Estimating the Opportunity Costs of REDD+
A training manual
Estimating the opportunity costs of REDD+: A training manual

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Foreword

Over the last years, reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (what is known as "REDD+") has arisen as a key issue in the international climate change negotiations and entered into the public media. There are good reasons for this. On the one hand, forest ecosystems, still covering one third of the earth’s surface, store more carbon than both the atmosphere and the world’s oil reserves combined. Forests are the most diverse terrestrial ecosystems, preserve watersheds and soils, regulate local climates and provide wood, energy, food, medicines, fibres and clean water to society, especially to forest-dependent peoples, a large number of whom are poor. On the other hand, ongoing deforestation and forest degradation, which the FAO estimates to amount to 5.2 million hectares net per year, accounts for up to one fifth of global anthropogenic carbon emissions.

In December 2005, at the climate negotiations in Montreal, the Coalition for Rainforest Nations introduced the idea of compensating developing countries for reducing national rates of deforestation. Since then governments, international and civil society organizations, indigenous peoples, scientific institutions and private firms have been feverishly negotiating at and in-between annual climate conferences to integrate REDD+ into a future international climate regime. Amongst the debated issues, the costs of REDD+ is crucial for forest countries, donors and buyers of potential carbon offset credits in the future. While the transaction or administration costs of REDD+ can be more readily estimated, a likely important cost component remains almost hidden: by conserving their present forests, countries and land owners forgo the benefits of potentially more lucrative alternative land uses, such as crops or livestock — the opportunity cost of REDD+.

This manual is a collective effort of the Facility Management Team of the Forest Carbon Partnership Facility (FCPF), the World Bank Institute Carbon Finance Assist program (CF-Assist) — the multi-donor trust funded capacity building program of the World Bank Institute Climate Change Practice (WBI-CC) — the Partnership for the Tropical Forest Margins (ASB) and the Consultative Group on International Agricultural Research (CGIAR).

The manual offers hands-on experiences from field programs and embraces the essential practical and theoretical steps, methods and tools to estimate the opportunity costs of REDD+. It addresses the calculation of costs and benefits of the various land use alternatives in relation to their carbon stocks. As such data are generally not readily available, this approach also includes information on inventory, data analysis and evaluation techniques.

The target audience of the manual includes governments, universities, research institutions, international or non-governmental organizations and program developers who may use the presented methods and tools to estimate opportunity costs and
incorporate these costs into recommendations for REDD+ policies and programs. A series of workshops is scheduled for countries participating in the FCPF and UN-REDD Programme in Africa, Asia and Latin America. Electronic versions of the manual will be made available in English, French and Spanish on the website of the World Bank Institute (http://wbi.worldbank.org/wbi/about/topics/climate-change).

The manual was edited by Pablo Benitez, Marian de los Angeles and Gerald Kapp (World Bank Institute), Benoit Bosquet, Stephanie Tam (World Bank Carbon Finance Unit), Stefano Pagiola (World Bank Latin America and Caribbean Region) and Carole Megevand (World Bank Africa Region). We are grateful for the dedicated work of the main authors Douglas White and Peter Minang (ASB) and their co-authors Brent Swallow, Fahmuddin Agus, Glenn Hyman, Jan Börner, Jim Gockowski, Kurniatun Hairiah, Meine van Noordwijk, Sandra Velarde and Valentina Robiglio. We also appreciate the contributions of Michael Richards and Simone Bauch. External reviews from Erick Fernandes, Gregory Frey, Ken Andrasko, Loic Braune, Martin Herold, and Timm Tennigkeit are appreciated.

Washington, DC, November 12, 2010

This is a living document. Please send your comments to the following address:
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<th>Definition</th>
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<tr>
<td>AFOLU</td>
<td>Agriculture, Forestry and Other Land Use</td>
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<tr>
<td>BAP</td>
<td>Bali Action Plan</td>
</tr>
<tr>
<td>BAU</td>
<td>Business as Usual</td>
</tr>
<tr>
<td>CDM</td>
<td>Clean Development Mechanism</td>
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<tr>
<td>CER</td>
<td>Certified Emission Reduction</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<tr>
<td>CO₂e</td>
<td>Carbon dioxide equivalent</td>
</tr>
<tr>
<td>COP</td>
<td>Conference of the Parties</td>
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<tr>
<td>DBH</td>
<td>Diameter at Breast Height</td>
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<tr>
<td>e.g.</td>
<td>for example</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas(es)</td>
</tr>
<tr>
<td>GIS</td>
<td>Global Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf Area Index</td>
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<tr>
<td>LCCS</td>
<td>Land Cover Classification System</td>
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<tr>
<td>LU</td>
<td>Land Use</td>
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<tr>
<td>LULUCF</td>
<td>Land Use, Land-Use Change and Forestry</td>
</tr>
<tr>
<td>LUS</td>
<td>Land Use System</td>
</tr>
<tr>
<td>MAI</td>
<td>Mean Annual Increment</td>
</tr>
<tr>
<td>MRV</td>
<td>Measurement, Reporting, Verification</td>
</tr>
<tr>
<td>NBSAP</td>
<td>National Biodiversity Strategy and Action Plan</td>
</tr>
<tr>
<td>NAPCC</td>
<td>National Action Plans for Climate Change</td>
</tr>
<tr>
<td>NFI</td>
<td>National Forest Inventory</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>POA</td>
<td>Program of Activities</td>
</tr>
<tr>
<td>REDD</td>
<td>Reducing Emissions from Deforestation and Degradation</td>
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<tr>
<td>REL</td>
<td>Reference Emission Level</td>
</tr>
<tr>
<td>RS</td>
<td>Remote Sensing</td>
</tr>
<tr>
<td>SBSTA</td>
<td>Subsidiary Body for Scientific and Technological Advice (UNFCCC)</td>
</tr>
<tr>
<td>SOM</td>
<td>Soil Organic Matter</td>
</tr>
<tr>
<td>tC</td>
<td>Metric ton of carbon (1tC = 3.67tCO₂)</td>
</tr>
<tr>
<td>tCO₂</td>
<td>Metric ton of carbon dioxide (1tCO₂ = 0.27tC)</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
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<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>VHRI</td>
<td>Very high resolution imagery</td>
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Estimating the opportunity costs of REDD+
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Chapter 1. Introduction

Objectives

1. Introduce the rationale behind REDD+ and REDD+
2. Describe the different costs of REDD+
3. Provide an introduction to opportunity cost analysis
4. Discuss risk and limitations of REDD+ and opportunity costs analysis
5. Summarize the objectives of the training manual
6. Identify the training manual (a) goal, (b) learning objectives, and (c) targeted participants/end-users
7. Summarize the current state of the art of REDD+ opportunity cost analysis
8. Present other costs of REDD+ and REDD+ risks

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What are REDD and REDD+?

1. REDD (Reducing Emission from Deforestation and Degradation) is a general term for an international policy and finance mechanism that will make possible the funding of forest conservation and establishment, and/or large-scale purchases and sales of forest carbon. It is intended to address both deforestation (the conversion of forested to non-forested land) and forest degradation (reductions in forest quality, particularly with respect to its capacity to store carbon).¹

2. REDD+ is a revised version of REDD, defined in the Bali Action Plan as: policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation; and the role of conservation, sustainable management of forest and enhancement of forest carbon stocks in developing countries.² Both REDD and REDD+ are intended to help reduce carbon emissions into the earth’s atmosphere. For the purposes of this training manual, REDD+ is emphasized.

3. By making conservation and sustainable management of forests (along with their carbon) economically feasible, REDD+ can influence land use decisions within countries. UNFCCC ratification of REDD+ will allow forested countries to sell carbon credits to interested buyers in markets or receive financial support from conservation funds. The particulars of REDD+ mechanisms, however, are still being clarified.

4. Financial flows from REDD+ programs could reach up to US$30 billion a year.³ This flow of funds, primarily North-South, could reduce carbon emissions, support new, pro-poor development, and help conserve biodiversity and other vital ecosystem services (UN-REDD, 2010).

National REDD+ strategies and benefit-sharing mechanisms

5. Assuming that REDD+ funds will pass through national governments, countries will likely decide how to disburse the benefits. In some cases, countries may determine to make direct financial payments to individuals and communities to compensate them for their activities that protect and conserve forests. In other cases, countries may create programs to finance capacity-building and investments for alternative livelihood strategies and/or other community development priorities. Such an approach is a form of indirect compensation.

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¹ A clear definition of degradation has not yet been generated, for more see http://www.fao.org/docrep/009/j9345e/j9345e08.htm.
² Paragraph 1 (b) (iii) of the Bali Action Plan (BAP).
³ Kindermann, et al. (2008) estimate that halving emissions from deforestation between 2005 and 2030, which corresponds to 1.7 to 2.5 billion tons of carbon dioxide (CO₂) emissions, would require financial flows of US$17 to 28 billion per year. This would require a payment of US$10-21/tCO₂. A 10% emissions reduction over the same period would cost between US$0.4 and 1.7 billion annually and US$2-5/tCO₂.
6. Besides these two general options, other REDD+ strategies and benefit-sharing mechanisms may be developed at the country level. In some contexts, however, effective and equitable benefit-sharing mechanisms may be less apparent. For instance, if a REDD+ intervention is to reduce illegal logging, compensation to stop illegal operators could create perverse incentives to cut trees in order to receive payments. Here, indirect compensation and other mechanisms would likely work best to achieve a REDD+ goal. (*More on the risks and limitations of REDD+ and opportunity costs are discussed below.*)

7. Regardless of whether or not individuals or communities are being compensated financially, if a REDD+ strategy limits their livelihoods (legal or not), then they bear an opportunity cost. If these costs are not compensated in some way (financially or otherwise) there are two implications: (1) pressure on forests will continue, or (2) the opportunity cost would cause harm to communities, in violation of international good practice standards (and World Bank Safeguards) of “doing no harm.”

8. This manual does not advocate any particular REDD+ strategy or benefit-sharing mechanism. Rather, it is the opinion of the authors that opportunity cost estimation can provide important information to the process of developing and implementing effective and equitable REDD+ strategies.

**Costs of REDD+**

9. In order to receive REDD+ funding, countries must reduce deforestation and forest degradation. This is not costless. Costs can be grouped into three general categories: (1) the opportunity costs resulting from the foregone benefits that deforestation would have generated for livelihoods and the national economy, and (2) the implementation of the measures needed to reduce deforestation and forest degradation, and (3) the transaction costs of establishing and operating a REDD+ program.† Brief descriptions of these costs are provided below and are summarized in Figure 1.1.

**Opportunity costs**

10. Deforestation, for all its negative impacts, can also bring benefits. Timber can be used for construction, and cleared land can be used for crops or as pasture. Reducing deforestation means foregoing these benefits. Similarly, forest degradation resulting from selective logging, fuelwood collection, or grazing of animals also brings benefits. Avoiding this degradation foregoes these benefits. The cost of foregone benefits (net of any benefits that conserved forest generates) is known as “opportunity costs” and is usually the single most important category of costs a country would incur if it reduced its rate of forest loss to secure REDD+ payments.

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*See Chapter 3 for discussion of safeguards.*

† These categories are not definitive, but provide an overview of the different REDD+ costs. For a full discussion, see Pagiola and Bosquet (2009). Costs can be arranged in fewer or more categories.
11. Opportunity costs include, most obviously, the foregone benefits of the alternative land use. They can also include social-cultural and indirect costs:

12. **Social-cultural costs.** Preventing the conversion of forests to other land uses, can affect the livelihoods of many rural dwellers significantly. Such an alteration in the way of life may bring about social and cultural costs that are not easily measured in economic terms.\(^6\) Examples of such costs could include psychological, spiritual or emotional impact of livelihood change, loss of local knowledge, and erosion of social capital.

13. **Indirect costs.** Changes in economic activities, from timber and agriculture to other productive sectors, can affect downstream actors of associated product supply chains. Less activity could also have an effect on national tax revenues. Similar to opportunity costs, indirect costs are not total, but need to estimated on a difference basis (that is with vs. without REDD+).\(^7\) Such indirect costs associated to REDD+ can be estimated by using multipliers or multi-market economic models.

14. Other indirect costs include global feedback relationships arising from REDD+ policy. Without REDD+, land uses within a country would change differently from a scenario with REDD+. Since more land would be in forest, the prices and costs of agricultural and ranching activities would likely be affected. The combined effect of less conversion of forest to agriculture and more restoration of forests from agriculture would reduce land under cultivation, potentially increasing the costs of food, fiber and fuel. Such land use changes could represent significant opportunity costs.\(^8\)

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\(^6\) See Chapter 3 for discussion of involuntary resettlement policy of the World Bank.

\(^7\) In addition, the growth of other productive sectors needs to be estimated, as economic conditions are not static.

\(^8\) Furthermore, global population increases and consumption patterns associated with higher living standards will also likely raise pressures to convert forests into pastures or agricultural fields, thereby increasing REDD+ opportunity costs. Nevertheless, these factors are independent of REDD+ programs and should therefore not be considered an indirect cost attributable to REDD+. Similarly, other factors such as technology change, which can improve the productivity of lands (e.g. higher yielding crops), could also be mistakenly included as an indirect benefit of REDD+. 
Implementation costs

In addition to opportunity costs, there are also costs involved in implementing a REDD+ program. These are the costs directly associated with actions to reduce deforestation, and hence emissions abatement. Examples include the costs of:

- guarding a forest to prevent illegal logging,
- relocating timber harvesting activities away from natural forests to degraded forests scheduled for reforestation,
- intensifying agriculture or cattle ranching so that less forest land is necessary for food, fiber and fuel production,
- re-routing a road project so that less forest land is destroyed as a result of opening the road,
- relocating a hydroelectric production project away from a natural forest,
- delineating and/or titling land of traditional and indigenous communities so that they have an incentive to continue protecting forests against conversion,
- providing capacity building, infrastructure or equipment to develop alternative livelihoods to communities.
16. All of these and similar measures incur investment and recurring costs for the public and/or the private sectors, which need to be adequately assessed and financed.

17. Implementation costs also comprise the institution- and capacity-building activities that are necessary to make the REDD programs happen. Examples of which include the expenses associated with the goods, training, research, and the political, legal and regulatory processes involved, including the consultations and government decision-making processes.

Transaction costs

18. Over and above opportunity costs and implementation costs, REDD+ also comes with transaction costs. These costs arise from (1) different parties involved in a REDD+ transaction, such as the buyer and seller or donor and recipient, and (2) external parties such as a market regulator or payment system administrator that establish if the REDD+ program has indeed achieved a certain amount of emission reductions.

19. Transactions costs are incurred throughout the process of identifying the REDD+ program, negotiating the transaction, and monitoring, reporting, and verifying the emission reductions. Transactions costs are also incurred by the implementers of a REDD+ program and third parties such as verifiers, certifiers, and lawyers. These costs are separate from implementation costs, since by themselves they do not reduce deforestation or forest degradation. These activities and associated costs are nevertheless necessary to the transparency and credibility of the REDD program and thus add value to the whole process. Transactions costs may also include so-called ‘stabilization costs’ arising from the need to prevent deforestation activities from moving to other countries that are not participating in REDD+. Nevertheless, it is not yet clear whether REDD+ participants will have to allow for such costs.  

Examples of REDD+ cost estimates

20. Opportunity costs can be very high (e.g. when forests are converted to establish lucrative oil palm plantations) or low and even negative (e.g. when forest conversion is for low productivity pastures). A review of 29 empirical studies from around the globe by Boucher (2008b) found an average opportunity cost of US$2.51/tCO₂. Eighteen out of the 29 estimates were less than US$2/tCO₂, and 28 out of 29 were less than US$10/tCO₂.

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9 Stabilization costs for the eleven most important high forest-low deforestation (HFLD) countries would cost an estimated US$1.8 billion annually. To cover 7 to 10 countries would cost only US$365 million to US$630 million (da Fonseca et al., 2007). These estimates refer to maintaining emissions constant. Stabilization costs of REDD+ are likely to be higher. Participating REDD+ countries will likely not pay these costs on an individual basis, rather a common fund would be established. Contribution mechanisms to the fund have yet to be determined but could be based on the size of the national REDD+ program, a flat-rate membership or a mix of these options.
21. For other REDD+ costs, US$1/tCO₂ was estimated to address transaction, implementation and administrative costs (Boucher 2008b). These costs somewhat overlap, possibly making it a conservative overestimation. At the same time, the estimate could be substantially higher in specific national contexts, thus impacting viability of some REDD+ program options. Nevertheless, since these estimates were largely based on a project basis, cost efficiencies may be possible to achieve with larger REDD+ programs. A brief discussion of how the structure (if size economies exist) and timing (being up-front or continuous) of these different costs could affect national REDD+ preparation and implementation appears in the conclusion chapter.

Why opportunity cost estimates are important

22. Estimating the opportunity cost of REDD+ is important for five basic reasons:

   One, opportunity costs are thought to be the largest portion of REDD+ costs (Boucher, 2008a; Pagiola and Bosquet, 2009; Olsen and Bishop, 2009). Boucher’s (2008a) review of 29 regional empirical estimates found average opportunity costs to be between 80 and 95% of the costs of avoiding deforestation in the countries with the most forest cover. This estimate will not necessarily be true in all cases. The relative magnitude of all REDD+ costs depends on national context and specific location. In some circumstances, the opportunity costs of some land uses especially in remote locations may be less than other REDD+ costs.

   Two, estimating opportunity costs provides insights into the drivers and causes of deforestation. Most economic agents do not cut down forests out of malice—they do so because they expect to benefit from do so. High opportunity costs tend to be linked with high deforestation pressures. Typically, such lands have been or are being converted to uses of higher economic value such as timber and agriculture (Pagiola and Bosquet, 2009). By helping to better understand drivers of deforestation, opportunity cost estimates can thus help develop appropriate responses. Here too, there is considerable variation; in some cases, forests are converted to very low-value uses (Chomitz et al., 2006).

   Three, opportunity costs can help understand the likely impacts of REDD+ programs across social groups within a country. Land uses are associated with different social groups. Knowing who would likely gain or would lose from REDD+ can help identify potentially moral/ethical consequences (if losses were borne by marginalized groups) and pragmatic repercussions (if losses were incurred by politically powerful groups able to prevent adoption of REDD+ policies or resist their implementation). With the insights gained from REDD+ opportunity cost

10 Transaction: $0.38/tCO₂; Antinori and Sathaye 2007, implementation: $0.58/tCO₂ (Nepstad, et al. 2007) and administration: $0.04/tCO₂ (Grieg-Gran 2006).
estimates, national REDD+ strategies can develop effective policies and mechanisms to reduce deforestation and avoid adverse social consequences (Pagiola and Bosquet, 2009).

Four, opportunity costs help to identify fair compensation for those who change their land use practices as part of REDD+. Since livelihoods are affected by land use changes arising from REDD+, opportunity costs are an estimate of the amount of income that alternative livelihoods would need to provide. For instance, in cases where natural protected areas are strengthened, the opportunity costs estimate the loss of income to nearby communities. Even if these communities are not directly compensated, the information is important for policy makers to understand the tradeoffs and risks of the REDD+ conservation policy.

Five, the information gathered to estimate opportunity costs is a basis for additional analysis of REDD+ costs. Along with other socio-economic information, field-level economic data can be used to understand farm, cattle and timber production within supply chains and impacts on the respective economic sectors. Analyses can be spatially differentiated to examine sub-national impacts, especially those of forest frontier regions. In addition, information gathered for opportunity cost analysis is a basis for conducting analysis of indirect costs. The calculation of opportunity costs also serves as a departure point for estimating indirect costs, whereby opportunity costs reflect a land use and economic context without REDD+.

**Risks and limitations of REDD+ and opportunity costs**

23. REDD+ activities have the potential to deliver significant social and environmental co-benefits. Nevertheless, many serious risks also exist. Restricting timber harvests or forest conversions to other (more profitable) land uses can affect the livelihoods of many. Therefore, analysis and policies should not only focus on opportunity costs – but also address other REDD+ costs that are important in developing nationally-appropriate REDD+ strategies.

24. Opportunity costs should never be applied uncritically. Many factors determine opportunity costs, both biophysical and socio-economic. For example, seemingly similar land uses may have very different opportunity costs due to different soil fertility or market access. The challenge of their proper estimation and use is a crucial discussion topic within this training manual. To foster a process of timely improvement (i.e. precision and
In opportunity cost estimates, three levels of data and analysis requirements (analogous to the UNFCCC Tiers 1,2,3) are suggested. (More on this in Chapter 2.)

