha)	SOC[#] (t/ha)	TOTAL CARBON (tC/ha)
Degraded forestland	High	1.80 *(0.00–7.30)* *SE-0.79*	0.43	26.98 *(7.40–56.48)* *SE-1.51*	29.21
	Medium	1.60 *(0.01–3.95)* *SE-0.69*	0.38		28.96
	Low	1.24 *(0.00–5.57)* *SE-0.52*	0.30		28.52
Degraded community land	High	2.73 *(0.00-5.65)* *SE-1.15*	0.65	30.21 *(22.20–45.01)* *SE-3.01*	33.59
	Medium	*1.00* *(0.00–4.05)* *SE-0.55*	0.24		31.45
	Low	0.75 *(0.00–2.74)* *SE-0.51*	0.18		31.14
Degraded and abandoned private land	High	0.79 (0.00–2.96) *SE-0.56*	0.19	27.74 *(13.39–49.88)* *SE-1.14*	28.72
	Medium	1.59 (0.00–3.61) *SE-0.38*	0.38		29.71
	Low	2.89 (0.00–3.94) *SE-0.69*	0.69		31.33

[#] *Figures in parentheses indicate SOC range; SE is standard error.*
Source: http://cdm.unfccc.int/Projects/DB/TUEV-SUED1291278527.37/view.

lands, indicating the degraded nature of such lands manifest in their low carbon content.

D.3. APPLICATION OF MODELS FOR PROJECTING C-BENEFITS

Section C.5 describes the features of some mitigation assessment models used extensively for projecting C-benefits from projects. This section describes, step by step, how three such models, namely COMAP, CATIE, and TARAM, are applied in estimating C-benefits (carbon stock changes and CO_2 emissions) from tree biomass.

COMAP, or the Comprehensive Mitigation Analysis Process, is a set of models currently used in many countries for developing and assessing tree-based mitigation options (Sathaye and Makundi 1995). The model comprises three modules, namely (1) BIOMASS, for assessing biomass supply and demand; (2) FOR-PROT, for assessing the potential and cost-effectiveness of different forest protection measures as mitigation options; and (3) REFOREST, for assessing the potential and cost-effectiveness of reforestation as a mitigation option. This section describes the use of the REFOREST model, which can be used for all tree-based CEMs/CEPs such as agro-forestry, shelterbelts, silvi-pasture, orchards, plantations, and forests. Models such as CENTURY and ROTH C are available for soil carbon modeling. However, the use of these models for estimation and projections is limited due to data and model limitations.

Reforestation is one of the well-known and popular options for sequestering carbon and generating sustainable biomass as a substitute for fossil fuels. Majority of the carbon abatement projects in forestry sector are reforestation projects, and REFOREST enables one to assess their potential for carbon sequestration or woody biomass production and their cost-effectiveness for carbon sequestration or emission reduction. The model uses data on area under different land categories, carbon fixation rates, and costs and benefits under Baseline and Mitigation scenarios to estimate:

- Annual changes in carbon stock
- NPV of benefits of mitigation options
- Cost-effectiveness indicators such as
    - Cost in $/tC sequestered
    - Cost in $/ha
    - NPV in $ /tC sequestered or emission avoided

Steps in using REFOREST and data inputs: Data input to REFOREST includes changes in area under forests and degraded lands in the baseline scenario, the area proposed for reforestation under the mitigation scenario, carbon densities for vegetation and soil, rates of carbon sequestration, and costs and benefits.

Step 1: Define land-use categories	• Define land categories relevant to the BASELINE as well as MITIGATION scenario; for example, forest, degraded land, or plantation
Step 2: Define baseline area under different land categories	• For the land categories selected, give the area, for example for the year 2011, and project the area under these categories annually for the future years up to, say, 2050
	• Normally, the degraded land area is assumed to remain stable or increase
Step 3: Define the area under reforestation (including agro-forestry, silvi-pasture, etc.)	• The rate of reforestation depends on the land area available, investment, funding, infrastructure support, organizational capacity, etc. • The area to be reforested has to be entered yearly from 2011 to, say, 2020 or 2050. It could be constant or at varying rates