A great risk also arises from indiscriminate interpretations of opportunity cost estimates taken out of the larger context of REDD+ costs. For example, although large-scale carbon savings may be realized at a low opportunity cost, such as from smallholder slash & burn farming, other REDD+ costs can be substantial. Other important costs to examine include:

- Transaction costs, especially in remote locations,
- Social costs, from likely rises in food prices, less local food production, changes to local livelihood activities and cultural habits, etc.
- Implementation costs, in particular for consulting with local populations regarding REDD+.

When all such costs are summed, different conclusions regarding the REDD+ costs could be reached. Thus, opportunity costs are one piece of the REDD+ cost puzzle.

Opportunity costs say little about the sustainability or destructiveness (e.g. negative downstream effects, biodiversity loss) or socio-cultural values of land uses. Any conclusions using opportunity costs should therefore only be drawn in the much broader socio-cultural and ecological context.

Opportunity cost analysis may not necessarily address underlying issues of governance where land and resource rights are not well defined or enforced. Since legal and customary rights may not coincide, determining the opportunity costs and who bears them may not even be possible. An opportunity cost estimation that only takes into account legal rights without recognizing customary rights and uses will fail to estimate the true cost impact of REDD+ on individuals and communities. Moreover, if REDD+ strategy or intervention is based on a misrepresented estimate, particular vulnerable groups could be disenfranchised.

In addition, opportunity cost estimates may have little relevance in determining appropriate strategies and interventions to reduce illegal forest activities. When laws are enforced as part of a national REDD+ strategy, actors in illegal practices will presumably bear an opportunity cost. How and if the opportunity costs are recognized, may be different according to type of actor. In cases such as illegal logging by foreigners, a country may decide it is not appropriate to compensate opportunity costs. Here, the more substantial cost of REDD+ would not be the opportunity cost, but the implementation cost of adequately enforcing the law. In other cases, such as customary but illegal activities

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11 Accuracy is how close the estimates are to the “true” value, whereas precision is how close the estimates are to each other.
undertaken by vulnerable groups, a country may decide to include address opportunity costs (either directly or indirectly). These distinct cases illustrate a need to discuss and identify which illegal activities to compensate and which to exclude.

29. As REDD+ moves forward, the participation of rural people in the identification and analysis of potential positive and negative impacts of REDD+ can inform safeguard policies that ensure forest users can maintain their traditional rights and uses of land resources. Advances in social and environmental safeguards include defining and building support for a higher level of social and environmental performance from REDD+ programs. An international review process is to ensure consistency across the country-specific interpretations (CCBA and CARE International, 2010). Proposed standards include principles, criteria and indicators that define the issues of concern and performance levels.

30. Efforts have been made to classify and prioritize REDD+ activities and assess critical constraints to sub-national project development. For example, well-defined land-use rights along with equitable and effective governance plays a key role in implementing REDD+ (illegal logging/conversion on public or private lands). To address these and other challenges review and reforms of legal, political, and institutional framework for carbon finance is typically required (see Richards, et al., 2010, The Forests Dialogue, 2010).

31. Furthermore, the opportunity cost approach presented here does not take into account feedback effects of REDD+. Although the approach includes an analysis of different future scenarios that can somewhat address economic changes, the estimated opportunity costs reflect a relatively static economic situation without REDD+. Policy decisions associated with REDD+ could substantially alter forestry and agriculture economic sectors, input and output prices, and patterns of land use. The authors consider our approach an essential step to understanding field-level opportunity costs, which can serve as a basis for additional analysis of indirect effects using multi-sector and multi-country economic models. This manual strives to illustrate a process that transparently generates opportunity cost estimates and avoids calculation and interpretation pitfalls.

An important question

32. Since opportunity costs can be the largest portion of REDD+ costs, associated compensation could increase incentives to better manage forest resources. Nevertheless, lost are the potentially larger profits from future agriculture, ranching and logging activities.12 So we need to ask:

Can REDD+ provide enough incentive to conserve or restore forests?

33. The quick reply: it depends on the international carbon price, on the nature of deforestation in the country, the incentives provided and on the different types of REDD+

12The term agriculture also includes ranching and tree-based or perennial cropping activities.
costs that a country will face in order to reduce emissions. Thus the answer to the question will be ‘yes’ for some forms of deforestation, and ‘no’ for others, and unclear in yet others. Because agro-ecological, economic, and social conditions can differ substantially from place to place within a country, the costs of REDD can likewise differ substantially. Furthermore, the cost and effectiveness of measures to reduce deforestation will vary.

34. The results of the analysis of REDD+ costs will thus consist of a range of costs applicable to different situations or areas. It is quite likely that every country will find that there are many areas in which REDD+ would not be justified by any realistic payment per ton of carbon emission reduction. Conversely, it is very likely that every country will find that it has many areas in which even quite modest payments for avoided emissions would render efforts to avoid deforestation attractive. The real issue is not whether REDD+ payments would be attractive at all, but how many emission reductions a country would find it attractive to provide at any given price per ton of carbon reduced. Understanding opportunity costs is a critical step (but not the only step) in answering this question.

35. Let’s first examine three typical land uses:

**High-value agriculture**
*Examples: soybean, oil palm or cattle on productive lands*

36. Income from a REDD+ program is likely to be less than the profits from high-value activities on productive lands. In other words, the opportunity cost of the high-value agriculture is greater than the compensation from a REDD+ program. Carbon prices would need to be very high in order for REDD+ to be attractive in these cases, unless there were also significant co-benefits to conserving forests, such as protecting the water supplies of downstream users.

**Mid-value agriculture**
*Examples: soybeans, oil palm or cattle on normal quality lands*

37. Income from a REDD+ program may be more than the profits of mid-value agriculture. Compensation from REDD+ would likely be slightly greater than the opportunity costs of such land use activities. Yet, transaction and implementation costs of a REDD+ program may erase net benefits.

**Low-value agriculture**
*Examples: shifting cultivation or cattle on marginal lands*

38. Most likely, income from a REDD+ program is more than the profits from agricultural activities on marginal lands. In this situation, it is more profitable for a landowner to accept compensation associated with REDD+ and maintain land as a forest (instead of converting it to agricultural use).
39. So far, we have only mentioned land use changes that involve deforestation. What about increasing carbon stocks on lands already where the forest cover has been partly or totally removed? Low-productivity lands exist throughout much of the world, such as some pastures, grasslands, shifting cultivation lands, old and exhausted perennial croplands, etc. Depending on the specific REDD+ policy negotiated and implemented, restored low carbon – low productivity lands may have a significant role to play in carbon funds and markets.

Low-value agriculture
Examples: shifting cultivation or cattle on low-productivity quality land

40. The investment costs to re-establish forests could likely be compensated by REDD+ programs. Earnings from the reforested areas will likely be greater than from low productivity agricultural or ranching uses.

What about the value of wood and timber?

41. The above examples only recognized the value of agricultural production after forest conversion. As we will show in this manual, the value from other sources can greatly affect opportunity cost estimates of land use change. These sources can include profits from timber, charcoal and firewood that are produced when clearing the forest or, alternatively, with forest management. When these profits exist, accurate REDD+ opportunity costs estimates should include these forest products as well.

An opportunity cost example

42. Since learning about opportunity costs is best illustrated with numbers, we present an example. Let’s compare a hectare of forest to a hectare of agricultural land. Figure 1.2 summarizes the carbon stock and profits of each land use. The forest has approximately 250 tons of carbon per ha (tC/ha), whereas agricultural use has about 5 tC/ha.13 The estimated profits from agriculture are $400/ha, expressed in Net Present Value (NPV). Forest profits are $50/ha. (An explanation of how to estimate NPV profits is in Chapter 6) Carbon value is represented by a typical C stock value for a land use expressed in tC/ha. (An explanation of how to estimate the C stock value per land use is in Chapter 5.)

43. While the forest stores more carbon, agriculture produces more profit, revealing a land use tradeoff between carbon and profits. Converting a forest into an agricultural land use increases profits by $350/ha but reduces carbon stock by 245 tC/ha.

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13 These figure are illustrative. Significant variation can arise within landscapes and across countries.
The opportunity cost of not changing forest to agriculture is equal to the $350/ha of profit difference ($400–$50=$350/ha) and 245 tC/ha not emitted (250–5=245tC/ha). Thus, the opportunity cost, per ton of carbon, is $1.43/tC ($350/245tC).

REDD+ compensation, however, is not based on carbon (tC), but rather on emissions of carbon dioxide equivalents (CO2e). A conversion factor of 3.67 is needed to change tC to tCO2e. (See Box 1.1 for further explanation.) So, the potential emissions of the land use change is 899tCO2e/ha (245tC/ha * 3.67 tCO2e/tC = 899tCO2e/ha).

With an estimate of the difference in profits ($350/ha) and the emissions avoided (899tCO2e/ha), an opportunity cost of emissions avoided can be estimated. $0.39/tCO2e is the opportunity cost of not converting a forest into agricultural land.

This per ton carbon equivalent estimate is one way of expressing opportunity costs. For landholders, the more relevant way to express opportunity costs is per hectare. In this example, the per unit land area estimated opportunity cost is $350/ha.

Although estimating opportunity costs is relatively simple in theory, in practice generating reliable estimates can be difficult. Many calculations are needed beforehand, each with possibilities of making errors. In addition, numerous assumptions about methods need to made, often requiring discussion, in order to generate precise and accurate estimates of both carbon and profits.

**Two opportunity costs:**
- per unit of carbon (tCO2e)
- per unit land area (ha)
Box 1.1. What is a carbon dioxide equivalent?

The major greenhouse gas associated with land use change is carbon dioxide (CO\(_2\)). Carbon is approximately 46% of the biomass (per kilogram of dryweight) stored in trees and 57% of soil organic matter. When one unit of tree carbon is burned or otherwise decomposes, the carbon combines with two units of oxygen to produce one unit of CO\(_2\). Given the atomic weights of carbon (12) and oxygen (16), one unit of C is equal to 3.67 units of CO\(_2\) ((12+(2\times16))/12)=3.67).

Deforestation and degradation affect the production of other greenhouse gases (GHGs) including nitrous oxide (N\(_2\)O) and methane (CH\(_4\)). They are more dangerous greenhouse gases. N\(_2\)O and CH\(_4\) have 231 and 23 times higher global warming potential than CO\(_2\). To standardize the effect of different emissions, international convention measures greenhouse gas loading in terms of CO\(_2\) equivalents, represented by CO\(_2\)e.


Examining carbon – profit tradeoffs

49. Let us extend the previous example to compare forests against three distinct land uses: agriculture, agroforests, and low-productivity pastures (Figure 1.3).

50. Comparing the land uses in this example, we can see that:

- Carbon stocks of agriculture, pasture and agroforestry are all lower than natural forest. Profit from agroforestry is highest, with agriculture about half as much. Profits from forest and pastures are both low.

Figure 1.3. Carbon and profits of four land use categories
• Low-productivity pastures have low carbon content (5tC/ha) and low profits ($40/ha). Therefore, unlike conversion to agriculture, conversion to such pastures would not present a carbon-profit tradeoff.

• In some cases, forest restoration would be attractive. For example, converting land currently used for low-productivity pastures to forest (i.e., reforest) would increase carbon storage by 240 tons/ha.

• Meanwhile, although agroforestry has lower carbon stocks than forests, carbon content of agroforestry is more substantial (80tC/ha) than agriculture. Of particular interest is the high NPV profit assumed here ($800/ha). Faced with such an example, the obvious question is: why would such a land use not be adopted spontaneously by landholders? Often, adoption of certain land uses may be hindered by a variety of obstacles, including high establishment costs, technical limitations, and lack of market infrastructure for perishable products. REDD+ compensation could help overcome these obstacles.

51. To illustrate different carbon-profit relationships exist in a landscape, Figure 1.4 plots eleven land uses according to their C stocks and NPV profits. Most of the land uses fall along a tradeoff arc (green line) ranging from high profitability with low carbon stocks to low profitability with high carbon stocks. The graph also identifies the landscape average (average C stock and average NPV). Details of these land uses are in Box 1.2.

52. A few points in the lower left corner (red circle) represent low level conditions of C stock and profit, such as low-productivity pastures. Converting these low carbon – low profit lands into more profitable land uses could be a feasible and attractive REDD+ policy priority.

![Figure 1.4. Tradeoffs and low-level conditions of NPV profit and carbon stocks](source: Authors.)
Box 1.2. An example of carbon, profitability and employment of land uses

People use land in many ways. Below is a table of eleven categories of land use with their respective estimates of carbon stock, profits and rural employment. These land uses are representative of many tropical countries and can be adjusted to match predominant land uses.

Land uses with trees tend to have higher carbon, but with lower profits and employment. Throughout this training manual, these eleven land use categories (s) and associated estimates will be used to illustrate positive and negative impacts of land use decisions. These representative land uses will also be used to demonstrate how REDD+ policies may affect countries, economic sectors and citizens.

<table>
<thead>
<tr>
<th>Land uses</th>
<th>C stock time-averaged (tC/ha)</th>
<th>CO₂ stock time-averaged (tCO₂e/ha)</th>
<th>Profitability (NPV, $/ha)</th>
<th>Rural employment (workdays/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural forest</td>
<td>250</td>
<td>918</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Logged forest</td>
<td>200</td>
<td>734</td>
<td>75</td>
<td>15</td>
</tr>
<tr>
<td>Heavily logged forest</td>
<td>120</td>
<td>440</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Agroforest 1</td>
<td>80</td>
<td>294</td>
<td>300</td>
<td>120</td>
</tr>
<tr>
<td>Agroforest 2</td>
<td>60</td>
<td>220</td>
<td>120</td>
<td>137</td>
</tr>
<tr>
<td>Cocoa</td>
<td>50</td>
<td>184</td>
<td>250</td>
<td>146</td>
</tr>
<tr>
<td>Oil palm plantations</td>
<td>41</td>
<td>150</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Improved pastures</td>
<td>5</td>
<td>18</td>
<td>180</td>
<td>7</td>
</tr>
<tr>
<td>Low-productivity pastures</td>
<td>2</td>
<td>7</td>
<td>116</td>
<td>5</td>
</tr>
<tr>
<td>Agriculture 8yr fallow</td>
<td>15</td>
<td>55</td>
<td>528</td>
<td>100</td>
</tr>
<tr>
<td>Agriculture 3yr fallow</td>
<td>5</td>
<td>18</td>
<td>741</td>
<td>500</td>
</tr>
</tbody>
</table>


Comparing opportunity costs

53. Figure 1.5 presents the opportunity costs of three types of land use change. The three changes in this example (forest to pasture, to agriculture, and to agroforestry) each have different opportunity costs. The opportunity costs of land use changes are positive for both forest to agriculture and forest to agroforestry. Agriculture and agroforestry produce higher NPV profits than forests. Since agriculture has lower NPV profits and lower carbon content than agroforestry, the costs of avoiding the emissions from changes to agriculture are less than those of agroforestry.

54. In the case of forest to low-productivity pastures, the opportunity costs of the land use change is not actually a cost. The opportunity cost is negative – or a gain. Landholders would realize an economic gain by not deforesting for producing cattle on low-productivity pastures. Profits would increase from $40 to $50/ha. Therefore, no carbon-profit tradeoff
exists. In terms of CO$_2$e, the opportunity cost is negative, that is -$0.01$/tCO$_2$e. This is an example of so-called low-hanging fruit – where REDD+ compensation is not needed, but may be available, to avoid such a land use change or restore a forest.

![Figure 1.5. Example opportunity costs of three land use changes](image)

Source: Authors.

55. Of the four land uses within the example, we have only examined three types of land use change: forest to pasture, agriculture and agroforestry. Nevertheless, nine other changes are possible within these four land uses, as shown in Figure 1.6. The diagonal of the table represents the non-changes in land use.

<table>
<thead>
<tr>
<th>Initial state</th>
<th>End state</th>
<th>Forest</th>
<th>Pasture</th>
<th>Agriculture</th>
<th>Agroforestry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Forest</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Pasture</td>
<td>1</td>
<td></td>
<td></td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 1.6. Example of possible land use changes](image)

56. A wide array of land uses can quickly end up requiring a large analysis. Therefore using a limited number of land uses and associated changes can be a cost-saving simplification. To better represent distinct biophysical and socio-economic conditions within a country, national analyses can add additional categories or subdivide particular categories. Compelling reasons for differentiation include different:
1. Agro-ecological, climate and/or topographic zones, for example:
   - wetland soils, peat, mangrove, volcanic mountainous soils with likelihood of high C losses, and/or
   - ‘poor soils’ of low production and low profitability and potential gain in C stocks.
2. Distance to roads and markets, affecting profitability (and possibly C stock),
3. Different REDD+ policy domains (e.g., forest definitions of tree cover, protected forest categories, production forest with logging concessions, forest conversions, planned deforestation).

57. As land uses are differentiated into more categories with different levels of carbon stock and profitability levels, the shape of an abatement cost curve will change from being stepped blocks to more of a smooth curve. Determining the level of specificity is an important discussion point for REDD+ analysis at a national level.

What is an abatement cost curve?

58. An abatement cost curve compares the quantity of potential emission reductions with their costs. The vertical axis represents the opportunity cost of the emissions reduction option (in monetary units per tCO$_2$e), and the horizontal axis depicts the corresponding quantity of reduction (often measured in million tCO$_2$e per year).

59. Besides representing potential REDD+ market transactions, an abatement cost curve helps to:
   - summarize the attractiveness and feasibility of REDD+ options in a given region or country,
   - compare opportunity costs of emission reduction options (e.g., the establishment of oil palm plantations versus shifting cultivation systems),
   - clarify potential gains from REDD+ carbon trading.

60. Opportunity costs can be estimated at different levels: sub-national, national, and global, depending upon the scale of a REDD+ program. Figure 1.7 is an example of a national abatement cost curve, for Indonesia. This example includes estimated abatement costs from both agricultural and industrial activities. Reduction options associated with REDD+ are highlighted with red boxes. Their relative contribution is measured by the width of the respective bars. For example, abatement of forest conversion to smallholder agriculture would reduce emissions by approximately 250 MtCO$_2$e per year. Avoiding timber extraction would reduce about 90 Mt CO$_2$e per year. Reforestation could reduce emissions by approximately 100 MtCO$_2$e per year (Dewan Nasional Perubahan Iklim and McKinsey & Co., 2009).
61. The differences in opportunity costs of emissions reduction options can be substantial. The vertical height of each bar represents the cost of each option. While reducing forest conversions to low productivity slash-and-burn agriculture is estimated to cost less than €2 per tCO₂e, the opportunity cost of reforestation is approximately €10 per tCO₂e and reduced forest conversion to intensive agricultural production can cost over €20 per tCO₂e. Such cost differences affect feasibility of REDD+ programs, both financially and politically.

Figure 1.7. A national abatement cost curve (Indonesia)

Source: Dewan Nasional Perubahan Iklim (National Council on Climate Change) and McKinsey & Co. 2009.

62. By representing the potential emission reduction and cost per type of land use change, an opportunity cost curve can help answer the question: what quantity of CO₂ emissions reduction may be possible at a compensation price of $X/tCO₂e? It can also help to answer the question: which emissions reduction options are attractive to the country at a compensation price of $X/tCO₂e?

63. Since land use, social and economic contexts are unique per country, opportunity costs can greatly differ. For example, prices and productivity of timber and agricultural activities depend upon numerous factors including market access, soil fertility and rainfall patterns. Other factors such as labor and machinery inputs are also included in the cost estimate. This manual provides a systematic approach to identifying and analyzing data required to estimate the opportunity costs of REDD+ market transactions.
It is important to note that the opportunity cost curve is not based on land use but rather the change in land use. Land use change is the difference between an initial state and an end state. The time period of analysis can be of any length, but should follow the Intergovernmental Panel on Climate Change (IPCC) reporting requirements (i.e., 5 years) and/or the time frame of a national strategic plan (perhaps more than 5 years).

**Box 1.3. Managing big numbers used with C accounting**

Since REDD+ at national or global scale address large quantities of carbon, the scientific notation commonly used can be unfamiliar and confusing. Even more confusing is that sometimes (particularly in the scientific literature) mass is expressed in terms of grams not tons (e.g., 1t = 1Mg). This table summarizes the notation.

**Useful scientific notation for weight measures**

<table>
<thead>
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A training manual for estimating REDD+ opportunity costs

65. To address these potential complications of REDD+ opportunity costs, the training manual contains detailed presentations of methods and assumptions. Below is a summary of the goal, objectives and likely users of the manual.

**Goal**

Forest countries generate economic information to help guide decisions on national REDD+ strategies.

**Objectives**

1. To provide methods and tools to estimate the opportunity cost of foregoing land use changes in forest landscapes,\(^\text{14}\)
2. To document case study examples that enable professionals working in organizations (governmental, university, non-governmental) to learn, adapt and use the analytical methods, interpret results and recommend national REDD-related policies.

**Likely users**

*National-level decision makers and planners* involved in REDD+ policy and planning who want to be able to interpret and apply the results of opportunity cost studies in REDD+ national plans and international negotiations,

*National practitioners and experts* involved in studies of opportunity costs of REDD+ who want to understand how their own expertise (e.g., agricultural and forestry economics, forest ecology, geography, remote sensing, spatial analysis) contributes to estimating opportunity costs and associated REDD+ policy decisions.

66. Within this manual, we provide guidance on how to gather and analyze the necessary information to address questions of economic viability and other decision criteria related to REDD+ at a national level. Such non-economic decision criteria include effects on biodiversity, water and livelihoods. The results from analyses will enable countries to:

- be informed of the potential costs linked to REDD+ commitments, and
- use opportunity cost information to support national development strategies.

**Who else may be interested in opportunity costs?**

67. The analytical methods and preparation plans within this manual can help to address a variety of questions arising from the concerns of people potentially affected by REDD:

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\(^{14}\) And also acknowledging and including the wide range of forests and other land use types found in those landscapes.
A government policymaker

68. Trees make money when cut for timber; under REDD+, they can also make money when they remain standing. With carbon payment schemes such as REDD, tree carbon becomes an internationally-traded commodity like lumber. Much of our national economy, however, depends on cutting trees. Timber companies create jobs and benefit nearby towns. If trees are not cut, such economic activities and growth would not happen.

- What would be the cost to our country and to our citizens of avoiding deforestation?
- How big would the cost be, and who would bear it?

An environmental conservation investor

69. We want to conserve lands and defend forests from being cleared. The value of carbon in these landscapes may be a good incentive to protect forests and watersheds and to restore degraded lands.

- What are the conservation costs, including opportunity costs, of different lands?
- How can environmental benefits from forests, such as biodiversity and water, affect decisions about REDD?

A logger, agri-business person, smallholder farmer, rancher

70. REDD+ programs will impact how I earn my living from the land. My livelihood depends on cutting trees clearing forest.

- How much should I be ask to be compensated?

71. The concept of REDD+ is based on the belief that forests can help mitigate climate change only if their protection is viable and attractive within national development strategies. Therefore, as countries advance REDD+ preparations, an analysis of future costs and benefits of these programs is needed to inform both national and international policy decisions. The next section outlines the different approaches used in opportunity cost analysis.

Current state-of-the-art in REDD+ opportunity cost analysis

72. Despite intense efforts to include REDD+ within climate change negotiations, relatively little is known about the opportunity costs of REDD. Existing studies can be divided into three distinct groups (Boucher, 2008b):

- Global models: a top-down approach, based on dynamic economic models.
- Regional-empirical models: a bottom-up approach, which relies on detailed empirical analysis of the tradeoffs between economic profits and carbon associated with land use change.
**Area-based models**: a per area approach, using a synthesis of sub-national and global analyses to generate global estimates.

73. The studies differ in the type of questions addressed. The top-down and per area approaches emphasize estimating amounts of global emission reductions at specific opportunity costs. In contrast, the bottom-up approach (presented in this training manual) is typically used for estimating the opportunity costs of specific land use changes. Within a REDD+ preparedness context, the bottom-up approach answers the question from the country perspective. All approaches employ a series of distinct methodological and data assumptions.

**Top-down approach (global models)**

74. Top-down approaches evaluate REDD+ economic potential from aggregate economic variables. Three research groups have produced the most frequently cited studies: Ohio State University, the International Institute for Applied Systems Analysis in Austria (IIASA), and the Lawrence-Berkeley National Laboratory.

75. Kindermann, et al. (2008) and Boucher (2008b) summarize the methods and assumptions of the top-down studies. The analytical models share a common approach, based on the opportunity costs of different land uses. The models differ, however, in many of their details, for example: the economic sectors included, how dynamics of the world economy (e.g., forest, agriculture and energy sectors) are simulated, spatial divisions of the globe and the interest rates applied. In addition, the models are based on different data sets, such as the distribution of carbon densities in world forests and rates of deforestation.

76. The Ohio State studies apply the Global Timber Model (GTM) – a dynamic model that calculates optimal area, tree age class, and management regime for 250 classes of forestlands worldwide (Sohngen, et al., 1999; Sohngen and Mendesohn, 2003). The GTM model assumes that forest lands are managed for timber production; it does not explicitly consider alternative land uses. GTM generally assumes lower opportunity costs than the other two models, partly because GTM assumes profits from agriculture and higher C stocks on forest land.

77. The IIASA studies apply the Dynamic Integrated Model of Forestry and Alternative Land Use (DIMA). The DIMA model focuses on the allocation of land between forestry, grazing and agriculture. The model predicts that deforestation will occur where land value in other uses is higher than in forest, and that afforestation will occur where land value in forestry is higher than in other land uses. The resolution of results from the DIMA model are based on 0.5° grid cells (~56x56 km at near the equator).

78. The Lawrence Berkeley laboratory studies use the Generalized Comprehensive Mitigation Assessment Model (GCOMAP). GCOMAP is a dynamic partial equilibrium model...
that analyzes afforestation in short- and long-term tree species and reductions in deforestation in ten regions of the world.

79. Limitations and uncertainties of global modeling efforts include:

- Use of average carbon stock estimates,
- Estimates of forest extent in each region based on imprecise data,
- Simplistic modeling of land use change (e.g., one type of forest to one type of agriculture),
- Only timber production considered to determine forest value,
- Lack of country-specific economic data.

Strengths of the global modeling efforts, include:

- explicit assumptions about future conditions shaping timber models (e.g., population pressure)
- explicit consideration of REDD+ policy effects on timber prices.

80. The three global models produce an array of results (Figure 1.8). Results generally reflect the higher productivity and value of agricultural activities in Asia and Latin America. With a scenario of reducing emissions from deforestation by 50% between 2005 and 2030, opportunity cost estimates range from a low of $1.7/tCO₂e in Latin America (GTM) to $38/tCO₂e in Asia (GCOMAP). The mean opportunity costs for Africa, the Americas and Asia were respectively US$2.22, US$2.37 and US$2.90/tCO₂e. Differences across the continents, however, were not statistically significant (Kindermann, 2008).

![Figure 1.8. Carbon price needed to reduce deforestation by 50% in 2030](image)

Source: Kindermann, 2008.
Bottom-up approach (regional-empirical models)

81. Bottom-up studies are based on sub-national, on-the-ground, empirical data. Both estimates of carbon density (ton/ha) and per-area opportunity cost ($/ha) are specific to particular regions or time periods. Thus, opportunity cost estimates depend on the availability and quality of local information.

82. Over twenty of these studies estimate a few land use changes, not complete supply curves (Boucher, 2008b). Much of the empirical base for the opportunity cost analysis in this manual was generated in the context of the Alternatives to Slash and Burn program (ASB). Swallow, et al. (2007) present sub-national opportunity cost curves for ASB sites in Indonesia, Peru and Cameroon. Such studies generate detailed cost curves based on detail field research thus requiring fewer assumptions than global models. Nevertheless, bottom-up approaches do not necessarily take into account global feedback relationships that would change prices (e.g., food and timber), and thus costs as a REDD+ system develops (Boucher, 2008b).

83. Börner and Wunder (2008) used a municipal-level methodology based on official Brazilian land-use statistics in a pilot analysis for two federal states. Including additional data sources (e.g., profit rates for land use categories, simulated future deforestation scenarios, etc.), the approach was extended to the entire Brazilian Amazon (Börner, et al., 2010).

Per area approach (area-based models)

84. The Grieg-Gran (2006) study within the Stern Review is an area-based synthesis of data and analysis from eight countries representing the majority of tropical forest (Brazil, Bolivia, Cameroon, Democratic Republic of the Congo, Ghana, Indonesia, Malaysia, and Papua New Guinea). The approach has a disadvantage of low resolution, thereby limiting its use at sub-national level. Furthermore, the opportunity cost estimates lack corresponding carbon density estimates, despite sub-national estimates opportunity cost information ($/ha) being used to estimate a global per-area cost of reducing deforestation. The midpoint (US$3.48/tCO2e) of the estimates was 36% higher than the mean of the local estimates of the bottom-up approach, due in part to no spatial variation of carbon density. The approach, however, permits data on per-area opportunity costs to be used for regions where no per-ton carbon costs exist (Boucher, 2008b).

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15 Borner and Wunder (2008) base their analyses largely on official government statistics, possible in Brazil because of their availability.
16 The effect of changing prices and costs can be addressed with sensitivity analysis (Module T).
18 To convert estimates based on area ($/ha) to emissions ($/Co2e), Boucher (2008b) used a conversion factor for mean carbon density: 3.94 billion tCO2 of emissions from 10.1 million hectares deforested, from Strassburg, et al. (2008).
Strassburg et al. (2008) conducted a similar study with data from 20 countries. The “field approach” used FAO data on forest area and past deforestation rates. Combined with global and regional biomass models and data, the analysis estimated carbon content per hectare for each country. Two different approaches were used to estimate profits from land uses. Recent field data from the top 8 developing countries by annual deforested area were used to estimate a general relationship between deforestation and opportunity costs that was then applied to the forest data of each of the 20 countries.

In the other approach, a recent GIS-referenced global map of potential economic returns from agriculture and pasture (Figure 1.9; Naidoo and Iwamura, 2007) was overlaid with GIS referenced global databases of spatial distribution of deforestation. Results show that at very low opportunity cost\(^1\) (~US$5.5/t), a mechanism could reduce 90% of global deforestation (Strassburg et al. 2008).

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**Figure 1.9. Agricultural returns per ha**


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**Three approaches compared**

Figure 1.10 summarizes the results of the three approaches. A review of sub-national opportunity cost analyses reveals a mean opportunity cost of US$2.51/tCO\(_2\)e, with 18 of the 29 estimates at less than US$2. Per area estimates conclude that in order to reduce global deforestation by 46 percent, opportunity costs range from US$2.76 to US$8.28/tCO\(_2\)e. Associated investments required to achieve such decreases range from US$5 to 15 billion per year. The global models produce much higher estimates of the costs of reduction than

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\(^1\) Since other costs of REDD+ were not considered, the original phrasing of CO\(_2\)e prices is more like an opportunity cost.
either the sub-national, empirical estimates or the area-based estimates of the Stern Review. Estimates from global models include the effects of local and global price changes arising from altered forest and agricultural activities (Boucher, 2008b).

Figure 1.10. Mean estimates of opportunity cost approaches (and high-low range)
Source: Boucher, 2008b.

88. In addition to the differences in opportunity cost per type of emission reduction, costs can increase significantly if all deforestation in a region is to be stopped. With the global models, smaller reductions in emissions are less costly. A 10% reduction over the same period would cost only US$ 1 to 8/tCO$_2$e. In Brazil, Nepstad et al. (2007) estimated that eliminating 94% of emissions from deforestation and forest degradation would cost $0.76 per tCO$_2$e. Costs to eliminate 100% would be nearly double ($1.49 per tCO$_2$e).

89. For the purposes of generating national-level analysis of REDD+ opportunity costs, the bottom-up approach is recommended. Opportunity cost estimates are not only based on local information but will also easily fit within analytic frameworks developed by the IPCC for land use change (IPCC, 2003) and national inventories of greenhouse gases (IPCC, 2006). Furthermore, individual countries considering participating in a REDD+ require information on what it would cost them to reduce emissions from deforestation, forest degradation, and reforestation. Estimates of global costs provide little assistance. Similarly, the average approximations of large-scale analyses do not reflect the potentially wide range in conditions found within a country (Pagiola and Bosquet, 2009).

90. The next chapter provides an overview of the training manual contents and the process of estimating REDD+ opportunity costs.
References and further reading


Blaser, J., C. Robledo. 2007. Initial analysis of the mitigation potential in the forestry sector. UNFCCC Secretariat, Bern, Switzerland


Dutschke, M., R. Wolf. 2007. Reducing Emissions from Deforestation in Developing Countries: The Way Forward. GTZ Climate Protection Programme, Eschborn, Germany.

http://www.rightsandresources.org/documents/files/doc_1555.pdf


Chapter 2. Overview and Preparations

Objectives

1. Summarize the content of the training manual,
2. Identify the people and skills required to estimate REDD+ opportunity costs
3. Assess one’s knowledge of REDD+ opportunity costs,
4. Provide different tactics for effective manual use,
5. Introduce a “how-to” process guide for conducting a national REDD+ opportunity cost analysis
6. Identify information needed beforehand in order to estimate opportunity costs

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References and further reading......................................................................................................... 2-13
1. If estimating REDD+ opportunity costs for all potential land use changes were simple, a training manual would not be needed. Here we explain the process needed to estimate REDD+ opportunity costs. This manual is designed for the many different types of people interested in REDD: analysts, academics, policymakers, agency administrators and staff, non-government organization personnel.

**Structure of the training manual**

2. This training manual shows how to conduct a national-level analysis of REDD+ opportunity costs. The approach used is based on detailed sub-national data. A strong foundation of empirical information helps to substantiate analysis results. Sampling and extrapolation procedures are also shown to generate cost-effective and accurate national-level estimates of REDD+ opportunity costs.

3. An initial step in estimating opportunity costs is understanding the REDD policy context (Chapter 3). Topics include an evolving UNFCCC eligibility policy, accounting stance (who pays what costs), reference emission levels and nationally appropriate mitigation actions (NAMAs).

4. Chapter 4, analysis begins with identifying and classifying land uses. Associated tasks include estimating changes in land use – both historical and likely future trajectories. This latter component also includes analysis of the drivers of deforestation, which helps guide analysis for scenarios of land use change and establishing reference emission levels.

5. Chapter 5 shows how to estimate carbon stocks. Chapter 6 illustrates how to estimate the profits of land uses. In addition to examining a range of land uses, these chapters also discuss how to conduct analysis over multiple year time horizons. With Chapter 4, these two chapters are the basic building blocks of opportunity cost analysis.

6. Chapter 7 brings together the information for estimating opportunity costs and creating an opportunity cost curve (Figure 2.1). The building blocks enable the analysis to advance in two ways, thereby generating the information for the vertical and horizontal axes of the curve. The vertical axis is based on an opportunity cost (oppcost) matrix, which summarizes the opportunity costs for all land use changes in $/tCO₂e. This is developed from the land use classifications along with associated carbon and profit information.

7. The horizontal axis also requires land use and carbon information, as represented by an emissions matrix. This matrix contains the quantities of emissions for all land use changes in terms of tCO₂e.
8. In addition, the manual includes presentations of how to identify the feasible level of analytical rigor (resolution) by increasing the precision and accuracy of opportunity cost estimates in a step-wise manner, similar to the IPCC Tiers (1,2,3).

9. In this overview, we introduce the more important components of the three analytical steps to estimating opportunity costs: (1) analyzing land use, (2) estimating carbon and profits, and (3) estimating opportunity costs and cost curve.

Analyzing land use

10. Land use systems are the framework for estimating opportunity costs of REDD+. Although identifying and categorizing lands may seem as a straightforward exercise, a number of challenges confront researchers and policymakers, including (1) a potentially wide array of land use systems, and (2) changing and complex land use systems, especially in forest frontiers.

11. A mix of national, IPCC and other criteria are used to determine categories. To enable systematic and rigorous analysis of REDD+ opportunity costs, land use systems need to be:

- Unambiguous (pertain to only one land use category),
- A basis from which to integrate multiple types of data,
  - Carbon-relevant (homogenous in C stock),

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**Figure 2.1. Analytical steps for developing an opportunity cost curve**

- **For the vertical axis:**
  - Ch4 Classify land uses
  - Forest
  - Ag
  - OppCost matrix ($/tCO_2e$)

- **For the horizontal axis:**
  - Ch4 Estimate land use change (matrix of histories or trajectories)
  - Emission matrix ($tCO_2e$)
  - Ch5 Carbon stocks ($tC/ha$)
  - Ch6 Profits ($$/ha$)
  - Ch7 Opportunity Costs
- Profit-relevant (homogeneous in profits),
- Policy-relevant (supports the mandates of different national agencies),
  - Valid for different versions of REDD++,
  - Consistent for reporting at multiple scales: global, national, local.

12. Easily observable bio-physical and socio-economic characteristics of rural areas (e.g., elevation, soil quality; population density, market accessibility, culturally homogeneous areas, etc.) serve as one of the determinants of land use system categories. Quantification of land use systems is achieved through a process of identifying land covers on maps (typically satellite images) and validating the actual land use systems, often by confirming on-site.

13. Estimating land use system change is essential for REDD+ opportunity cost analysis. Past changes are calculated by comparing land use systems from different years. Probable future land use trajectories can be determined by extrapolating past changes and/or by developing land use models. The quantity of each type of land use change affects the estimate of national emission levels.

14. Frequent discussions and critiques from a range of professional expertises and scientific disciplines (discussed below) make the analytic approach and results not only accurate, but also more understandable to a wider audience – including those who may be affected by REDD+ policy.

**Estimating carbon and profits**

15. The collected biophysical data and associated estimation methods are largely based on the general requirements set by the United Nations Framework Convention on Climate Change (UNFCCC). Especially for estimating carbon stocks, the training manual follows the available methods provided in the 2003 Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Uses (GL-AFOLU) on how to estimate emissions from deforestation and forest degradation.

16. In contrast, socioeconomic data do not have protocols for collection and analysis. Nevertheless, similar to biophysical analysis, rigorous data collection, data management and analytical methods facilitate the generation of accurate and robust socioeconomic information needed to estimate profits of land uses. One important challenge is taking account of how revenues and costs differ within a land use system.

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20 Levels of homogeneity to be determined according to impact on results. In some instances, 5-10% difference may not greatly affect opportunity cost estimates. The topic of precision and rigor is a matter of discussion whereby the costs of data collection and analysis are weighed against the benefits of better estimates.
**Estimating opportunity costs**

17. Accurate biophysical and socioeconomic results are not sufficient. Equally important is the **integration** of socioeconomic and biophysical information to develop estimates of opportunity costs.

18. Opportunity cost analysis of REDD+ generates a money-based ($/ha, $/tC or $/CO$_2$e) representation of the tradeoff between storing carbon and generating profits on lands. The graphical representation of this tradeoff, called an **opportunity cost curve**, is a key objective of the analysis.

19. Opportunity costs estimates are a basis for further analysis and discussion. Such topics include:
   - sensitivity analysis of opportunity cost estimates,
   - biodiversity and water co-benefits,
   - scenario analysis of
     - different future land use trajectories,
     - distributional impacts of REDD+ policies and compensation upon
       - different land users (e.g., smallholders, plantation owners), and
       - associated economic sectors (timber, agriculture, etc.)

**Additional analyses**

20. Other analyses related to opportunity cost estimation are important to conduct. These include analyses of sensitivity, co-benefits and scenarios.

**Sensitivity**

21. Critical review of a REDD+ opportunity cost analysis also includes an evaluation of the data, methods and assumptions used. One way to do so is via **sensitivity analysis**, whereby specific parameters are adjusted, such as technical coefficients (e.g., carbon stock, profit estimates). Discussion of sensitivity analysis and exercises are in Chapter 7.

**Co-benefits**

22. Forests generate other environmental or ecosystem services in addition to storing carbon. Such services, or **co-benefits**, include biodiversity and water. The value of these services can be significantly greater than the value of carbon alone, thereby having the potential of lowering the apparent opportunity costs of reducing emissions. Discussion of co-benefits and their implications on opportunity cost estimates are within Chapter 8.