STEPS 1, 2, AND 3: WORKSHEET FOR DATA ENTRY

REFORESTATION	2011	2012	2013	2014	2015
From Steps 2 and 3: Land Area (ha)					
Baseline scenario					
Wasteland (degraded land)					
Mitigation scenario					
Wasteland (degraded land)					
Reforested land					

Step 4.1: Aggregate carbon densities in soil and vegetation under the baseline scenario	• Estimate carbon densities of vegetation (above-ground woody biomass) and soil in t per ha • Carbon density data are available in literature for vegetation as well as soil • Normally, vegetation carbon densities are expected to decline under the BASELINE scenario because of anthropogenic pressures; similarly, soil carbon densities are likely to decline from year to year depending on the end-use of land • Add the soil and vegetation carbon densities to get total carbon density/ha

STEP 4.2: BASELINE SCENARIO—WASTELANDS

	2011	2012	2013	2014	2015
Vegetation carbon					
Dry weight (t/ha)					
Carbon density (%)					
Soil carbon					
Amount of carbon stored in soil (tC/ha)					

Step 4.2: Calculate carbon density under the Mitigation scenario—Vegetation	• Carbon density is projected to increase annually because of natural regeneration plus carbon accumulation in vegetation as a result of planting and protection • The rate of carbon accumulation depends on a number of factors such as tree species, density, rainfall, nutrient supplements, and rotation period • The rotation period could be different for different reforestation options: ▪ Short rotation forestry: 6 to 10 years ▪ Long rotation forestry (for sawn wood): 30 to 50 years ▪ Carbon sequestration storage projects: indefinite length

(*continued*)

Step 4.3: Calculate carbon density under the Mitigation scenario—Soil	• Soil carbon density is normally low in degraded soils • Under reforestation options, which involve planting trees, soil carbon density increases because of litter fall and decomposition • The rate of carbon accumulation is normally low and linear and continues to increase over a long period; for example, it could increase by 1 to 2 tC per ha per year
Step 4.4: Calculate carbon density under the Mitigation scenario—Carbon from decomposing matter	• The forest and/or plantation litter consists of woody and nonwoody plant biomass. The nonwoody biomass gets decomposed quickly in a year or two. The woody litter stays on the forest floor for many years, often beyond 10 years • Carbon density of the decomposing matter could vary from 5 t per ha to 25 t per ha at different periods • These data may have to be obtained from literature
Step 4.5: Carbon density under the Mitigation scenario—Product carbon	• The woody biomass sequestered and harvested has diverse end uses, where carbon emissions occur at different periods

STEP 4.2: MITIGATION SCENARIO: REFORESTATION

	2011	2012	2013	2014	2015
1. Vegetation carbon					
Rotation period (years)					
Annual yield (t/year/ha)					
Carbon density (%)					
2. Soil carbon					
Rotation period (years)					
Amount of carbon stored in soil (tC/ha)					
3. Decomposing matter carbon					
Decomposition period (years)					
Amount of decomposing carbon (tC/ha)					
4. Product carbon					
Average age (years)					
Amount of carbon stored in product (tC/ha)					

Outputs of the Model

The model generates outputs on potential mitigation options, the cost-effectiveness of different options, and net financial benefits. The model also generates total carbon sequestered and stored in the Baseline scenario and in the Mitigation options for the area defined under these options. The total includes carbon stored in soil, vegetation, and storage products. The annual incremental carbon sequestered or stored in different carbon pools in addition to total stocks is also generated. The model also generates total costs and benefits of carbon sequestration and cost-effectiveness indicators such as NPV in $/t carbon sequestered or stored, NPV in $/ha

STEP 6.1: TOTAL CARBON POOL (tC)					
	2011	2012	2013	2014	2015
Annual incremental carbon projected					
Baseline scenario					
Wasteland (degraded land)					
Mitigation scenario					
Wasteland (degraded land)					
Reforested land					

reforested, initial cost in \$/t C sequestered or stored, and life cycle costs in \$/tC sequestered and \$/ha.

CATIE, the carbon assessment tool for afforestation reforestation (CAT-AR) developed by CATIE, or the Centro Agronómico Tropical de Investigación y Enseñanza, in Costa Rica for the World Bank, is a simplified version of TARAM. The tool closely follows the CDM approach to accounting of GHG in A/R projects, providing a transparent, conservative, and simple, yet credible assessment. The tool also provides default values from the 2003 IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC-GPP LULUCF), and the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC-GNGGI). Data inputs for CATIE include the following items:

- Baseline: general information regarding a stratum—land-use category, biomass stocks (both tree, such as woody, and nontree, such as nonwoody), root-to-shoot ratio, carbon fraction
- Project Area: planted, phasing of planting, and area planted per year, rotation period, woody biomass per stratum, wood density of species, root-to-shoot ratio, carbon fraction
- Leakage of CO_2
- Project management details: site preparation, fertilizer application, thinning, harvesting, and consumption of fossil fuels

The model readily provides project-level changes in carbon stocks and GHG emissions and removals as well as the following values:

- Total carbon stocks in planted trees and pre-existing trees, in woody and nonwoody vegetation, and total carbon stocks
- Sum of changes in carbon stocks—above- and below-ground (changes since project inception)
- Total anthropogenic sum of changes in carbon stocks (sum of above- and below-ground stocks and sum of changes in carbon stocks)
- Actual net GHG removals by sinks, defined as the sum of changes in carbon stocks minus GHG emissions

CATIE is an Excel-based tool comprising eight spreadsheets (Start, Main, Stand Models Current Annual Increment [SM CAI], Baseline Strata [BLS], AR-Project, Leakage, Net, and Tables):

- The Start sheet provides general instructions on how to use the tool. The Main and SM (CAI) sheets are for the user to input data
- Results of the baseline net anthropogenic GHG removals by sinks are provided in the BLS sheet
- Project net anthropogenic GHG removals by sinks are included in the AR-Project sheet
- The Net sheet provides the final results of the AR project carbon footprint in the form of net anthropogenic GHG removals by sinks
- IPCC default values used in the tool are provided in the tables sheet

The **main sheet** requires inputs from the user to calculate GHG emissions and removals in the baseline and AR-Project scenarios and leakage. The necessary inputs could be regrouped into five groups: baseline, project activity, leakage, strata, and key default values. Each of these groups and the data input needed are described below.

Baseline: Fill in general information on the baseline. The parameters to be filled in include the following.

		UNIT	BLS1		BLS2		BLS3	
Peak biomass: the maximum biomass that can be achieved in a stratum. This is to be filled in by the user or defaults could be chosen. *Root-to-shoot ratio:* if this parameter is unknown, the tool will guide to a list of default values. *Carbon fraction:* use a site-specific value or choose a default.	Area of the baseline stratum	ha						
	Stratum name	descriptive						
	Land-use category of stratum	descriptive						
	Nonwoody biomass							
	Peak biomass (t dm. ha^{-1})	t dm.ha^{-1}						
	Root-to-shoot ratio	t dm / tdm						
	Carbon fraction	tC / t dm						
	Woody biomass							
	Is there pre-existing woody vegetation on the BLSx?							
	Living stand volume at the beginning of the project beginning	m^3.ha^{-1}						
	Living stand volume at the end of the project	m^3.ha^{-1}						
	Living AGB at the project beginning	t dm.ha^{-1}						
	Living AGB at the end of the project	t dm.ha^{-1}						
	Wood density of existing trees	t dm. m^{-3}						
	BEF	dimensionless						
	Root-to-shoot ratio	t dm / t dm						
	Carbon fraction	tC / t dm						

Woody biomass: Is there pre-existing woody vegetation on the BLSx?	yes / no Specify data unit for woody vegetation, either volume (m^3.ha^{-1}) or biomass (tdm.ha^{-1}). Default data are also available.
If input data is in m^3/ha	Living stand volume at the project beginning (m^3.ha^{-1}) Living stand volume at the end of the project (m^3.ha^{-1}) Wood density of existing trees (tdm.m^{-3}) BEF (dimensionless)
If input data is in t/ha	Living AGB at the project beginning (tdm.ha^{-1}) Living AGB at the end of the project (tdm.ha^{-1})
Inputs required for both volume and mass units	Root-to-shoot ratio (tdm/tdm) Carbon fraction (ton of carbon/tdm)