**Scenarios**

23. **Scenario** analysis can reveal how assumptions regarding future conditions can potentially affect estimates of land use impacts, associated reference emission levels and tradeoffs. Related to sensitivity analysis, analysts and policymakers can contrast a range of potential policy actions to identify preferable conservation and development outcomes. A dramatic rise in food and energy prices, for example, may increase incentives to expand
agricultural production into forests. Thus, opportunity cost estimates would need to be recalculated. Analytical results from updated opportunity cost analysis will assist policy development and decision processes. Discussion and exercises are found in Chapter 9.

Conclusions and next steps

24. Reviews to and revisions of opportunity cost estimates should be conducted as new technical evidence becomes available (e.g., improved estimates of carbon stocks) or when significant shifts in market conditions occur. The opportunity cost models can be used for scenario analysis on an on-going basis. Discussion of analysis updates, communication of results and next steps is in Chapter 10.

Who should do the work?

25. Estimating the REDD+ opportunity costs requires a wide variety of expertise. Moreover, the scope of the work required at the national level is beyond what can be managed by one or two people. Therefore, a first step is getting the correct people and organizations involved. Only then can a country be assured that they can generate estimates, critique the methods used to reach the findings, and prepare the best national strategy for participating in REDD+ funds and marketplaces.

26. The chapters in this manual help countries identify the team of both analytic and policy-oriented people required to estimate REDD+ opportunity costs. The team needs expertise from different scientific disciplines and professional backgrounds to work together, such as forestry, economics, agriculture, geography, and policy.

27. Another question is how many representatives of different perspectives to include. Since many will be affected by REDD+, others may want to be aware and participate, such as ecologists, hydrologists, community activists, and private sector.

A national REDD+ analytic and policy team

28. National experts involved in REDD+ research and policy analysis should estimate opportunity costs. Since no one person, or even government agency, can do all of the above, a national REDD+ team needs the expertise of:

1. *geographers / spatial analysts* to map land uses and changes,
2. *foresters and carbon specialists* to measure carbon in land uses,
3. *agricultural and forest economists* to estimate profits of land uses,
4. *hydrologists and biodiversity specialists* to estimate possible co-benefits,
5. *sociologists* to help identify possible adverse social consequences, and
29. Participation from both inside and outside of government would be beneficial. Personnel within government agencies can discuss REDD+ concepts and help link directly with decisionmakers and policymakers (Box 2.1). Non-government organizations and university staff can help ensure continuity and resilience of analytic capacity, since personnel within government agencies can change frequently. Rural community-based organizations and the private sector may also wish to be involved.

Box 2.1. Opportunity cost analysis as a boundary object

An opportunity cost analysis is a boundary object that facilitates communication between science and policy. Many IPCC reports, for example, are boundary objects. Boundary objects must meet stringent demands. Their content must be credible and open to scrutiny, while the presentation is sensitive to the needs of policymakers at sub-national, national and international levels.

Working together helps communication and understanding. Crunching numbers, filling databases and generating numbers is not sufficient. Nor is quickly reading final reports and attending policy meetings. The process of estimating opportunity costs requires discussion amongst scientists and policymakers.

On the way to generating opportunity cost curve estimates, other intermediate boundary objects need to reconcile different levels of understanding: amongst academic distinct disciplines, professional expertise and the policy interests. Some of the most important boundary objects in opportunity cost analysis are the national typology of land use systems or map legend that serve as the skeleton of the analysis. We foresee a stepwise and iterative learning process to derive an appropriate land use typology.

The overall analysis approach can benefit from the Millennium Ecosystem Assessment and similar multidisciplinary efforts intended for wider audiences. Participation of policymakers in during the work in-the progressing work enables them to express concerns, need and make suggestions to be shared. This collaborative approach can make the final results more meaningful, useful and compelling.

Do I know enough already?

30. The topic of REDD+ opportunity costs can be confusing and difficult to understand. Some words and terms may be new. How many do you know?

- Ground-truth – minimum mapping unit – land use trajectory
- Discount rate – net present value – accounting stance
- Reference emission level – business as usual
- Carbon flux – allometric equation

31. If you feel comfortable with all these terms, you are a rare person. You earned a score of 10 of 10. For the rest of us, including us authors, understanding the complex and
sometimes subtle workings of REDD+ opportunity costs requires a time investment. The contents of this manual and practice exercises will help us reach a high level expertise.

**Ways to use this manual**

**Time commitment**

32. Achieving proficiency in REDD+ opportunity cost analysis requires different levels of investment, depending on the person involved. Given the quiz above, you probably have a better idea of what type of knowledge could be of use. In the list below, see which objective best matches yours, and identify the likely time investment required:

I need to:

- quickly read to confirm my knowledge (10 – 40 min);
- read to learn something important (1 hour – 1 day), enough to know:
  - who should participate in the training workshops,
  - who should be part of the national REDD+ analytic and policy team;
- thoroughly read to be familiar with a few of the subjects in order to question findings, and policy implications (1.5 – 5 days).
- read, participate in a workshop and practice with examples in order to be well-versed with all the subjects required to critically question findings, analytical methods, and policy implications (5 – 15 days).

**Likely topic priorities per expertise**

33. *National decisionmakers and policymakers* would benefit from an ability to interpret, critique and apply the results of opportunity cost studies. Such capacity is necessary to know what policies are needed to develop REDD+ national and sub-national plans. To achieve such capacity, the information contained the following chapters are considered important within the manual:

- Introduction
- Overview and preparations
- REDD+ policy context
- Opportunity cost analysis
- Tradeoffs and scenarios
- Conclusions and next steps
34. **Sub-groups of the national REDD+ analytic and policy team** would concentrate on chapters intended for specific analyses. The following chapters need inputs from the following types of experts:

- **Land use & land use change**: remote sensing experts, geographers and land use planners;
- **Carbon**: foresters, agronomists, carbon measurement specialists;
- **Profitability**: agronomists, foresters, economists, sociologists;
- **Water & Biodiversity Co-Benefits**: hydrologists, ecologists, sociologists, economists.

**Process of estimating opportunity costs**

**Improving accuracy and precision**

35. Although countries may not have all the data required to estimate a wide range of opportunity costs, information may be available on similar land use systems in other countries. A preliminary analysis can generate approximate opportunity cost estimates, mirroring the three tier system used by the IPCC for estimating carbon stocks.

36. A recurring challenge of estimating REDD+ opportunity costs is improving their accuracy and precision. Since the carbon price received is likely to be significantly higher for better (substantiated) estimates, a stepwise process with increasing levels of time and money investments is recommended, analogous to the IPCC Tier 1, 2, 3 approach (Box 2.2).

**Box 2.2. IPCC reporting tiers**

**Tier 1**: Basic estimation methods and existing data are used. Default values can be used when data is unavailable (e.g., from the IPCC emission factor database). Data are often spatially coarse (e.g., estimates of deforestation rates), and have large error range (e.g., ~70% for aboveground biomass).

**Tier 2**: Intermediate estimation methods use country-defined emission factors and activity data within the same approach as Tier 1. Estimates for specific regions and land use categories typically require higher-resolution activity data, which need to be collected.

**Tier 3**: Rigorous estimation methods, such as measurement systems and models, are used repeatedly over time and adjusted to reflect national characteristics. Areas of land use change are monitored. High-resolution activity data is collected with analysis disaggregated at the sub-national or district level. Parameterized models with plot data can be used to analyze all carbon pools. Models typically go through quality checks, audits and validations. Models may incorporate a climate dependency factors and can provide estimates of inter-annual variability.

*Source: Adapted from Havemann, 2009 and IPCC, 2003.*
37. To increase the level of analytical precision and accuracy, the REDD+ analytic and policy team can follow a requires an iterative process of data identification and collection. Tier 1 - type analysis generates initial estimates that provide an initial sense of the orders of magnitude regarding opportunity costs. With these results, targeted efforts can improve key aspects of the information required for analysis, which might use either Tier 2 or Tier 3 methods, or a mix, depending on time and resources available, country land use context and the potential benefits of improved estimates.

Opportunity costs analysis within a REDD+ readiness process

38. Results generated from an opportunity cost analysis help to support policymakers involved in REDD+ policy planning and implementation. While speedy availability of results is valuable for informing decisions, accurately estimating opportunity costs requires substantial data inputs and sophisticated analytical methods. If the needed data is not readily available, significant investments of time and cost must be made. In the meantime, Tier 1 or 2 type analyses can be advanced.

39. Countries are at different stages in the REDD+ preparation process. Figure 2.2 summarizes three phases for implementing a comprehensive REDD+ program and associated levels of opportunity cost analysis. The tiered approach allows policymakers to have important information in a timely manner in order to support discussion of potential REDD+ impacts within REDD+ readiness, consultation, consensus building and strategy development processes (REDD+ Phase 1). Improved opportunity cost results will also help with policy design and implementation within national development strategies (REDD+ Phase 2).

40. During these phases, some of the technical information (e.g., profitabilities, carbon stocks) may be general estimates applied to national conditions. As a country moves up the tiers, increasing amounts of national and sub-national technical information is required. Matured opportunity cost analysis enables countries to improve REDD+ policy effectiveness and efficiency (REDD+ Phase 3). Government ownership of the process and commitment from key actors in a country are important for successful REDD+ planning and implementation.
Table 2.1 provides a summary of tasks and associated expertise needed to accomplish them. Within the table, tasks appear in the rows and the required expertise are represented by the columns. Some tasks only require one type of expertise and can be advanced without much collaborative input from other members of the national REDD+ team. Given the nature of REDD+ opportunity cost analysis, however, many tasks require participation of different types of professionals.

Independent tasks have only one colored cell, whereas collaborative tasks requiring meetings have multiple colored cells. National workshops can be divided into sub-national workshops to focus on different contexts within a country.
Table 2.1. Process planner and checklist

<table>
<thead>
<tr>
<th>Topic</th>
<th>Task</th>
<th>Required expertise/skills</th>
<th>Process</th>
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<td>Geography/remote sensing</td>
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<td>Forestry</td>
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<td>Carbon measure</td>
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<td>Economics (Ag,For)</td>
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<td>Field (Ag,For)</td>
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<td>Hydrology</td>
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<tr>
<td>Team preparation</td>
<td>Participant identification</td>
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<td>Regional workshop</td>
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<td>Workshop training</td>
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<td>Invitation and TOR of presentation</td>
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<td></td>
<td>Identify deforestation drivers</td>
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<tr>
<td>Land use</td>
<td>Diagnose and review data and analysis</td>
<td></td>
<td>National workshop 1</td>
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<tr>
<td></td>
<td>Develop a national land use framework</td>
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<tr>
<td></td>
<td>Create land use maps</td>
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<td>Validate land uses and classifications</td>
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<td>Estimate land use change</td>
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<td></td>
<td>Identify land use trajectories</td>
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<td></td>
<td>Coordinate with national accounting system</td>
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<td>Meetings</td>
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<td>Diagnose and review data and analysis</td>
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<td></td>
<td>Establish sampling procedure</td>
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<td>Sub-team activity</td>
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<td>Measure C in different land uses</td>
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<td>Carbon</td>
<td>Diagnose and review data and analysis</td>
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<td>Meeting</td>
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<td></td>
<td>Clarify accounting stance and other assumptions</td>
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<td></td>
<td>Develop enterprise budgets</td>
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<td>Sub-team activity</td>
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<td></td>
<td>Estimate profits from land uses</td>
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<td></td>
<td>Estimate NPV of land use trajectories</td>
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<tr>
<td>Water &amp; BioD</td>
<td>Diagnose and review data and analysis</td>
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<td>Meeting</td>
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<td>Identify co-benefit areas</td>
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<td>Prioritize co-benefit areas</td>
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<td>National workshop 2</td>
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<tr>
<td>Analysis &amp; discussion</td>
<td>Estimate opportunity costs</td>
<td></td>
<td>National workshop 2</td>
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<tr>
<td></td>
<td>Map the REDD opportunity costs</td>
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<td></td>
<td>Analyze scenarios and sensitivity of results</td>
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<td></td>
<td>Discuss policy implications</td>
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<td></td>
<td>Develop national REDD strategy</td>
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<thead>
<tr>
<th>Task</th>
<th>Required expertise/skills</th>
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What information is needed upfront?

43. To estimate the opportunity costs of REDD+ at the national level, a country will need to know:

- the **area of all land uses** (e.g., agriculture, pastures, forest),
  - and likely future land uses (i.e. trajectories),
- the **profits** of all land uses in the country (e.g., agriculture, forests, pastures etc.),
- the **carbon stock** of each type of land use,
  
  (also helpful: information on **co-benefits of water & biodiversity**).

In other words, three sets of information are the building blocks. Fortunately, all this work does not need to start from zero. Many studies typically exist within a country that can be used, including National Biodiversity Strategy and Action Plans (NBSAP) and National Action Plans for Climate Change (NAPCC), national forest plans and other land use planning information. Information on the profitability of at least some land use systems is often available from Ministries of Agriculture and/or producer groups.

44. By using existing data, collecting new data, conducting analyses and reviewing results, the team will be able to estimate the opportunity costs of REDD+ (and other costs of REDD+, the training manual contains guidance on this too.)

Technical and analytic support

45. Support for the training material and workshops on REDD+ opportunity costs is part of the Forest Carbon Partnership Facility (FCPF) effort to test and evaluate different approaches to REDD+ in tropical and subtropical countries. Opportunity costs are within issues identified in Step 4 (Planning: Define the issues to consult on) of the FCPF technical guidance on how to prepare an effective consultation and participation plan (FCPF, 2009).

References and further reading

Africover. [http://www.africover.org/index.htm](http://www.africover.org/index.htm)


Chapter 3. RED(D++) policy context

Objectives

1. Provide a background on REDD+ eligibility policy
2. Introduce the concept of reference emission level (REL)
3. Discuss issues of accounting stance
4. Present the concept of nationally appropriate mitigation actions (NAMAs)
5. Introduce WB safeguards relevant to REDD+

Contents

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Nationally Appropriate Mitigation Actions (NAMA) ................................................................ 3-7
Safeguard policies of the World Bank ....................................................................................... 3-8
References and further reading .................................................................................................. 3-10
1. Terms and phrases that are commonly used when discussing REDD+ policy are in Box 3.1. For definitions, see Glossary in Appendix A.

<table>
<thead>
<tr>
<th>Box 3.1. REDD+ policy speak</th>
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<tbody>
<tr>
<td>Deforestation</td>
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<td>Degradation</td>
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<td>AFOLU/REALU</td>
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2. A chapter on REDD+ policy could span dozens of pages. Here we briefly present five REDD+ policy issues that are linked with opportunity cost analysis:

- **Eligibility policy** – what types of land use changes qualify within the terms of REDD+ endorsed by the UNFCCC,

- **Accounting stance** – the perspective from which costs and benefits are estimated, typically individual groups, government agency or national.

- **Reference emission level** – a future optimal emission level of a country, based on carbon prices and opportunity costs, thereby identifying the line between a good and bad REDD+ market transactions.

- **Nationally Appropriate Mitigation Actions (NAMAs)** – are a set of policies and actions that countries undertake as part of a commitment to reduce greenhouse gas emissions. Countries may take different actions on the basis of equity and in accordance with common, but differentiated, responsibilities and respective capabilities.

- **Safeguard policies** – provide guidelines for the World Bank and clients in the identification, preparation, and implementation of programs and projects. Safeguard policies have often provided a platform for the participation of stakeholders in project design, and have been an important instrument for building ownership among local populations.

3. An evolving REDD+ eligibility policy

REDD+ is maturing. REDD+ itself is an evolving concept whereby rules, regulations and other matters continue to be develop, debated, and improved. Since the Montreal Conference of Parties (COP) in 2005, the United Nations Framework Convention on Climate Change (UNFCCC) Parties have held extensive discussions regarding the scope of REDD.
The UNFCCC talks began with RED (i.e. limited to only deforestation\textsuperscript{21}) and expanded to REDD taking into consideration forest degradation (a less concentrated deforestation).

4. The discussion next broadened to also consider forest conservation, sustainable forest management, and enhancement of forest carbon stocks (REDD\textsuperscript{+}). In Bali December 2007, the parties to the UNFCCC confirmed their commitment to addressing global climate change, yet an agreement on REDD\textsuperscript{+} was not reached. Advances were made towards an agreement including reference to REDD,\textsuperscript{22} calling for:

\textit{Diverging opinions to continue debate whether a primary set of deforestation/degradation measures should be established, with a secondary set for other forest-based mitigation options (REDD\textsuperscript{+}).}

5. Agreement has not yet been reached on whether the Parties intend “enhancement of forest carbon stocks” to be forest restoration only on lands already classified as forests, or also include forestation of non-forest land.\textsuperscript{23} A long-term vision remains for comprehensive carbon accounting across the entire spectrum of Agriculture, Forest, and Other Land Uses (AFOLU), also known as Reducing Emission from All Land Uses (REALU) or REDD\textsuperscript{++}.\textsuperscript{24} The definition of forest also may have implications on REDD\textsuperscript{+} (see Box 3.2 for details on what is considered forest).

\begin{boxedtext}
\textbf{Box 3.2. What is a forest and does the name matter?}

The agreed forest definition of the UNFCCC within the Kyoto protocol has three significant parts:

1) Forest refers to any area of at least 500m\textsuperscript{2} (0.5ha) and a country-specific choice of a threshold canopy cover (10-30\%) and tree height (2-5 m),

2) The above thresholds are applied through ‘expert judgment’ of ‘potential to be reached \textit{in situ},’ not necessarily to the current vegetation status,

3) Temporarily unstocked areas (with no specified time limit) remain ‘forest’ as long as national forest entities claim that such areas will, can or should return to tree cover conditions.

Parts 2 and 3 were added to restrict the concept of re- and afforestation and allow ‘forest management’ practices including clear felling followed by replanting to take place within the forest domain. The above forest definition has a number of counter-intuitive consequences (van Noordwijk and Minang, 2009), such as:

- Conversion of forest to oil palm plantations may not be considered deforestation; such plantations can meet the definition of forest,

\end{boxedtext}

\textsuperscript{21} Changing carbon-rich forest land into another land use with lower carbon stocks.

\textsuperscript{22} UNFCCC Decision 1/CP.13, UNFCCC Decisions 2-4/CP.13, Decision 2/CP.13 dedicated to REDD.

\textsuperscript{23} The option will require policies and efforts to avoid double counting with eligible clean development mechanism (CDM) afforestation/reforestation projects.

\textsuperscript{24} The second \textsuperscript{+} can have different meanings, depending on a person or context. It used to imply afforestation/reforestation, social safeguards, and REALU (Frey, 2010; personal communication).
There is no deforestation in countries where land remains under the institutional control of forest agencies, and is considered only ‘temporarily unstocked’;

Swidden agriculture and shifting cultivation can be removed from the list of drivers of deforestation, as long as the fallow phase can be expected to reach minimum tree height and crown cover;

Most tree crop production and agroforestry systems do meet the minimum requirements of forest; whereas unpruned coffee, for example, can reach a height of 5 m;

The current transformation of natural forest, after rounds of logging, into fastwood plantations can occur fully within the ‘forest’ category;

A substantial part of the peatland emissions may not fall under forest-related emission prevention rules if the associated deforestation is claimed before a cut-off date yet to be specified.

Substantial tree-based land cover types fall outside of the current ‘institutional’ frame and jurisdiction of ‘forests’, and require broad-based implementation arrangements.

Although no single definition of forest can provide a ‘clean’ separation of forest and non-forest within the continuum of land uses, such a definition is likely not needed for the concept of REDD+ to advance. A draft version from the Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA) of the UNFCCC (2009a) text states:

*the following safeguards should be [promoted and supported] [ensured]:*

(…)

(e) *Actions that are consistent with the conservation of natural forests and biological diversity, ensuring that actions referred to in paragraph 3 below are not used for the conversion of natural forests [into plantations, as monoculture plantations are not forest], but are instead used to incentivize the protection and conservation of natural forests and their ecosystem services, and to enhance other social and environmental benefits;[1]*

In sum, the implications for the categorizing something as forest or non-forest may be unimportant if forest degradation is included. A forest definition will affect reporting procedures, not actions on the ground.