		Woody biomass							
		Is there pre-existing woody vegetation on the BLSx?							
		Living stand volume at the project beginning	m^3.ha^{-1}						
		Living stand volume at the end of the project	m^3.ha^{-1}						
		Living AGB at the project beginning	t dm.ha^{-1}						
		Living AGB at the end of the project	t dm.ha^{-1}						
		Wood density of existing trees	t dm. m^{-3}						
		BEF	dimensionless						
		Root-to-shoot ratio	t dm/t dm						
		Carbon fraction	tC/t dm						

Project Activity

General information	How many stand models or activity types does your project activity have?
What type of growth and yield data are available?	None: default values will be used. MAI: site-specific information must be entered. CAI: the user has to fill out the SM_(CAI) spreadsheet, with year by year information on stand volume, current annual increment, and thinning and harvest.
Area to be planted	Specify the area in ha.
Name or code used in the project	It can be a name or a description of the stand model or activity.
Woody vegetation	
Number of years to complete planting	Refers to phasing of activities and the number of years to complete planting of the total project area.
Calendar year of the first planting	For example, 2011
Rotation	The number of years of a rotation cycle, such as 6 years for eucalyptus and 40 years for teak.
MAI ($m^3.ha^{-1}.year^{-1}$)	None: default values will be used MAI: site-specific information must be entered for the MAI CAI: the user is invited to fill out the SM_(CAI) spreadsheet
Wood density of main species ($tdm.m^{-3}$)	If the parameter is unknown, default values are available. Drop-down list includes a "Not available in this list" option, which is the arithmetic average of all the values in this list.
BEF	BEF of main species is to be entered here to extrapolate the bole or commercial biomass to whole tree biomass. Defaults available for different climatic zones and forest types.
Root-to-shoot ratio of main species	Defaults available as a drop-down list.
Carbon fraction of main species (tC/tdm)	Default available.

The *project activity* is the sum of changes in carbon stock and in greenhouse gas emissions/removals that occur due to sustainable forest management (the project activity). Different types of plantations may have different rates of carbon stock change, and therefore, the SFM project activity must be stratified in *Stand Models* (SMx). One stand model is different from another when its expected carbon stock change rate ($tC.ha^{-1}.year^{-1}$) is different from that of other stand models.

How many stand models does your project activity have?									
What type of growth and yield data do you have?									
			Unit	SM1	SM2	SM3			
		Area to be planted	ha						
		Name or code used in the project	descriptive						
		Woody vegetation							
		Number of years to complete planting	year						
		Calendar year of the first planting	(e.g. 2010)						
		Rotation	year						
MAI			$m3\ ha^{-1}\ year^{-1}$						
		Wood density of main species	$t\ dm.m^{-3}$						
		BEF of main species	dimensionless						
		Root-to-shoot ratio of main species	t dm / t dm						
		Carbon fraction of main species	tC / t dm						

Management Activities

Information on site preparation that would help account for emissions resulting from the treatment of pre-existing vegetation, harvest, or burning of pre-existing biomass is to be provided here by the user. The calculation takes into account the values for nonwoody and woody vegetation. Further, details of fertilizer application, liming, thinning, and harvest are also to be provided by the user.

1. Site preparation									
		Treatment of pre-existing woody biomass	descriptive						
		Treatment of pre-existing nonwoody biomass	descriptive						
2. Fertilizer application									
		Will fertilizers be applied?	descriptive						
		Number of years with inorganic fertilizers	years						
		Tons of nitrogen applied through inorganic fertilizers	$t\ N.ha^{-1}$						
		Number of years with organic manures	years						
		Tons of organic nitrogen applied through organic manures	$t\ N.ha^{-1}$						
3. Liming									
		Will there be liming?	descriptive						
		Number of years with $CaCO_3$ application	years						
		Tons of $CaCO_3$ applied	$t\ CaCO_3\ .ha^{-1}$						
		Number of years with $CaMg\ (CO_3)_2$ application	years						
		Tons of $CaMg\ (CO_3)_2$ applied	$t\ CaMg\ (CO_3)_2\ .ha^{-1}$						
4. Thinning and harvesting									
		Will there be thinning?	descriptive						
		Will there be final harvesting?	descriptive						
First thinning		Age	age						
		Volume extracted	$m^3 \cdot ha^{-1}$						
Second thinning		Age	age						
		Volume extracted	$m^3 \cdot ha^{-1}$						
Third thinning		Age	age						
		Volume extracted	$m^3 \cdot ha^{-1}$						
Fourth thinning		Age	age						
		Volume extracted	$m^3 \cdot ha^{-1}$						
Final harvest		Age	age						
		Volume extracted	$m^3 \cdot ha^{-1}$						
5. Fossil fuel consumption within the forest stand									
		Liters of gasoline consumed per m^3 harvested	$l.m^{-3}$						
		Liters of diesel consumed per m^3 harvested	$l.m^{-3}$						