[1] *Taking into account the need for sustainable livelihoods of indigenous peoples and local communities and their interdependence on forests in most countries, reflected in the United Nations Declaration on the Rights of Indigenous Peoples and the International Mother Earth Day.*

6. Opportunity cost analysis of land use changes, both avoided (e.g., forest preserved) and achieved (e.g., forest restored), will enable countries understand the potential benefits of REDD+. Such benefits are not only economic, but also include water and biodiversity co-benefits that could be substantially affected by REDD+. In other words, REDD+ policies have the capability of altering national forests, agriculture, and livestock production along with affecting the national provision of environmental goods and services of water and
biodiversity resources. In sum, countries will want to know how altered eligibility rules affect achievable emission reductions from avoided and achieved land use changes.

**Who pays what costs: accounting stance**

7. Identifying who pays the costs, and receives benefits, of REDD+ is essential to understanding how the policy will function. For REDD+, three types of perspectives are important to recognize: individual groups or actors, national or country and government agency. The mixing of these perspectives can lead to estimation errors and potentially misinform policy decisions. The perspective from which impacts are estimated is termed an accounting stance.25

8. The perspective of individual groups is also known as a private or financial accounting stance, whereas, a national perspective can be termed social or economic (Table 3.1). For purposes of analyzing the impacts of REDD+, the terminology has been adjusted to avoid confusion. Here, social costs refer to societal costs. (The term social costs is more aligned with socio-cultural costs associated with non-economic livelihood impacts, such as psychological, spiritual and emotional – as mentioned in the Introduction).

<table>
<thead>
<tr>
<th>Country/National</th>
<th>Social</th>
<th>Economic</th>
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<tr>
<td>Individual groups</td>
<td>Private</td>
<td>Financial</td>
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**Table 3.1. Contrasting names for accounting stances**


9. Three important differences exist between the accounting stances. One refers to the costs and benefits to include. A national accounting stance includes all costs that are received within the country, net of any benefits that are received anywhere within the country, omitting any costs and benefits that accrue outside the country.26 In contrast, the perspectives of individual groups and of the government only include specific costs and benefits that these groups receive. (The distribution of REDD+ costs is discussed further below.)

10. The second difference refers to how costs and benefits are calculated. Under the national perspective, costs and benefits are valued at the social value of resources (their value in their next-best alternative use) rather than at their observed market prices. In some countries, these prices may differ either because of policy distortions (e.g., taxes, taxes, taxes).

25 This presentation is adapted from Pagiola and Bosquet, 2009.

26 Examples include the climate change mitigation benefits of carbon sequestration and biodiversity conservation, as such benefits are realized primarily outside the country.
subsidies, trade restrictions, etc.) or because of market imperfections (e.g., monopoly power, externalities,\textsuperscript{27} or public goods). In contrast, costs to individual groups are valued at the prices that these groups actually pay, including taxes. Years ago, the difference between social values and observed market values was quite significant. Governments would systematically distort the prices, especially of agricultural inputs and outputs. As a result of reform processes, such distortions are typically less, yet can persist to different degrees according to country.

11. The third difference refers to the discount rate used to assess future costs and benefits. A national perspective should use the social discount rate normally applied by the government. In contrast, the discount rate for individual groups should reflect market rates or their individual rate of time preference. These rates can be represented by a bank loan rate, if credit is available, or other (often higher) rates if no credit is available. The topic of discount rates is discussed further in Chapter 6.

12. From the country’s perspective, all REDD+ costs have to be taken into consideration, including opportunity costs (including, where relevant, social-cultural and indirect costs) as well as implementation and transaction costs (Table 3.2). Nevertheless, some of these costs are cancelled out since they are simply transfers within the country. The value of a government payment to forest owners, for example, is a cost to government, however, it is also a benefit to the landowner. The administrative cost remain a cost to the country.

13. Individual groups, in contrast, typically are only aware of a subset of REDD+ costs, primarily opportunity costs (again, including socio-cultural and indirect costs where relevant), although in some cases they may also face some of a REDD+ program’s implementation costs.\textsuperscript{28}

14. Government agencies will assume a number of budgetary costs. Such costs typically include administrative, transaction, and implementation costs. In considering implementation costs, it is important to bear in mind that a large portion may consist of transfers, depending on how efforts to reduce deforestation are implemented. Any portion of budgetary costs which compensate individual landholders for their opportunity and other costs would be a transfer, and as such this portion would \textit{not} be considered an economic cost to the country. (For more on this subject, see Pagiola and Bosquet, 2009, and Chapter 6 on \textit{Estimating the profits from land uses}.)

\textsuperscript{27} Externalities are the consequences of an action that affect someone other than the decisionmaker, and for which the decisionmaker is neither compensated nor penalized. In the context of forest management, impacts such as sedimentation, biodiversity loss, greenhouse gas emissions are externalities.

\textsuperscript{28} An illustrative example comes from a payment for environmental service program in Costa Rica. Individuals were responsible for the costs of preparing management plans, fencing and locating signposts, and monitoring by independent organizations (Pagiola, 2008; Pagiola and Bosquet 2009).
Table 3.2. REDD+ cost and benefit perspectives

<table>
<thead>
<tr>
<th>Cost category</th>
<th>Individual</th>
<th>Government agencies</th>
<th>Country</th>
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<tbody>
<tr>
<td>Opportunity</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Implementation</td>
<td>*</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transaction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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* denotes a cost that may be partially assumed by individuals.

**Reference emission levels**

15. How much emission reduction can be achieved at a specific carbon price? The answer to this question enables a country to establish a reference emission level (REL) – a basis from which a country commits to reduce emissions. The REL is an important component of REDD+ preparation because:

- If a country reduces deforestation too little, it will miss opportunities to increase its net REDD+ revenues.

  or

- It is possible for a country to reduce deforestation ‘too much’ – that is, to reduce deforestation at a cost that is higher than the compensation it receives through REDD+.

16. Figure 3.1 illustrates the above cases. The abatement level $A^*$ (on the horizontal axis) is the quantity at which the carbon price $P^*$ (on the vertical axis) is equal to REDD+ costs. At this level of abatement, the country receives a REDD+ payment the area of the rectangle $0P^*m_n$. To reach this level of abatement, it faces costs equal to the area under the abatement curve up to $A^*$. The difference between these costs and the REDD+ payment are a net benefit to the country (known as a ‘rent’ or a ‘producer surplus’). Should a country reduce fewer emissions by less than this level (for example, abatement level $A_1$), it would give up some of this potential rent (the area of the triangle $t_s m$). Conversely, if the country chooses an abatement level higher than $A^*$ (for example, $A_2$), it will face additional costs that are not compensated by the additional REDD+ income (area $n m w v$).
17. It is important to note, however, that agreements on payment mechanisms and associated rules have not yet been reached. Thus, such REDD+ rents may not be structured exactly as explained above. For more on reference emission levels see Angelsen (2008, 2009) and Meridian (2009).

Nationally Appropriate Mitigation Actions (NAMA)

18. The term *Nationally Appropriate Mitigation Actions* (NAMA) is based on the concept that different countries take different nationally appropriate actions on the basis of equity and in accordance with common but differentiated responsibilities and respective capabilities. The concept is also linked with financial and technical assistance from developed countries to developing countries to reduce emissions. REDD can be seen as a subset of NAMA.

19. NAMA became part of the international agenda through its inclusion in the Bali roadmap, at COP13, alongside REDD. The Bali Action Plan of COP13 was centered on four main building blocks: (1) Mitigation, (2) Adaptation, (3) Technology, and (4) Financing. NAMA formed an important part of the mitigation component. Future discussions on mitigation were to address:

- Measurable, reportable and verifiable nationally appropriate mitigation actions or commitments (NAMA) by all developed countries, and
- Nationally appropriate mitigation actions (NAMAs) by developing country Parties, supported and enabled by technology, financing and capacity-building, in a measurable, reportable and verifiable manner.

20. Initially, interest in NAMA articulation was less than that in REDD since no financial mechanisms existed for international support. Although the COP15 in Copenhagen did not result in binding agreements, countries were asked to express their national commitments,
in a context where international investment would be linked to such commitments (but without imposing a hard conditionality).

21. The Copenhagen Accord in December (UNFCCC, 2009b) retained the concept of NAMA: *Nationally appropriate mitigation actions seeking international support will be recorded in a registry along with relevant technology, finance and capacity building support. Those actions supported will be added to the list in appendix II. These supported nationally appropriate mitigation actions will be subject to international measurement, reporting and verification in accordance with guidelines adopted by the Conference of the Parties.*

22. In Indonesia, for example, the NAMA concept has become the major driver of the national climate change policy, with the REDD activities embedded within broader efforts to reduce emissions and other aspects of economic development. Indonesia has a NAMA commitment to reduce its emissions by 26% relative to a 2020 business as usual scenario. This is now the basis of the concept of an ‘own commitment’ NAMA to be linked with an ‘international co-investment’ NAMA.

23. A challenge remains in achieving Globally Appropriate Mitigation Actions (tentatively called GAMA) and Locally Appropriate Mitigation Actions (LAMA). Both are connected to NAMA as a concept for articulating “common but differentiated responsibility” within the UNFCCC principles.

**Safeguard policies of the World Bank**

24. A number of World Bank safeguard policies may affect REDD+ strategies and implementation. The following policies are some of the more relevant safeguard policies to REDD+.

25. The environmental and social safeguard policies are a cornerstone of the World Bank in its support to sustainable poverty reduction. The objective of the policies is to prevent and mitigate undue harm to people and their environment in the development process. The policies provide guidelines for bank and borrower staffs in the identification, preparation, and implementation of programs and projects. Safeguard policies have often provided a platform for the participation of stakeholders in project design, and have been an important instrument for building ownership among local populations.

**Involuntary resettlement**


[^30]: Operational Policy 4.12
The policy aims to avoid involuntary resettlement to the extent feasible, or to minimize and mitigate its adverse social and economic impacts.

27. The policy promotes participation of displaced people in resettlement planning and implementation, and its key economic objective is to assist displaced persons in their efforts to improve or at least restore their incomes and standards of living after displacement. The policy prescribes compensation and other resettlement measures to achieve its objectives and requires that borrowers prepare adequate resettlement planning instruments prior to Bank appraisal of proposed projects.

Indigenous peoples
28. The World Bank policy on indigenous peoples\textsuperscript{31} underscores the need for Bank staff and participating countries to identify indigenous peoples, consult with them, ensure that they participate in, and benefit from Bank-funded operations in a culturally appropriate way - and that adverse impacts on them are avoided, or where not feasible, minimized or mitigated.

Natural habitats
29. The policy on Natural Habitats\textsuperscript{32} seeks to ensure that World Bank-supported infrastructure and other development projects take into account the conservation of biodiversity, as well as the numerous environmental services and products which natural habitats provide to human society. The policy strictly limits the circumstances under which any Bank-supported project can damage natural habitats (land and water areas where most of the native plant and animal species are still present).

30. Specifically, the policy prohibits Bank support for projects which would lead to the significant loss or degradation of any Critical Natural Habitats, whose definition includes those natural habitats which are either:
   - legally protected,
   - officially proposed for protection, or
   - unprotected but of known high conservation value.

31. In other (non-critical) natural habitats, Bank supported projects can cause significant loss or degradation only when
   i. there are no feasible alternatives to achieve the project's substantial overall net benefits; and
   ii. acceptable mitigation measures, such as compensatory protected areas, are included within the project.

\textsuperscript{31} Operational Policy (OP)/Bank Procedure (BP) 4.10
\textsuperscript{32} Operational Policy 4.04
Projects in Disputed Areas

32. Projects in Disputed Areas may affect the relations between the Bank and its borrowers, and between the claimants to the disputed area. Therefore, the Bank will only finance projects in disputed areas when either there is no objection from the other claimant to the disputed area, or when the special circumstances of the case support Bank financing, notwithstanding the objection. The policy details those special circumstances.

33. In such cases, the project documents should include a statement emphasizing that by supporting the project, the Bank does not intend to make any judgment on the legal or other status of the territories concerned or to prejudice the final determination of the parties’ claims.

References and further reading


UNFCCC 2009a. Ad Hoc Working Group on Long-Term Cooperative Action under the Convention. Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in

33 Operational Policy (OP)/Bank Procedure (BP) 7.60
FCCC/AWGLCA/2009/L.7/Add.6, 15 December. 
http://unfccc.int/resource/docs/2009/awglca8/eng/l07a06.pdf 


van Noordwijk, M., P.A. Minang. 2009. “If we cannot define it, we cannot save it” ASB Policy Brief No. 15. ASB Partnership for the Tropical Forest Margins, Nairobi, Kenya. Available at: 
www.asb.cgiar.org 

http://en.wikipedia.org/wiki/Nationally_Appropriate_Mitigation_Action
Chapter 4. Land use & land use change

**Objectives**

Show how to:

1. Develop a national land use framework and legend,
2. Create land use maps,
3. Validate land use maps,
4. Estimate land use change,
5. Explain land use change.

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Introduction

1. This chapter describes how to classify land uses, estimate land use change, and explain land use change, thereby providing vital information for opportunity cost analysis. The approach is based on identifying different land use systems common within a country. These land use systems range from forests to agriculture, pasture, and urban areas.

2. The approach includes a series of steps to generate land use maps and assess land use change. In addition, the chapter explains how to acquire, organize, and classify remote sensing data and how to validate the accuracy of the derived maps. The approach described in this module is largely based on the GOFC-GOLD REDD Sourcebook, which should be consulted for in-depth guidelines on land use and land cover mapping (GOFC-GOLD, 2009). For detailed technical information related to developing land use maps, the chapter directs practitioners to additional sources. Deforestation monitoring and MRV activities should be consistent with other studies employing similar methods, independent of the scale and detection technologies used.

3. In sum, this chapter provides guidance to produce the following outputs for opportunity cost analysis:
   1. Land use framework and accompanying legend,
   2. Land use maps of different dates,
   3. An error analysis to assess the accuracy of the maps,
   4. Land use change matrices,
   5. Deforestation drivers and land use transitions

4. Land use analysis has its own vocabulary. For definitions, please refer to the Glossary in Appendix A.

**Box 4-1. Spatial analysis and remote sensing speak**

<table>
<thead>
<tr>
<th>Land cover</th>
<th>Spatial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>Ground truth</td>
</tr>
<tr>
<td>Land use system</td>
<td>Minimum mapping unit</td>
</tr>
<tr>
<td>Classification system</td>
<td>Mixed mapping unit</td>
</tr>
<tr>
<td>Land use legend</td>
<td>Vector GIS</td>
</tr>
<tr>
<td>Land use trajectory</td>
<td>Raster GIS</td>
</tr>
<tr>
<td>Attribute table</td>
<td>Resolution</td>
</tr>
<tr>
<td></td>
<td>Spectral</td>
</tr>
</tbody>
</table>
Identifying land uses

5. Although land cover and land use are related, they are not the same. Within a country, matching land covers (e.g. vegetation types) identified from satellite images with observed land use on-the-ground is one of the greatest challenges of land use mapping (Cihlar and Jansen, 2001).

6. Remote sensing experts and specialists with field knowledge of specific geographic areas (e.g. land managers, scientists, and government staff) are needed to identify and classify land uses. The opportunity cost analysis team should ensure that categories are compatible with monitored land cover classes and are consistent with carbon content and economic activities.

7. To enable correct and consistent use of land use information (e.g., carbon, profits) for opportunity cost analysis at a national level, a **hierarchical land use framework can be** employed (Figure 4.1).
Figure 4.1. A hierarchical land use framework in Cameroon humid forest zone.34


34 Caf: Cocoa Agroforest with different levels of shade trees coverage. Forest classes are defined on the basis of the level of disturbances/degradation. Classes may be associated to different types of management (Community Forest, Council Forest, Protected Areas) that provide for different intensities of logging.
A national land use framework for REDD+

8. An initial step in developing a national land use framework is to identify the current state of land use mapping in the country. Since many countries already have a national land use framework, a literature search and acquisition of existing maps is essential. If existing frameworks are unsuitable for the opportunity cost project, the project team will need to improve these frameworks in line with the requirements of the project. The discussion below serves as a guide to decide whether to use and adapt an existing framework or develop a new one.

9. The most important consideration for developing a workable national land use classification framework for an opportunity cost analysis is compatibility of resolutions between land use, economic and carbon information. A meaningful classification scheme must account for variation of carbon and profits across the landscape and country. Many factors cause variation, including:
   
   1. Agro-ecology climate and/or topographic zones,
   2. Soils, special consideration is needed for
      a) wetland, peat, mangrove, volcanic soils with potentially high C losses,
      b) 'poor soils' of low profitability yet potential gain in C stocks,
   3. Policy, institutional and management boundaries (agriculture and forest zones, tenure systems, etc.),
   4. Accessibility characteristics of transport infrastructure (e.g. paved road, dirt road, river, etc.),
   5. Preceding uses of land, which can affect soil fertility and carbon content.

10. How many land use classes? The selected number of class categories depends on:
    availability of geographic data and analysis, ability to detect differences in land cover on remote sensed imagery (image resolution), availability of carbon and profitability information of land uses, and the desired rigor of the opportunity cost analysis. Such a variety of factors points to a need for a multidisciplinary team with a clear understanding of opportunity cost analyses in the context of programs to reduce emissions from deforestation and degradation.

11. Splitting land uses into sub-classes is needed if a class does not accurately represent a land use in terms of carbon stock or net returns. Soil properties or uses may differ within the same land cover. Different levels of net returns within a class may arise on the basis of accessibility and location. Profitability for the same crop may vary, depending on whether it was produced near to or far from the market.

12. On the other hand, aggregating (lumping) classes together may be needed. One reason is technical. The minimum mapping unit (MMU) of imagery may not be small enough to differentiate classes, thus a mixed mapping unit is required. Simplifying the land use framework is another reason for lumping classes. A higher number of classes requires
increased data management and analysis. In addition, a false sense of precision may arise by creating numerous sub-classes from inadequate resolution of images and carbon or profit information.

13. Note that the level of detail in a land use framework needs not be the same throughout the country. A greater level of detail may be used in areas that are of particular interest, or to take advantage of better available data in some areas. Moreover, the level of detail need not be static. As additional information becomes available, land use categories might be split into sub-categories. Alternatively, previously separate categories might be joined together if the differences are found to be less than anticipated. In this as in many aspects of estimating the opportunity costs of REDD+, it is useful to think of the work as an iterative process rather than a one-time task. In sum, decisions about splitting or aggregating classes will be guided by the level of spatial detail in the mapping process and the availability of ancillary data about biophysical and socio-economic/infrastructural or management data.

14. Table 4.1 shows a land cover and land use classification with four levels of hierarchy. This mixed classification system was part of an international effort to map deforestation in the tropics (Puig, et al., 2000; Achard, et al., 2002). The first level contains broad classes of land cover such as forest, agriculture and mixed covers. The second level includes land cover types of greater detail. The third level is even more specific, including some land types that are specific to certain sub-national regions. The fourth level only refers to forest, using percent canopy cover as distinguishing criteria. In this example, these differences in canopy cover (land cover) could be used to detect levels of selective logging (land use). Once the framework has been defined, the project team can focus on the logistics of remote-sensing analysis and the making of land cover and land use maps. During later stages of the analysis process, the analysts may need to revise the legend further.

15. A land use legend is the map key that expresses each class as a distinct color or pattern on the map. In this manual, classes and sub-classes in a land cover legend are matched with land uses. Thus, at the end of the classification process, the hierarchical land use framework spans from general global land cover classes to local land use classes. The land use legend is the basis for identifying land covers and mapping land uses.

16. The land use legend must match a land cover legend that follows best practices for mapping, and meets additional criteria for compatibility with a REDD initiative (Cihlar and Jansen, 2001; GOFC-GOLD, 2005; Herold et al., 2006; IPCC, 2006; Herold and Johns, 2007). One of the best resources for developing the legend is the Land Cover Classification System35 (LCCS; Di Gregorio, 2005). The LCCS includes a thorough description of classification concepts and guidelines for matching land cover types to global standards.