Net Sheet or Outputs

The Net sheet presents the annual cumulative carbon footprint of the project in the form of net anthropogenic GHG removals by sinks, in tCO_2e. The outputs include:

- Baseline net GHG removals by sinks
- Actual net GHG removals by sinks
- Leakage of CO_2
- Net anthropogenic GHG removals by sinks, including yearly increment

NET					
PROJECT YEAR t* YEAR	**BASELINE NET GREENHOUSE GAS REMOVALS BY SINKS tCO$_2$e**	**ACTUAL NET GREENHOUSE GAS REMOVALS BY SINKS tCO$_2$e**	**LEAKAGE tCO$_2$e**	**NET ANTHROPOGENIC GREENHOUSE GAS REMOVALS BY SINKS CUMULATIVE tCO$_2$e**	**NET ANTHROPOGENIC GREENHOUSE GAS REMOVALS BY SINKS YEARLY INCREMENT tCO$_2$e**
2002	0.00	–570,999.19	0.00	–570,999.19	–570,999.19
2003	0.00	–1,141,998.38	0.00	–1,141,998.38	–570,999.19
2004	0.00	–1,712,997.57	0.00	–1,712,997.57	–570,999.19
2005	0.00	–2,283,996.77	0.00	–2,283,996.77	–570,999.19
2006	0.00	–2,854,995.96	0.00	–2,854,995.96	–570,999.19
2007	0.00	–3,425,995.15	0.00	–3,425,995.15	–570,999.19
2008	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2009	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2010	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2011	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2012	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2013	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2014	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2015	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2016	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2017	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2018	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2019	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2020	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2021	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2022	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2023	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2024	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2025	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2026	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2027	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2028	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2029	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2030	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
2031	0.00	–3,425,995.15	0.00	–3,425,995.15	0.00
				TOTAL	**–3,425,995.15**

TARAM, the tool for *ex ante* estimation of forestry CERs, is an Excel-based tool jointly developed by the BioCarbon Fund of the World Bank and CATIE to facilitate the application of approved methodologies to project activities related to afforestation and reforestation under the CDM. TARAM does not include a routine for uncertainty analysis in its current version. The data needs for TARAM include basic information such as species or group of species to be planted, wood density of species, BEF, and root-to-shoot ratio.

Input Spreadsheet for Tree Species

SPECIES												
For each species or group of species that you have in the baseline and project scenario specify the appropriate parameter values. Choose conservative values. When using IPCC default values for BEF_j and R_j specify the upper value for species in the baseline and the lower one for species in the project scenario. If the same species exist in both scenarios, specify the parameter values for each scenarios separately.												
SPECIES OR GROUP OF SPECIES	**SPECIES ID**	**NITROGEN FIXING?**	**WOOD DENSITY**	**CARBON FRACTION**	**BIOMASS EXPANSION FACTOR**		**ROOT SHOOT RATIO**			**APPLICABILLTY OF R_j ACCORDING TO ABOVE-GROUND BIOMASS (AGB)**		
Species may be grouped if they have similar growth behavior and if the parameters on the right are similar for each species include in the group.	**ID_j**		**D_j**	**CF_j**	**BEF_j-1** (Method 1)	**BEF_j-2** (Method 2) Recomended	**R_j-1**	**R_j-2**	**R_j-3**	Use **R_j-1** when AGB is less than	Use **R_j-2** when AGB is between	Use **R_j-3** when AGB is above
Dimensionless	1, 2, 3, . . .		$td.m.m^{-3}$	$tC(td.m.)^{-1}$	dimensionless		dimensionless			$td.m.ha^{-1}$	$td.m.ha^{-1}$	$td.m.ha^{-1}$

Input Data on Baseline

Information on land cover, land use, presence of pre-existing vegetation (both nonwoody and woody), if any, and its growth.