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35 The LCCS manual and software can be acquired from the Global Land Cover Network website (http://www.glcn.org/).
Table 4.1. A legend from a hierarchical land cover classification system

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Forest</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Unknown</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
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<td>3</td>
</tr>
<tr>
<td>5</td>
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<td>4</td>
</tr>
<tr>
<td>6</td>
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</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Deciduous Forest</td>
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</tr>
<tr>
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<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
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<td>6</td>
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<td>4</td>
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<tr>
<td>7</td>
<td>Other</td>
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</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Inundated Forest</td>
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</tr>
<tr>
<td>4</td>
<td>Unknown</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
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</tr>
<tr>
<td>6</td>
<td>Unknown</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Peat swamp forest</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Other</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Forest Regrowth</td>
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</tr>
<tr>
<td>5</td>
<td>Mangrove</td>
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</tr>
<tr>
<td>6</td>
<td>Other</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
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<td>8</td>
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</tr>
<tr>
<td>2</td>
<td>Mosaic</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Shifting Cultivation</td>
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<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cropland &amp; Forest</td>
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</tr>
<tr>
<td>3</td>
<td>Other Vegetation &amp; Forest</td>
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</tr>
<tr>
<td>4</td>
<td>Other</td>
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<td>Non-forest Natural Vegetation</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
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<td>7</td>
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<tr>
<td>9</td>
<td>Other</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Grassland</td>
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<tr>
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<td>Unknown</td>
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</tr>
<tr>
<td>4</td>
<td>Unknown</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Regrowth of vegetation</td>
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</tr>
<tr>
<td>4</td>
<td>Other</td>
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</tr>
<tr>
<td>5</td>
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</tr>
<tr>
<td>4</td>
<td>Agriculture</td>
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</tr>
<tr>
<td>1</td>
<td>Arable</td>
<td>0</td>
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<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>Unknown</td>
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<tr>
<td>4</td>
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</tr>
<tr>
<td>5</td>
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</tr>
<tr>
<td>2</td>
<td>Plantations</td>
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<td>2</td>
<td>Other Vegetation</td>
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</tr>
<tr>
<td>3</td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Non-vegetated</td>
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</tr>
<tr>
<td>1</td>
<td>Urban</td>
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<tr>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>3</td>
<td>Roads</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Infrastructure</td>
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</tr>
<tr>
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<td>Other</td>
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</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Barren land</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Water</td>
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</tr>
<tr>
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<td>River</td>
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</tr>
<tr>
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<td>Lake</td>
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</tr>
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</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bare soil</td>
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<tr>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>Sea</td>
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</tr>
<tr>
<td>9</td>
<td>No data</td>
<td></td>
</tr>
</tbody>
</table>

Source: Puig et al., 2000
Steps to identify land uses

- **Consult the literature.** Cihlar and Jansen (2001) provide an overview on how to match land covers with land uses. Case studies from Lebanon and Kenya are practical examples (Jansen and Di Gregorio, 2003; Jansen and Di Gregorio, 2004).

- **Check map availability:** Reviewing previous land use change analysis is an important early task. Available land cover and land use maps may only need small modifications for use in an opportunity cost analysis. For example, existing land cover and land use maps may be suitable for developing a preliminary land use legend for lower rigor opportunity cost analyses (Tiers 1, 2).

- **Develop decision rules to convert land cover classes to land uses.** Rules will most often be based on local expert knowledge. For example, small patches of forest and cleared areas (land cover) shown in remote sensing data indicate shifting cultivation (land use). These decision rules should be put into a table for reference.

- **Collect land use information during fieldwork activities.** One assumption of the analysis is that all land cover classes can be matched to all land uses. The fieldwork should confirm and validate the rules matching land cover to land use.

- **Confirm land cover and land use data.** Monitoring, reporting and verification (MRV) activities are an opportunity to confirm the match between land cover and land use.

- **Consider image resolution when developing land use legend:** Different land uses may look the same on a satellite image (e.g. intensive or extensive agriculture or the degree of forest degradation). Mixed mapping units are used if the elements composing a mapping unit are too small to be delineated independently.

Box 4.2. Data management and analysis

Analysis of land use change requires careful management of data. The data management principles of an opportunity cost analysis are similar as those for REDD activities, such as monitoring, reporting and verification (MRV) of carbon stock data. Developing a system for data management and analysis described above requires a substantial investment. Costs will depend on the size of the country, existing expertise and resources and other factors. For example, to build a national-level MRV system – something outside the normal scope of an opportunity cost analysis – Herold and Johns (2007) estimated a cost between several hundred thousand and US$2 million. Given these high costs, a national team conducting opportunity cost analysis has incentives to collaborate with and build on existing work and expertise. If your country has an MRV system, most or all of the information needed for the analysis may be available.

Countries that lack MRV systems will need to identify experts who have the resources to be able carry out the land use change analysis and develop a robust information system for analyzing opportunity costs. If you were to build an information system for the land use change assessment of an opportunity cost analysis from scratch, five elements are needed: human resources, data and documentation, analytical methods, hardware and software.
1. **Human resources**: Expertise will be needed in remote sensing and geographic information systems (GIS) science and technology. Remote sensing experts should have prior experience producing land use and land cover maps. Experts should know how to pre-process data for subsequent classification and analysis, including knowledge of coordinate systems and data registration. Specialists should ideally have experience with visual interpretation of imagery, digital image processing, supervised and unsupervised classification and image segmentation. Experts should know how to conduct field work with global positioning systems and digital photography. Personnel typically have a Masters degree or equivalent experience in fields that use remote sensing and GIS methods.

2. **Data and documentation**: An inventory of data needed should be made to determine the feasibility of acquiring imagery, and whether additional expenditures will be needed. If a national MRV activity is not yet established or no remote sensing data or classified land cover information is available, the costs (time and money) of acquiring data and their analysis must be considered. Documenting data, methods and results of any opportunity cost analysis is a high priority. Context and description of data (or metadata) are needed, especially since the analysis requires the participation and contribution of many types of scientific expertise and participants may change over time. Documentation enables analysis to be repeatable and meet peer-review quality standards. The IPCC (2006) or other international standards can serve as guidelines. For remote sensing and spatial data, a national effort should produce metadata that meets the standards of the International Standards Organization (ISO) or the U.S. Federal Geographic Data Committee (FGDC). An opportunity cost analysis, or REDD effort should align itself with any national efforts to develop national spatial data infrastructure (NSDI). More information on geospatial metadata can be found through the Global Spatial Data Infrastructure (GSDI).

3. **Analytical methods**: The complexity and targeted level of analysis will determine the analytical methods employed. Any country can draw on an extensive GIS and remote sensing literature.

4. **Hardware**: Required capacity of the computer hardware will also depend on the rigor of the analysis. Personal computers with large hard drives and ample memory (i.e. RAM) are typically sufficient.

5. **Software** options for land use analysis may be freely-available open source or proprietary, including: Google Earth, GRASS (http://grass.itc.it/), SPRING (Camara, et al. 1996), ILWIS (http://www.ilwis.org/), low-cost IDRISI (Eastman, 2009), ArcGIS from Environmental Systems Research Institute (ESRI) and other software packages. The capacity of the software to identify appropriate characteristics must be considered. For example, do the image interpretation algorithms work well in tropical contexts?
Creating land use maps

17. This section is a general overview of available remote sensing (RS) techniques and associated challenges of developing land use maps for opportunity cost analysis. An extensive handling of the tools for estimating, accounting and reporting on land cover and carbon stocks is found in the IPCC Good Practice Guidelines and Guidance and the GOFC-GOLD REDD Sourcebook (IPCC, 2006; GOFC-GOLD, 2009).

Remote sensing data

18. Remotely sensed information comes from different sources, each with unique resolution, frequency (i.e., orbit cycle) and cost (Table 4.2). Two websites are useful for acquiring remote sensing data: the United States Geological Survey's GLOVIS site (http://glovis.usgs.gov/) and the Global Land Cover Facility at the University of Maryland (http://glcf.umbc.umd.edu/index.shtml). Remote sensing specialists are advised to consult the GOFC-GOLD Handbook (2009) for a complete discussion of the considerations related to selecting remote sensing imagery.
Table 4.2. Characteristics of satellite images

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Resolution (Spatial)</th>
<th>Orbit cycle</th>
<th>Image cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>TERRA</td>
<td>MODIS</td>
<td>250 m</td>
<td>2 days</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANDSAT 7</td>
<td>ETM+</td>
<td>15 m (185 km)</td>
<td>16 days</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 m (185 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMC II</td>
<td>XS</td>
<td>32 m (80x80 km)</td>
<td>1 day</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 m (60x60 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPOT 1-3</td>
<td>XS</td>
<td>20 m (60x60 km)</td>
<td>26 days</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>PAN</td>
<td>10 m (60x60 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPOT 4</td>
<td>XS</td>
<td>20 m (60x60 km)</td>
<td>26 days</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>PAN</td>
<td>10 m (60x60 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VGT</td>
<td>1 (2000 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPOT 5</td>
<td>HRS</td>
<td>10 m (60x60 km)</td>
<td>26 days</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>HRG</td>
<td>5 m (60x60 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TERRA</td>
<td>ASTER</td>
<td>15 m</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRS-C</td>
<td>Pan</td>
<td>5.8 m (70 km)</td>
<td>24 days</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>LISS-III</td>
<td>23 m (142 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IKONOS</td>
<td>PAN</td>
<td>1 m (min10 x 10 km)</td>
<td>3 days</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>4 m (min10 x 10 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QUICKBIRD</td>
<td></td>
<td>2.5 m (22x22 km)</td>
<td>3 days</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61 cm (22x22 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALOS</td>
<td>PRISM</td>
<td>2.5 m (70 km)</td>
<td>46 days</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>AVNIR2</td>
<td>10 m (70 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PALSAR</td>
<td>10 m (70km)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from GOFC-GOLD, 2010.

19. One satellite data option is high resolution imagery such as IKONOS and Quickbird. Such remote sensing data, however, becomes more expensive with smaller minimum mapping units (MMU) and require substantial computing power to be able to manage large quantities of small pixels. Moreover, geographic coverage of high resolution imagery is limited, especially in many areas of the tropics.
20. In contrast, low resolution imagery (large MMUs) are widely available at low cost. For example, MODIS images have 250m spatial resolution and can be freely downloaded from the Internet. The poor resolution, however, makes it difficult to distinguish land classes. This problem is compounded in the humid tropics where landscapes often contain small agricultural plots (Figure 4.2).

![Spatially heterogeneous farm landscape in Cameroon](image)

*Figure 4.2. A spatially heterogeneous farm landscape in Cameroon.*

*Source: Robiglio.*

21. Medium resolution imagery such as Landsat and Aster represent an attractive compromise of resolution and cost (Figure 4.3). An important advantage of Landsat is the availability of older images to establish a baseline for determining medium term deforestation rates. However, Landsat 7 has a sensor error that seriously limits image use since 2003. Therefore, the analyst should consider alternative sensors to overcome gaps in recent images.
22. The remote sensing data options described above are standard alternatives. Nevertheless, land use and carbon stock assessments may be able to take advantage of new methods and approaches to monitoring and measuring deforestation, forest degradation and land use change (see discussion on LIDAR in Box 4.3 below). As they become available and accepted, analysts can consider these new approaches.

Box 4.3. Estimating carbon stocks from biomass maps versus land use maps

Remote sensed imagery can be useful to estimate carbon in biomass and understand the geographic distribution of carbon across a landscape (Baccini, 2004; Foody, et al. 2003, Goetz et al. 2009). For example, Saatchi et al. (2007) estimated total carbon of 86 Pg C from their remote sensing assessment of aboveground live biomass in the Amazon. Biomass levels varied with the length of the dry season and across the landscape.

Biomass assessments have less relevance for calculating the opportunity cost of avoided deforestation. Opportunity cost calculations require information on land uses with associated C content (see Chapter 5) and profitability measures. Only from land use, can the net present values of economic activities be estimated.

Image analysis

23. Remote-sensing requires preprocessing of the satellite imagery. Such work often includes image geo-referencing and radiometric correction to account for atmospheric distortions. Nevertheless, many remote-sensing providers deliver satellite imagery that has...
already been pre-processed. Standard methods to conduct the preprocessing are available in the remote sensing literature (for example, see Jensen, 1995; Lillesand and Kiefer, 2000).

In general, three methods are available to interpret remote-sensing imagery: (1) visual interpretation, (2) pixel-based digital image processing, and (3) image segmentation. To date, there is no consensus in the REDD literature on the best method. Selection of the interpretation method may depend on national human resource capacities, on the relative costs of the different methods, and on the characteristics and size of the area.

1. **Visual interpretation.** Analysts draw polygons around visible differences in the satellite images on the computer screen (Puig et al., 2002). The polygons are associated with a class from the land cover legend. An advantage of this method is that recent imagery can be updated using the base map from an initial date. A disadvantage is that the method is more subjective than other methods, depending on analyst judgment. In addition, for large countries, visual interpretation may be impractical and time-consuming.

2. **Pixel-level digital image processing.** Computer algorithms are used to conduct unsupervised and supervised classifications. Most digital image processing in the past has been conducted at the pixel level (Jensen, 1995). Each pixel is considered a land unit and is clustered into groups of similar pixels. The clustering may be based only on the digital number of the pixel, a method referred to as unsupervised classification. With supervised classification, however, an analyst assigns pixels representing a land cover to a class in the legend. This second method depends on the analyst knowledge of the study area. Digital image processing is more objective compared to visual interpretation, as it depends on computer algorithms to assign pixels to land classes.

3. **Image segmentation.** Recent remote-sensing software includes image segmentation methods to classify land cover and land use (Camara, 1996; Eastman, 2009). An algorithm clusters groups of pixels together based on their spectral responses and a set of rules established by the analyst. An advantage of this approach is relatively low cost over large areas. Nevertheless, careful linking of land cover with land use ground truth information is needed to avoid large scale errors.

After an image interpretation method is selected, an analysis can be conducted and digital maps produced. The next step will be validation of the results. Analysts will need to review and improve image interpretation processes and results, depending on the outcome of the verification and validation analysis. In general for tropical land uses, a high level of expert judgment and ground knowledge are needed.
Box 4.4. The challenge of identifying forest degradation

Forest degradation is a reduction of canopy cover or stocking within the forest (Schoene, et al, 2007). Forests are degraded by human or natural causes. The magnitude/intensity of degradation monitored depends on the definition of forest. For example, if a country identifies forest with a minimum surface of 0.5 ha then a loss of forest smaller than 0.5 would be reported as degradation. Losses in areas higher than 0.5 ha would be considered deforestation. A similar logic can be applied to other forest definition thresholds for canopy cover and height. For a discussion of the importance of definitions, see Sasaki and Putz (2009), van Noordwijk and Minang (2009) and Guariguata et al. (2009).

Degradation can be difficult to identify on satellite images. In the land use legend presented earlier in this chapter (Table 4.1), forest degradation is accounted for by identifying the different levels of canopy cover. Ancillary spatial data may be used to identify areas where degradation may be occurring (e.g. in logging concessions). Data on forest density and tree coverage can be interpreted accordingly using expert judgment.

Identification of forest degradation is a hot topic in remote-sensing research. Asner (2009) developed a method to combine traditional satellite mapping approaches with an active airborne, laser technology approach called LIDAR (Light Detection and Ranging). LIDAR produces information on the height of trees and the structure of the forest, making it especially useful for determining whether a forest has been selectively logged over. More recently, LIDAR combined with MODIS imagery was used to map tree canopy height over the entire world (Lefsky, 2010). This new method and others promise to improve our capacity to identify forest degradation.

Checking accuracy

26. Are the land use estimates accurate? Validation of land cover and land use classification is a standard practice that opportunity cost analysis must include. Accuracy assessment and validation of land uses are important to assure the credibility of land use change estimates. This section discusses (1) sources of error and uncertainty, and (2) the validation process.

Sources of error and uncertainty

27. An analysis should identify the sources of error and their magnitude. With this information, the analysis team can revise the work in an effort to reduce these problems.

28. Using multiple images – across the study area or for different dates – requires a separate classification process for each individual scene. These differences in the images and in the processing may lead to inconsistencies in quality of the classification for the study area. For example, a challenge could arise related to the timing of imagery. Interpretations may reflect errors due to varying vegetation vigor if different nearby image scenes were captured at different times of the year. If one scene was captured in the dry season and another in the wet season, the classification may reflect seasonal differences in vegetation, and not the longer-term land cover and land use.
29. Another typical challenge to land use mapping in the tropics is cloud cover. The analyst will need to acquire additional images for areas covered by clouds. Otherwise, areas with cloud cover must be left out of the analysis. Future technological development for the use of Radar and LIDAR images could help overcome cloud problems.

30. Cloud cover is a persistent problem, in particular in the coastal countries of Central Africa. The improved accessibility to SPOT images (Mercier, 2010) and the establishment of an Earth Observation Receiving Station for the Central African region in Gabon (Fotsing et al. 2010) are expected to facilitate RS mapping and consistent monitoring of forest cover change in the area.

31. Acquiring imagery with appropriate spatial resolution is also a potential challenge. Difficulties arise when interpreting smallholder agriculture and degraded forests. A key task is to ensure that the resolution of the remote sensing imagery can capture land cover and related land uses that are relevant for the analysis. Expert use of the definition and composition of mixed mapping units for land use mosaics can help overcome problems of inappropriate spatial resolution.

Validation process

32. Validation methods can be found in textbooks and the remote sensing literature and should be consulted in depth (Jensen, 1995; Lillesand and Keifer, 2000; Congalton, 1991; Foody, 2001; Congalton and Green, 2009). This section briefly describes the general process to conduct a validation exercise for land cover and land use maps.

33. Validation requires information on the “true condition” of land use throughout the study area. Information can come from two sources: 1) ground truthing, or 2) reference data.

1. **Ground-truthing** is a remote sensing term for field verification. To acquire such information, a field survey is conducted to collect ground characteristics at sample points using a comprehensive sampling scheme. One way to develop sample points is by using random point generators within a GIS to assign locations to be verified. The points should cover as much as possible the variation in the RS imagery. Nevertheless, no well-established rule exists on how many data points are needed for the validation. One rule of thumb, however, is that 30 to 50 points are needed for each land cover / land use class.

The key technologies and tools needed for the field validation are spreadsheets, databases, global positioning systems (GPS), and digital cameras. An available field verification protocol document includes a sample survey form for recording information.36 The field team records the data in a standardized form. With ground truthing, the ability of survey team to access all parts of a study area may be limited.

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Many areas lack roads or present difficult terrain, making a representative sample of land uses and covers difficult to acquire. Therefore, sampling schemes need to be somewhat opportunistic, taking most points in places where access is low-cost and practical. (See Box 4.5 for other cost-savings approaches.)

2. Reference data are imagery or maps with a high degree of validity. The most common reference data are very high resolution imagery (VHRI), which may have spatial resolutions of 1 m, a level of detail that enables validation against land cover and land use classification. Common sources of VHRI include Quickbird and IKONOS. For some areas, virtual globes such as Google Earth and Microsoft Virtual Earth often include VHRI, displayed in their optical bands. Limitations to their use include an inability of the optical range to discern differences in some land uses, and a suitability of image date for comparisons.
**Box 4.5. Optimizing activities in the field**

Fieldwork in the study area can accomplish multiple purposes at the same time. For example, while researchers are taking plot level measurements of biomass, digital photographs and global positioning system (GPS) points can be collected with notes on the land conditions.

Before image interpretation, field work is needed to identify homogenous land units for classification. During field work, the analysis team can collect on-the-ground information that can be used for training and validation. To avoid any confusion, two different data sets have to be created – one with training points and the other with points for validation.

Ground-truth information should be managed in a data management system. For example, the figure below shows a Google Earth interface to photographs, GPS points and field notes stored in an online spreadsheet. The study area was visited in a *ground truthing* campaign in the central Peruvian Amazon. To match photographs with locations, timestamps of the digital photos were matched with timestamps of the GPS point.

![Example of a ground-truth point within a landscape](source: Swallow et al., 2007.)

After the “true” land cover or land use has been determined for sample points, comparison with the classified map can begin. The recorded validation data is digitized into a map with its accompanying attribute table. Then the validation sample map is overlaid on top of the land use map. This point-in-polygon overlay produces a table where one column shows the land use validation information from the field survey or the VHRI. Another column shows the land use from the classification. These two columns of data are then used to create an error matrix (Table 4.3). This example compares a classified map to VHRI in Google Earth.
The value in each cell is the number of validation points for each combination of land use designated according to the classified map and to the VHRI.

### Table 4.3. An error matrix.

<table>
<thead>
<tr>
<th>Land Cover Classes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>Google</th>
<th>Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>43</td>
<td>93.0</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>29</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33</td>
<td>93.9</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>28</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34</td>
<td>82.4</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26</td>
<td>92.3</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56</td>
<td>64.3</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>36</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
<td>31</td>
<td>83.9</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>41</td>
<td>73.2</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td></td>
<td>4</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>31</td>
<td>83.9</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>77.8</td>
</tr>
</tbody>
</table>

| Landsat | 42 | 35 | 31 | 37 | 26 | 50 | 41 | 37 | 25 | 324 |
| Producers | 95.2 | 88.6 | 93.5 | 75.7 | 92.3 | 72.0 | 73.2 | 70.3 | 84.0 |

LCC Notes: 1-Forest, 95% canopy; 2-Forest, 80% canopy; 3-Forest, 65% canopy; 4-Forest, 50% canopy; 5-oil palm; 6-shifting cultivation; 7-short rotation fallow; 8-large cattle ranches; 9- without vegetation.


35. The error matrix shows the overall number of correctly-classified points, as well as those that were misclassified. Using the results of the point-in-polygon overlay, the analyst fills the error matrix table. The vertical axis of the table represents the map classification based on Landsat images and the horizontal axis represents the VHRI imagery. The “Users” accuracy (far right column in the table) is the number of correctly assigned pixels divided by the total number of assigned pixels in that class, indicating errors of commission when pixels are committed to an incorrect class. The “Producers” accuracy (last row of the table) is the number of correct pixels for a class divided by the actual number of reference pixels for that class, indicating errors of omission when pixels are omitted from their correct class.

36. For example, the upper left-hand cell shows that 40 points were interpreted (from classified map) and verified (from a VHRI in Google earth) as 95% forest canopy. All 40 points were correctly classified, and therefore appear in diagonal set of numbers (shaded cells). Misclassified points are outside the diagonal set of numbers. For example, row 1 column 6 indicates that three points of the map were classified as 95% forest canopy, but according to VHRI were areas of shifting cultivation.

37. The advantage of the error matrix is that it allows the analysts to assess which land use and land cover change combinations have the highest errors. The results of the error matrix are used to review and improve the map. Analysts may conduct several sequences of map
improvement and subsequent error assessment, until an acceptable level of an error is attained.

38. Error analysis and validation can be a difficult task. The above description is intended to give an overview of the process of map validation. Documentation of the validation effort must be complete in order for independent experts to assess the quality of the maps.

**Estimating land use change**

39. This section describes how to calculate land use change. The procedure contains four basic steps.

1. **Prepare**: Ensure that the maps for each individual date use the same classification system and the images are consistent in terms of area covered, season and sensor (spatial and spectral resolution).

2. **Overlay**: Use GIS or image processing software to overlay land use maps from two different dates. The overlay process creates a new table – called an *attribute table* – where each polygon or pixel in the map contains the recorded land use on both the first and second dates.

3. **Simplify**: The attribute table should be reduced to the set of unique combinations of land use change. Each individual polygon contains the land use code for the dates in the land use change analysis. The different land use change combinations are listed for each polygon. In order to reduce the attribute table to unique combinations of land use change, each distinct land use transition must be identified with its areas summed.

4. **Create the land use change matrix**: Information within the attribute table of land use change is an input to develop a land cover change matrix. The area values are summarized for each combination of land use change.

40. More information on methods and procedures can often be found in textbooks on natural resources assessments or software manuals (e.g. Lowell and Jaton, 2000; Eastman, 2009). In addition, some image processing and GIS software programs include tools to conduct LU change analysis, such as the low-cost and popular IDRISI (Eastman, 2009).

41. Table 4.4 is an example of a country level land cover change matrix. The vertical column indicates the year of the initial land cover image (2003). The duration of the period of change extends to 2006, as shown on the horizontal row. The diagonal of the table indicates unchanged land area units between 2003 and 2006 (in blue font).

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37 Using a raster GIS, the system automatically reduces the attribute table to unique combinations. Vector systems will need some kind of *dissolve* operation.

38 This procedure is often called DISSOLVE in database and GIS software packages. In the Peru analysis, 60 unique combinations of land use change were identified.
Notice how these numbers are usually larger than most other numbers in the table. In most study areas, especially if the period of change is relatively short, the overall area of change is likely to be small. The figure in the first row and the second column indicates that 1.22 million ha changed from forest land in 2003 to cropland in 2006. Each cell in the land cover change matrix is read the same way. The total value at the end of the first row is the area in Forest in 2003 (93.60). The total value at the bottom of the first column is the total area in Forest in 2006 (98.46). Therefore the study area lost almost 5 million ha of forest between the two dates.

### Table 4.4. A hypothetical land use change matrix.

<table>
<thead>
<tr>
<th>Change from</th>
<th>Land cover 2003</th>
<th>Change to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FL</td>
<td>CL</td>
</tr>
<tr>
<td>FL</td>
<td>89.11</td>
<td>1.22</td>
</tr>
<tr>
<td>CL</td>
<td>0.87</td>
<td>45.28</td>
</tr>
<tr>
<td>GL</td>
<td>1.79</td>
<td>1.27</td>
</tr>
<tr>
<td>WL</td>
<td>1.22</td>
<td>0.65</td>
</tr>
<tr>
<td>SL</td>
<td>0.03</td>
<td>0.17</td>
</tr>
<tr>
<td>OL</td>
<td>0.20</td>
<td>0.28</td>
</tr>
<tr>
<td>ND</td>
<td>5.25</td>
<td>1.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>98.46</strong></td>
<td><strong>50.37</strong></td>
</tr>
</tbody>
</table>

*Land covers: FL= forest land, GL= grassland, WL= wetland, SL= settlement, O= other land, ND= no data.*

*Source: Authors*

The land use change matrix is a key input for the opportunity cost analysis spreadsheet. The matrix is copied directly into the spreadsheet where land use change information can be used with economic data to calculate opportunity costs.

The measurement of land use change, as described above, provides important data for opportunity cost analysis and for REDD+. In addition to providing data needed for the opportunity cost analysis, the land use change matrix can be used to assess the driving forces of deforestation and land use trajectories over time. The final section of this chapter below describes how to use land use change data in an effort to explain land use change.
Box 4.6. Land use maps for Jambi Province, Indonesia

Below is an example of land use maps derived from remote sensing in Indonesia (van Noordwijk et al., 2007). The study area has been zoned according to accessibility and the presence of peat soils, factors important in assessing the opportunity cost of avoided deforestation.

Land use maps for 1990 and 2005 in Jambi province, Indonesia

Source: van Noordwijk et al., 2007.
Explaining land use change

45. Land uses can change rapidly or slowly, sometimes for obvious reasons and sometimes because of hidden forces. Within a REDD+ context, understanding and explaining land use change is essential to both identifying appropriate emission level reductions and effective policies to maintain and increase carbon stocks.

46. Here we discuss two related topics, the drivers of deforestation and land use transitions. While inquiry into the drivers of deforestation emphasizes answering why deforestation initially occurs, the topic of land use transitions is a longer term analysis of land use change, essential to estimating the changing levels of carbon and profits from land.

Driving forces of deforestation

47. An ultimate goal of REDD+ is to provide incentives for lands to maintain and increase carbon stocks. Knowledge of the broader factors driving deforestation helps analysts understand the potentially complex causes of land use change and estimate both business-as-usual and reference emission levels, needed for REDD+ participation.

48. Causes of deforestation can be either observable or hidden (Meyer and Turner, 1992; Ojima, et al., 1994). A global meta-analysis of 152 sub-national case studies categorized deforestation across the tropics into three categories of observable causes: (1) agricultural expansion, (2) wood extraction, and (3) infrastructure extension (Geist and Lambin, 2001, Table 4.5). These causes are in turn influenced by underlying driving forces that are more difficult to assess. Such hidden driving forces typically act in conjunction with each other – at different temporal and spatial scales.
Table 4.5. A categorization of observable and hidden causes of deforestation

<table>
<thead>
<tr>
<th>Observable causes</th>
<th>Hidden causes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agricultural expansion</strong></td>
<td>Demand growth in urban centers</td>
</tr>
<tr>
<td>Staple food expansion (smallholder)</td>
<td>Increased accessibility to urban markets</td>
</tr>
<tr>
<td>Commercial agriculture (large-scale and smallholder)</td>
<td>Changes in consumer diets (e.g., meat)</td>
</tr>
<tr>
<td><strong>Wood extraction</strong></td>
<td>Poverty</td>
</tr>
<tr>
<td>Timber extraction</td>
<td>Price shocks</td>
</tr>
<tr>
<td>Private company logging</td>
<td>Missing or underperforming credit and input markets</td>
</tr>
<tr>
<td>Undeclared logging</td>
<td></td>
</tr>
<tr>
<td>Domestic uses rural &amp; urban</td>
<td></td>
</tr>
<tr>
<td>Industrial uses</td>
<td></td>
</tr>
<tr>
<td>Fuelwood/charcoal</td>
<td></td>
</tr>
<tr>
<td><strong>Infrastructure extension</strong></td>
<td>Export taxation, price interventions (e.g., subsidies)</td>
</tr>
<tr>
<td>Roads (public, logging)</td>
<td>Industrial policy</td>
</tr>
<tr>
<td>Hydropower</td>
<td></td>
</tr>
<tr>
<td>Private enterprise infrastructure</td>
<td>Agricultural research and extension</td>
</tr>
<tr>
<td>Mining</td>
<td></td>
</tr>
<tr>
<td>Human settlements</td>
<td></td>
</tr>
<tr>
<td><strong>Policy and institutional factors</strong></td>
<td>Land reforms</td>
</tr>
<tr>
<td>Formal policies</td>
<td></td>
</tr>
<tr>
<td>Open access to forest lands (Cote d’Ivoire, Ghana, Cameroon)</td>
<td></td>
</tr>
<tr>
<td><strong>Agricultural technology</strong></td>
<td></td>
</tr>
<tr>
<td>Labor saving innovations</td>
<td></td>
</tr>
<tr>
<td>Little or no generation of land saving innovations</td>
<td></td>
</tr>
<tr>
<td>Technological stagnation leading to extensification</td>
<td></td>
</tr>
<tr>
<td><strong>Demographic</strong></td>
<td></td>
</tr>
<tr>
<td>Population growth</td>
<td></td>
</tr>
<tr>
<td>Migration</td>
<td></td>
</tr>
<tr>
<td>Spatial population distribution</td>
<td></td>
</tr>
<tr>
<td><strong>Social triggers</strong></td>
<td></td>
</tr>
<tr>
<td>Health &amp; economic crisis conditions (e.g., epidemics, economic collapse)</td>
<td></td>
</tr>
<tr>
<td>Government policy failures (e.g., abrupt shifts in macro-policies)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Geist and Lambin, 2001.

49. In Peru, for example, the national REDD+ team first reviewed the global literature on the drivers of deforestation (Velarde, et al., 2010). Next, existing national deforestation studies were reviewed. Based on these resources, an analysis framework was created with the direct and indirect drivers of deforestation in the Peruvian Amazon (Figure 4.4). While this information is not directly needed for opportunity cost calculations, the analysis enabled the national team to develop future scenarios of land use and estimate reference emission levels (RELs). This information can help to prioritize specific land uses for opportunity cost analysis.
Figure 4.4. Direct and underlying causes of deforestation in the Peruvian Amazon.

Source: Adapted from Geist & Lambin (2002) and the Reducing Emissions from All Land Uses project (REALU; Velarde, et al., 2010).
Identifying land use trajectories

50. The term land use change can have different meanings, especially within a REDD+ context. Land use can imply a change from forest to agriculture, from one agricultural crop to another, or a series of land use changes. Therefore, clarification of what is meant by land use change is essential to REDD+ policy discussions and the estimation of opportunity costs.

51. Land use change is rarely a quick, one-time independent event, such as: natural forest to agricultural production. Especially in forest frontiers, lands typically undergo a series of inter-related changes over many years. An often-observed sequence begins when loggers enter a forest to selectively cut the highest value timber trees. Later, logging companies selectively cut other lower-value species. Next, pioneer settlers convert the remaining forest with slash-and-burn techniques into agricultural land parcels. After a few years of production, the parcel is left fallow for several years. Such swidden agricultural (crop-fallow) practices may continue, or the parcels may be converted to pastures for cattle or to intensive agriculture.

52. Analysis of land use histories within forest frontiers provides important indications of how land use would likely change without a REDD+ program. These future land use change scenarios are termed land use trajectories. Each of the land uses that comprise the changes have distinct carbon stocks and profit levels, and thus have an effect on REDD+ opportunity cost estimates.

53. The approach presented here integrates the whole sequence of changes, which takes into account land uses during and after forest conversion (e.g., from the initial forest to the end stage). This comprehensive approach of land use change enables countries to understand the current situation and estimate likely land uses in the future.

54. Identification of land use change is best achieved through collaborative discussions amongst local and external specialists. This dialogue can be advanced while identifying predominant land uses and the level of precision for the opportunity cost analysis (Tiers 1, 2, 3).

55. To guide a land use analysis of national level, five general types of land use change are identified. These changes are based on product (forest versus agricultural/ranching) and frequency of change within the analysis horizon: cyclical, direct or one-time and transitional. The five types are forest harvests, forest conversions, agricultural cycles, agricultural transitions and direct changes, and are depicted in Figure 4.5.
Some human activities within forests can generate profits with little or no effect upon trees. Harvesting activities, such as hunting and some non-timber forest product collection (NTFP), can occur consistently throughout a time horizon and not affect a forest’s carbon density levels. Other activities, such as logging or intensive fuelwood collection can significantly impact carbon. These activities change the forest from its natural state.

Even relatively invasive timber harvesting practices which have a great impacts upon a forest may not cause it to lose its land use categorization of forest. Recall that the broad
IPCC definition of forest enables somewhat substantial changes to occur (i.e. a reduction in tree coverage or degradation).

58. Each of these forest harvest activities generates different products and profit, with different carbon impacts upon forests. Therefore, carbon and profitability estimates from forest land uses should consider a potentially broad array of different forest management and harvest practices, some of which occur a few times in a given period (e.g., timber harvests) and others that occur more frequently, perhaps annually (e.g., NTFP collection).

Forest conversion

59. Conversion from forest to other uses is a well-known type of land use change. This one-time change, however, can produce distinct financial results depending on the context. Trees can be a financial burden or a benefit during the conversion process. If sold for timber or charcoal, trees can generate substantial profits. In contrast, if tree products cannot be sold, then the cost of their removal can reduce profits.

60. Forests are not all the same. Many forests, especially in established frontier areas, have been partially harvested, with high-value timber already having been logged. REDD+ opportunity cost analysis requires recognizing the often-spatially determined factors of tree use (and profits). This wide range of potential financial impacts can greatly affect estimates of REDD+ opportunity costs. More on this topic in Chapter 6.

The next three land use changes primarily refer to agricultural and ranching activities.

Cyclical change

61. Cyclical land use change is a repetitive series of land uses, often called a land use system. An example of a cyclical change is an agricultural crop and fallow rotation. This cycle of land use typically repeats itself throughout a time horizon. Although specific crops within the cycles may differ, general patterns can be discerned that can simplify a profitability analysis.

Transitional change

62. Land use transitions are changes that do not repeat over time. A common transition is slash-and-burn agriculture to perennial land uses, such as tree crop or cattle systems. The new enterprise activity typically replaces the fallow phase, rather than continuing a crop-fallow cycle. Substantial investments of capital and labor are often needed before the new land uses generate positive earnings.

Direct change

63. In some forest margin areas, lands are directly converted from forest to agricultural or tree production. Often led by large multinational firms, soy or oil palm plantations are examples of direct changes.
The following use changes refer to the “+” in REDD+.

Reforestation
64. Reforestation refers to the replanting of a cleared or partially cleared forest (i.e. degraded forest).

Afforestation
65. Growing new forests is termed afforestation. Such an activity typically where forests did not exist or were present many years ago.

References and further reading


Rubliogo, V. 2010. REDD-ALERT, WP1,WP2 internal report. IITA. Cameroon.


van Noordwijk, M., P.A. Minang. 2009. “If we cannot define it, we cannot save it” ASB Policy Brief No. 15. ASB Partnership for the Tropical Forest Margins, Nairobi, Kenya. Available at: www.asb.cgiar.org


Chapter 5. Carbon measurement of land uses

Objectives

1. Explain basic concepts of terrestrial carbon cycle and global carbon accounting systems,
2. Guide carbon analysis within a national accounting frameworks,
3. Introduce carbon measurement protocols and reference materials, using a bottom-up approach for C measurements from plot to land use, to landscape/sub-national level, and to national scale,
4. Identify data sources, gaps and measurement priorities,
5. Relate “typical C stock values” of land uses for use in an opportunity cost analysis.
6. Assess costs for capacity building based on available national capacities.

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Establish a carbon analysis framework.......................................................................5-7
Estimate “typical carbon stock” of a land use ............................................................5-9
References and further reading..................................................................................5-24
1. Numerous terms are used in the measurement of carbon. For definitions, please refer to the Glossary in Appendix A.

**Box 5.1. Forester and carbon specialist speak**

<table>
<thead>
<tr>
<th>Allometric equation</th>
<th>Diameter at Breast Height (DBH)</th>
<th>Biomass</th>
<th>Litterfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Humification</td>
<td>Landscape</td>
<td>Necromass</td>
</tr>
</tbody>
</table>

**Know your carbon**

2. How much carbon would be lost if a given hectare of forest were converted to another use? The answer to this question is a critical part of opportunity cost analysis. In this chapter, we first present basic concepts of terrestrial carbon (C) cycle and global carbon accounting systems. Next, we show how to estimate *typical carbon stock values* at sub-national and national levels. Key carbon measurement protocols and reference materials are presented along with how to identify data sources, gaps, and carbon measurement priorities. Cost estimates for applying these methods are provided.

3. This module presents a bottom-up approach and explains how to obtain carbon measurements from plot to land use, to landscape/sub-national level, and to national scale. The cost estimates shown vary depending on the existing in-country capacities for measuring, reporting and verification (MRV) of greenhouse emissions.

**Terrestrial carbon cycle**

4. Carbon dioxide (CO₂) is exchanged between terrestrial vegetation and the atmosphere. The net balance between sequestration and release changes according to the time period: (a) minute-to-minute (e.g., with cloud interception of sunlight), (b) day-night pattern, across a seasonal cycle of dominance of growth and decomposition, and (c) the lifecycle stages of a vegetation or land use system. Within this manual, we focus on the latter time scale, as part of annual (or 5-yearly) accounting of land use and land use change. At this time scale, many exchanges (fluxes) can be expected to cancel out, thereby enabling a focus on net carbon changes.

5. Carbon takes different paths. The annual net effect of photosynthesis and respiration (decomposition) is a relatively small increment in stored carbon in most years. Sometimes accumulated gains are lost in drought years where fire consumes organic matter. Some of the organic products (e.g., wood, resin, grain, tubers) leave the area of production and become part of trade flows, usually being concentrated in urban systems and their waste...
dumps. Only small amounts of stored carbon may leach out of soils and enter long-term storage pools in freshwater or ocean environments, or contribute to peat formation.

**Deforestation and carbon balance**

6. When forests are converted to other uses, a large net carbon release occurs into the atmosphere. The process can happen in a matter of hours, in case of fire; over a number of years, due to decomposition; or over decades, where wood products enter domestic/urban systems. The net emissions can be estimated by examining the decrease or increase in the ‘terrestrial carbon stocks’. Tropical forests in their natural condition contain more aboveground carbon per unit area than any other land cover type (Gibbs, et al., 2007).

7. Consistent accounting for all the inflows and outflows is more complex than a simple check of the bottom-line change in total carbon stock. Current estimates stating that ‘land use, land use change and forestry’ (LULUCF) is responsible for 15-20% of total greenhouse gas emissions is based on this type of stock accounting. Net sequestration is occurring in temperate zones and large net emissions in the tropics. Tropical peat areas are small source areas with high emission estimates (IPCC, 2006).