BASELINE STRATUM 1

$ID_{i,b}$	A	
Description	Degraded forest land	a) no growing trees or woody perennials exist, and b) no trees or other woody perennials will start to grow at any time during the crediting period
Land cover	a	c) growing trees or woody perennials exist (but will not reach the thresholds for the national definition of forests)
Land use	a	a) abandoned b) grazing

yes

PRE-EXISTING VEGETATION

Non-woody vegetation	*Bpre,i*	td.m.ha-1 Pre-existing average above-ground living non-woody biomass
	CFpre	tC(td.m.)-1 Average carbon fraction of dry biomass in pre-existing non-woody vegetation
	RbPre,i	dimensionless Root to shoot ratio

	TREE SPECIES OR GROUP OF TREE SPECIES IN THIS BASELINE STRATUM (AS SPECIFIED IN THE WORKSHEET SPECIES)									
PROJECT YEAR t* YEAR	**010 *BASELINE SPECIES* STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**	**STAND VOLUME *Vijt* m3ha-1**
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										

Input data on Project Activities

Input data include project-specific information such as existing vegetation if any and its volume in m^3 per ha per year, area planted under different strata, A/R plan (phasing of planting), and growth rate or MAI of species to be planted under different strata in t per ha per year.

Input Data Sheet on Stand Volume of Trees

Stand model 1

ID_k	1	
Description Rotation Planting density Replanting expected Fertilization	Restoration foresty model high 40 1100 35.0% no	years (The tool assumes replanting. If this is not the case, choose 30 years' rotation and fill with "0" the growth data after the final harvesting) trees per hectare (if assisted natural regeneration is used, fill with "0") % of planted trees to be replanted due to mortality in the first year

Treatment of pre-existing vegetation for site preparation

Woody vegetation	PBB_1	100.00% 0.00%	% biomass left standing and not burned (carbon stock remains) % biomass harvested and not burned (carbon stock decreases) % biomass burned (carbon stock decreases and burning produces)
Non-woody vegetation	PBB_1	1.70%	% biomass burned (always produces a 100% carbon stock decrease; non-CO_2 emission are calculated only from the burned fraction)

Fuel consumption within the stand

Activity	Fuel consumption per unit liters	Unit	Fuel type
Site preparation	0.00	ha	diesel
	0.00	ha	gasoline
Planting	0.00	ha	diesel
	0.00	ha	gasoline
Thinning and harvesting	0.00	ha	diesel
	0.00	ha	gasoline
Fuelwood-collection	0.00	ha	diesel
	0.00	ha	gasoline

Soil carbon pool

Csoc	*yes*	(yes or no) Available data of changes in soil organic carbon
Change	*0.5*	Carbon stock change in soil organic matter tC ha-1 yr-1
Tfor	*20*	Time period required for transition from SOC Non-For to SOC For, in years
Csoc_n_for		Soil organic carbon stock of non-forested degraded lands in tC ha-1
Csoc_for		Soil organic carbon stock of A/R or F area in tC ha-1
Csoc_ref		Reference soil organic carbon stock under native forests in tC ha-1 (See IPCC GPG-LULUCF Table)
f		Adjustment factor for the effect of management intensity, dimensionless (Between 0–1, default values)

To download the IPCC Tool for Estimation of Changes in Soil Carbon Stocks, click here

Nitrogen content of fertilizer

Synthetic	NC_{SF}	Nitrogen content of synthetic fertilizer applied, dimensionless
Organic	NC_{OF}	Nitrogen content of organic fertilizer applied, dimensionless

Species
Tree species or group of tree species in

IDj	*species name*	*Selection*
001 0 0 0 0 0 0	Reforestation_High alt	001 Reforestation_High alt

Method	2	1) Carbon gain-loss method 2) Stock change method (recommended)
Data type	b	a) Stand volume data a) Allometric equations (biomass data)

Outputs of the Model

THE SPECIES OR GROUP OF TREE SPECIES IN THIS STAND MODEL (AS SPECIFIED IN THE WORKSHEET "SPECIES")										
STAND AGE ***t*** **AGE**	**001** ***REFORESTATION HIGH ALT*** **ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**	**ABOVE-GROUND BIOMASS** ***Bijt*** **T d.m. ha-1**
1	4.68									
2	9.36									
3	14.04									
4	18.72									
5	23.40									
6	28.08									
7	32.76									
8	37.44									
9	42.12									
10	46.80									
11	51.48									
12	56.16									
13	60.84									
14	65.52									
15	70.20									
16	74.88									
17	79.56									
18	84.24									
19	88.92									
20	93.60									
21	98.28									
22	102.96									
23	107.64									
24	112.32									
25	117.00									
26	121.68									
27	126.36									
28	131.04									
29	135.72									
30	140.40									

***Ex ante* estimation of net anthropogenic greenhouse gas removals by sinks**		
Starting year of the AR-CDM project activity	2006	Calendar year
Project year of the first verification	4	
CDM crediting period	20	
No further inputs are required below this line - go to Financial (optional)		
Total net anthropogenic greenhouse gas removal by sinks	749,614	tCO_2e
Average net anthropogenic greenhouse gas removal by sinks over the crediting period	37,480.7	$tCO_2e\ yr^{1}$
Average net anthropogenic greenhouse gas removal by sinks per hectare and year	10.80	$tCO_2e\ yr^{1}\ ha^{-1}$

PROJECT YEAR t*	**CALENDAR YEAR**	**BASELINE NET GREENHOUSE GAS REMOVALS BY SINKS**	**ACTUAL NET GREENHOUSE GAS REMOVALS BY SINKS**	**LEAKAGE**	**NET ANTHROPOGENIC GREENHOUSE GAS REMOVALS BY SINKS**	**$TCER_S$**	**$ICER_S$ (WITH REVERSAL)**	**$ICER_S$ (WITHOUT REVERSAL)**	**LIFETIME OF ICERS**
YEAR	**YEAR**	**tCO_2e**	**tCO_2e**	**tCO_2e**	**tCO_2e**	**UNITS**	**UNITS**	**UNITS**	**YEAR**
1	2,006	–	2,114	–	2,114				19
2	2,007	–	6,802	–	6,802				18
3	2,008	–	18,017	–	18,017				17
4	2,009	–	43,716	–	43,716	43,716	43,716	43,716	16
5	2,010	–	80,926	–	80,926				15
6	2,011	–	125,505	–	125,505				14
7	2,012	–	170,085	–	170,085				13
8	2,013	–	214,664	–	214,664				12
9	2,014	–	259,243	–	259,243	259,243	215,527	215,527	11
10	2,015	–	303,822	–	303,822				10
11	2,016	–	348,402	–	348,402				9
12	2,017	–	392,981	–	392,981				8
13	2,018	–	437,560	–	437,560				7
14	2,019	–	482,139	–	482,139	482,139	222,896	222,896	6
15	2,020	–	526,718	–	526,718				5
16	2,021	–	571,298	–	571,298				4
17	2,022	–	615,877	–	615,877				3
18	2,023	–	660,456	–	660,456				2
19	2,024	–	705,035	–	705,035	705,035	222,896	222,896	1
20	2,025	–	749,614	–	749,614				–
21	2,026	–	793,892	–	793,892				–
22	2,027	–	837,807	–	837,807				–
23	2,028	–	880,790	–	880,790				–
24	2,029	–	921,716	–	921,716				–
25	2,030	–	960,988	–	960,988				–
26	2,031	–	999,205	–	999,205				–
27	2,032	–	1,037,423	–	1,037,423				–
28	2,033	–	1,075,641	–	1,075,641				–
29	2,034	–	1,113,858	–	1,113,858				–
30	2,035	–	1,152,076	–	1,152,076				–
			Total			**1,490,134**	**705,035**	**705,035**	

The model estimates the following values under baseline and mitigation scenarios:

- Total net anthropogenic greenhouse gas removal by sinks
- Carbon leakage estimates
- Average net anthropogenic greenhouse gas removal by sinks over the crediting period
- Average net anthropogenic greenhouse gas removal by sinks per ha and year
- Cost-benefit analysis

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