**Carbon is not just carbon**

8. Carbon is found in different pools. The terrestrial carbon stocks of all carbon stored in terrestrial ecosystems (Figure 5.1) are in:

   - Living plant biomass (above- and below-ground)
   - Dead plant biomass (above- and below-ground)
   - Soil (in soil organic matter and, in negligible quantities as animal and microorganism biomass)

9. In the IPCC guidelines these pools are described as *above-ground biomass, below-ground biomass, dead wood and litter, and soil carbon.*
**Figure 5.1. Terrestrial carbon pools**

*Source: Adapted from Locatelli (2007) and EPA (2009), by Honorio and Velarde (2009).*

**Living plant biomass carbon**

10. Above-ground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as understory plants and herbaceous growth. For agricultural lands, this includes trees (if any), crops and weeds. Below-ground biomass comprises roots, soil fauna, and the microbial community.

**Dead plant biomass carbon**

11. The dead organic matter (necromass) includes fallen trees and stumps, other coarse woody debris, the litter layer and charcoal (or partially charred organic matter) above the soil surface. Carbon stock of litterfall in a tropical rain forest is typically about 5 tC ha⁻¹ yr⁻¹, with a mean residence time in the litter layer of about 1 year. Dead trees may take about 10 years to decompose, and necromass is about 10% of total aboveground carbon stock in a healthy natural forest. Logging tends to focus on harvesting the more valuable trees, yet damaging many others. After logging, necromass may be 30-40% of the aboveground carbon stock. If fire is used in land clearing, the carbon in this necromass will be emitted directly, otherwise it may take a decade.

**Soil Carbon**

12. Soil carbon consists of organic carbon, inorganic carbon, and charcoal. Bicarbonate, an inorganic form of carbon, exists in calcareous soils, but is insignificant in neutral and acid
soils. The main form of soil carbon is in various stages of humification, with turnover times reaching up to 100’s (or even 1000’s) of years. In peat soils turnover times can reach 1000’s of years.

13. For mineral soils, the change in soil organic carbon is relatively small and mostly occurs in the top 30 cm of the soil layer (IPCC, 1997). Organic carbon concentration in soils generally decreases with depth, with a higher fraction of relatively stable pools accompanying the lower total carbon concentration. The strongest response of soil carbon stock to land cover change occurs in the top 20-30 cm. With empirical data, however, only changes in the layer 0-5 cm depth are often noticeable. The change in soil carbon contents due to land use change is rarely larger than 20 Mg carbon ha\(^{-1}\) (IPCC, 1997; Murty, et al., 2002), unless in wetland conditions.

14. Many factors affect soil carbon. Under specific climatic conditions (e.g., with an annual rainfall surplus but prolonged dry season in flat terrain with deep groundwater storage) trees with deep root systems are able to prolong the growing season. Therefore, the turnover of fine roots at depth adds soil carbon stocks at depths that can be significant and lead to soil carbon changes after conversion in excess of 20 Mg carbon ha\(^{-1}\). For example, when *Imperata* grassland is converted to oil palm plantation on mineral soil, an increase in soil carbon stock of as high as 13.2 ± 6.6 Mg ha\(^{-1}\) from the initial stock of 40.8 ± 20.4 Mg ha\(^{-1}\) can be expected (Agus et al., 2009).

**Box 5.2. Most of the biomass is in the few really big trees**

The carbon stock in an individual tree depends on the size. Trees of 10-20 cm stem diameter (measured at standardized 1.3 m above the ground and called ‘diameter at breast height’ or DBH), may have a biomass of around 135 kg/tree. The corresponding mass is 121.5 t/ha. Yet, most of the biomass is in the few really big trees. With a DBH of 70-80 cm, the mass per tree could be approximately 20,000kg (20 tons). With 10 trees/ha, the biomass would be about 200 t/ha. The below table summarize an example.

<table>
<thead>
<tr>
<th>DBH (cm)</th>
<th>Kg/tree</th>
<th>No. Trees / ha</th>
<th>Mass (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-19</td>
<td>135</td>
<td>900</td>
<td>121.5</td>
</tr>
<tr>
<td>20-29</td>
<td>2 250</td>
<td>70</td>
<td>157.5</td>
</tr>
<tr>
<td>30-49</td>
<td>8 500</td>
<td>20</td>
<td>170.0</td>
</tr>
<tr>
<td>50-70</td>
<td>20 000</td>
<td>10</td>
<td>200.0</td>
</tr>
</tbody>
</table>

The implications of large trees on biomass (and carbon) per ha is significant. Although selective logging may only remove a few big trees per ha (and damage surrounding ones), it can lead to a substantial decrease in total biomass and carbon stock.

**Example of tree biomass composition in a hectare of tropical forest**
Priority carbon pools

15. The decision on which carbon pools should be measured as part of national carbon accounting scheme are determined by several factors, such as:

- availability of financial resources,
- availability of good quality of existing data,
- ease and cost of measurement,
- the magnitude of potential changes in carbon pools.

16. Since REDD estimates at the national level could be incomplete and highly uncertain, a principle of conservativeness should be applied to increase credibility of the estimates (Grassi et al., 2008). Conservative analysis implies not overestimating, and/or minimizing the risk of overestimation and error propagation. For example, not including soil carbon in the accounting is a conservative approach. Although fewer REDD credits might be obtained as a result, including the estimates of soil carbon could decrease the credibility of the estimates of total emissions reductions. (For details of the application of this principle see Grassi et al., 2008.)

17. Given limited resources, fieldwork to estimate carbon stocks needs to be selective. The highest carbon pools with the greatest likelihood of conversion/emission should prioritized. (See Chapter 4 for more information on drivers of deforestation and degradation). For example, the most vulnerable areas tend to be those with higher opportunity costs, such as forests next to roads.

18. Table 5.1 summarizes the priorities in measuring different carbon pools along with the methods and relative cost involved. In general, we suggest giving the highest priority to tree biomass and soil carbon. The carbon stock of field crops tends to be low and can be inferred from the literature. For peatlands, the highest carbon pool is the peat itself and thus measurement of its carbon content is highly recommended.39

19. In IPCC terminology, the prioritization of carbon pools process is regarded as “key category analysis.” It takes into account which are the major sources and sinks of CO₂ and also at what level should they be reported, that is, Tier 1 or global scale data for non-key categories (or lower priority categories) and Tier 2 and 3 or finer scale/resolution for key categories. (IPCC, 2006, Vol 4, Chapter 1.3.3)

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39 Nevertheless, it is not clear whether or how peatlands will be included in REDD+.
Table 5.1. Priority and costs of measuring carbon by type of pool and method

<table>
<thead>
<tr>
<th>C pool</th>
<th>Method</th>
<th>Cost</th>
<th>Priority</th>
<th>Cost</th>
<th>Priority</th>
<th>Cost</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree biomass</td>
<td>DBH and allometric equations</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understorey biomass</td>
<td>Destructive samples</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop</td>
<td>Literature, secondary data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead biomass</td>
<td>Non destructive</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Litter</td>
<td>Destructive</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil C</td>
<td>Destructive: density and C content</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: The highest values (shaded green) indicate greater priority or higher cost. Example from Indonesia.

Establish a carbon analysis framework

20. Clear and simple approaches to carbon stock measurement contribute to transparency. Ensuring an understanding of how carbon stocks are estimated is essential to a national REDD+ program. The approach proposed here is consistent with the Good Practice Guideline (GPG) of the IPCC, to be used for national accounting of carbon stocks and greenhouse gas emissions. The GPG discusses the information needed to estimate the carbon stocks, and the emission and removal of greenhouse gases associated with Agriculture, Forestry and Other Land Use (AFOLU) activities, in terms of classification, area data, and sampling. Generally, all data should be:

- **Representative:** Capable of representing land-use systems/land cover categories, and conversions between land-use systems/land cover, as needed to estimate carbon stock changes and GHG emissions and removals;
- **Time consistent:** Capable of representing land-use systems/land cover categories consistently over time, without being unduly affected by artificial discontinuities in time-series data;
- **Complete:** All land within a country should be included, with increases in some areas balanced by decreases in others, recognizing the bio-physical stratification of land if needed (and as can be supported by data) for estimating and reporting emissions and removals of greenhouse gases; and
Two methods for carbon measurement

21. Changes in average carbon stocks per land cover can be monitored using various methods, including secondary datasets and estimations from the IPCC (2003). In addition, countries can conduct in situ forest inventories and sampling using permanent plots for land-use systems. To measure changes in carbon stocks resulting from degradation, the IPCC (2006) recommends two non-mutually exclusive options (Figure 5.2):

- the stock-difference method, and
- the gain-loss method.

22. The stock-difference method builds on carbon stock inventories from land uses to estimate sequestration or emissions. Carbon stocks in each carbon pool are estimated by measuring the standing stock of biomass at the beginning and at the end of the accounting period.

23. The gain-loss method is based on growth models with an ecological understanding of how forests and other land uses grow along with information on natural processes and human actions that lead to carbon losses. Biomass gains are estimated on the basis of typical growth rates in terms of mean annual increment minus biomass losses estimated from activities such as timber harvesting, logging damage, fuelwood, and other products collection, overgrazing as well as from fire (Murdyarso, et al., 2008). The cost of this method is usually lower because carbon pools are determined only once in the beginning and then modeled over time.

Figure 5.2. Comparison of stock-difference and gain-loss methods

Source: Modified from Murdyarso et al., 2008
24. The choice of measurement method will depend largely on the data availability, and on the resources and capacities to collect new data. If the purpose is national carbon accounting, a combination of both methods can be used. Consistency checks are needed, however, if methods are combined.

25. The measurement approach used in this training manual is the stock-difference method, because we need a single ‘typical carbon stock’ of a land use system (t C/ha), for comparison with a typical economic attribute (NPV) ($/ha) to calculate the ratio for any type of land use change.

Estimate “typical carbon stock” of a land use

26. For the purpose of a REDD+ opportunity cost analysis, a value of a typical carbon stock is needed for each land use (in IPCC, 2000, this was termed a time-averaged carbon stock). This single value is used for carbon accounting purposes and compared with a single-value economic indicator of net present value (NPV). A typical carbon stock value integrates the gains and losses over a life-cycle of a land use. Carbon data may already be available or may need to be collected. Below, we discuss (1) establishing a national carbon accounting system, (2) approaches for measuring carbon, and (3) diagnosing carbon data quality, sampling procedures and field measurements of carbon stocks.

27. Determining the typical carbon stock value starts by recognizing the life-cycle of the land use (see Figure 5.3). For land uses that are in an equilibrium situation with regard to their age (all ages are equally likely), the time-averaged value will also be the spatially-averaged value, when applied to a sufficiently large landscape. Such a typical must equal the sum of gains and losses that will be accounted for in the accounting system selected.

28. For systems that are increasing in area, the spatial average will be lower than the time-averaged value, and likewise the spatial average will be higher than the time-averaged value for systems that are in decline. Therefore, the carbon loss or sequestration potential of a land use system is not determined by the maximum carbon stock of the system at any one point of time, but rather by the average carbon stored in that land use system during its life-cycle time (ASB, 1996). Specific steps to calculate time average carbon stock for a monoculture and mixed systems are in Appendix 2.
Figure 5.3. Aboveground carbon stock and cash flows of three land uses

Box 5.3. ‘Time-averaged carbon stock’ in agroforestry systems

In agroforestry systems, where farmers incorporate various trees species on farms, the carbon stocks behave differently than in cropland or managed forests. For example, trees in agroforestry systems are harvested more frequently than under forest management. The time-averaged carbon stock takes into account the dynamics of land uses (Palm et al., 2005). The approach accounts for tree re-growth and harvesting, and allows the comparison of land uses that have different tree growth harvest rotation times and patterns.

Example carbon stock changes of different land uses

Source: IPCC/LULUCF-section 4, 2000

The annual time courses of the carbon stocks are solid lines; time-averaged carbon stocks are dotted lines: 230 tC/ha for forest, 80 tC/ha for agroforestry, and 29 tC/ha for imperata grasslands. For (climax) natural forests, carbon measurement samples are used to estimate the time-averaged carbon stock.
Diagnosing existing carbon data

29. When compiling or reviewing estimates for the typical carbon stocks of land uses, a variety of data may already be available. Such information is associated with IPCC Tiers:

- **Tier 1**: Global scale data (remote sensing imagery).
- **Tier 2**: National scale data
  - forest inventory data, often focused on timber volumes of commercially-attractive timber species, yet potentially including all trees,
  - primary data that can be converted to total biomass estimates,
- **Tier 3**: Plot/watershed data
  - bio-economic models of biomass production under different management regimes, calibrated on plot-level biomass data (usually available for main crops and some plantation crops),
  - ecological data on long-term plots that include all biomass and necromass pools.

30. As mentioned earlier, the prioritization of carbon pools or “key category analysis” takes into account the major sources and sinks of CO₂ and associated reporting level. Non-key categories, or lower priority categories, can be reported with Tier 1 data whereas key categories should use Tier 2 and 3 or finer scale/resolution data (IPCC, 2006, Vol 4, Chapter 1.3.3). Existing carbon data within a country may be of varying types and quality. Therefore, a diagnosis of available national carbon data is needed to identify gaps and areas of weakness, where new data collection is warranted.

31. Since virtually all types of remote sensing depend on ground-based carbon stock measurements, efforts to spatially extrapolate and analyze temporal changes require carbon data sampled using transparent protocols. With any such data their usefulness and value depend on:

- adequate description of the method used in selecting the plots,
- completeness of records that allow the plot to be interpreted as part of a land use system with known intensity and time frame,
- representativeness of the collection of plots for the domain to be represented (e.g., across climatic, soil, and accessibility variations),
- adequate description of the method used in measurement, including the sample size or sampling intensity used in ‘plot-less’ sampling,
- viability of the primary data and opportunity for further calculations.

32. Questions about any of these issues can make data suspect for use for the current task, and may at the least warrant a sampling program to fill gaps and check uncertain parts of the data set.
Measuring carbon of different land uses

33. A basic premise of the IPCC Good Practice Guidelines (GPG) is that land can be allocated to one (and only one) of six categories described below. A land use may be considered a top-level category for representing all similar land-uses, with sub-categories describing special circumstances significant to carbon content, and where data are available.40

34. This IPCC GPG assumption of non-ambiguous land categories may agree with existing institutional traditions in some countries, but the premise does create challenges. Where does a rubber agroforest on peatland belong? Such a land use (1) meets the minimum tree height and crown cover of forest, but is (2) on a wetland, and (3) its production is recorded within agricultural statistics. Therefore, consistency of accounting methods across land categories requires a good understanding of such relations. The IPCC land categories are:

(i) Forestland
35. This category includes all land with woody vegetation consistent with the thresholds used to define Forestland in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below those thresholds, but in situ could potentially reach the threshold values used by a country to define the Forestland category.

(ii) Cropland
36. This category includes agricultural land, including rice fields, and agro-forestry systems where the vegetation structure (current or potentially) falls below the thresholds used for the Forestland category.

(iii) Grassland
37. This category includes rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forestland category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvopastoral systems, consistent with national definitions.

(iv) Wetlands
38. This category includes areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forestland, Cropland, Grassland, or Settlements categories. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

40 For REDD+ opportunity cost analysis, sub-categories are also needed for land use systems generating different levels of profit.
(v) Settlements
39. This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with national definitions.

(vi) Other land
40. This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available. If data are available, countries are encouraged to classify unmanaged lands by the above land-use categories (e.g., into Unmanaged Forest Land, Unmanaged Grassland, and Unmanaged Wetlands). This will improve transparency and enhance the ability to track land-use conversions from specific types of unmanaged lands into the categories above.

Box 5.4. Off-site carbon storage
Part of the biomass of forests, tree crop plantations, or annual cropping is removed from the field and enters within economic trade flows. Although efforts have been made to assign the carbon stocks of such products to the areas where they originated (especially in the case of wood), the integrity and transparency of the global carbon accounting system would be at risk if such calculations were to be made. Current IPCC (2006) guidelines do not include off-site products as part of the system, although stock changes in the forest can be estimated from the difference between biomass increment and offtake (e.g., removals, harvests), if there are reliable data for both. Carbon stock accounting benefits from the simplicity that at any point in time all stocks can be inspected on site.

C stock sampling and measurement
41. Once the carbon pools to be measured are prioritized and the measurement method is defined, sampling will follow a series of guidelines with respect to the:

- sampling scheme, including stratification (See Chapter 4 of this manual, Dewi and Ekadinata, 2008, and Winrock, 2008),
- hierarchical system for land use classification (see Chapter 4).

42. Guidelines for obtaining the number of samples units needed can be found in Box 5.5. It is important to note that increasing the desired level of accuracy and precision will have cost implications.
Box 5.5. Steps to determine the number of sampling plots

**Step 1. Select the desired level of accuracy and precision**
The selection of precision and accuracy level is almost always related to the resources available and the demands of the buyer (the market). The level of precision required will have a direct effect on inventory costs. Usually, the level of precision for forest projects (sampling error) is +/-10% of the average carbon value with a level of confidence of 95%. Small-scale Clean Development Mechanism (CDM) forestry projects can use a precision level up +/- 20% (Emmer, 2007). Nevertheless, specific levels of precision can be defined for each type of land use system of the inventory. The highest precision generates higher costs.

The following figure illustrates the relationship between the number of plots and the level (degree) of precision (+/- % of total carbon stock in living and dead biomass) with 95% confidence for four types of combined carbon pools (above- and below-ground biomass, litter and soil organic matter) present in six vegetation categories of the Noel Kempff project in the tropical forest of Bolivia.

To achieve a precision level of +/-5%, 452 plots are needed, whereas only 81 plots would give a +/-10% level of precision. This example illustrates the cost-benefit implications of a higher precision level.

![Graph showing relationship between number of plots and precision level](image)

*Source: IPCC 2003, chapter 4-3.*

**Step 2. Select areas for making preliminary data gathering**
Before determining the number of plots required for monitoring and measurement carbon, an estimate of the existing variance must be obtained for each type of deposit (e.g. soil carbon) in each land use system corresponding to the land use legend. Depending on the occurrence of the same stratum in the project area, each layer must be sampled over an area (repetition), so that results have statistical validity. Initially, a recommended set is four to eight repetitions for each land use system.
Step 3. Estimating the average, standard deviation, and variance of carbon stock preliminary data

The time-averaged carbon stock is calculated for each land use system or land use legend from the preliminary data (or obtained from literature if one can find studies of similar area).

Output: Average, standard deviation and variance of carbon per land use system/legend.

\[
\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n} = \frac{\sum_{i=1}^{n}X_i}{n} \quad S^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n - 1} \quad S = \sqrt{S^2}
\]

Average Variance Std. deviation

Step 4. Calculating the required number of sampling plots

Once the variance for each land use system/legend is known, the desired level of precision and estimated error (referenced in the confidence level selected) and the number of sampling plots required can be calculated. The generic formula for calculating the number of plots is as follows:

Formula for more than one land use system:

\[
n = \frac{(\sum_{h=1}^{L}N_h \cdot s_h)^2}{N^2 \cdot \frac{E^2}{t^2} + (\sum_{h=1}^{L}N_h \cdot s_h^2)}
\]

Where:

- \(n\) = number of plots
- \(E\) = allowed error (average precision x level selected).
- As seen in the previous step, the recommended level of accuracy is ± 10% (0.1) of average but be up to ± 20% (0.2).
- \(t\) = statistical sample of the t distribution for a 95% level of confidence (usually used as a sample number)
- \(N\) = number of plots in the area of the layer (stratum area divided by the plot size in ha)
- \(s\) = standard deviation of land use system

Source: Section adapted from Rugnitz, et al., 2009.

Online tools for calculating number of plots: Winrock International has developed an online tool: “Winrock Terrestrial Sampling Calculator” that helps calculate the number of samples and estimating the costs for base line studies as well as monitoring. See: http://www.winrock.org/ecosystems/tools.asp
43. Once the number of sampling units is calculated, a design of the sample is needed. Figure 5.4 summarizes the recommended sizes of plot and sub-plots under each sampling unit.

**Figure 5.4. Recommended plot and sub-plots sizes for carbon stocks sampling**


**Plot level sampling**

Measuring carbon stock at the plot level requires assessing:

- **Biomass**
  - destructive sampling of small plots of understory vegetation, annual crops, or grasses, and
  - non-destructive tree biomass estimates using allometric biomass equations.
  - default values for below-ground biomass (roots).

- **Necromass**
  - destructive (for litter remains on soil surface) or
  - non-destructive (for dead wood).

- **Soil organic matter.**

44. The procedures of carbon measurement of various pools are explained in detail in Hairiah, et al., 2010 (in English), Rugnitz, et al., 2009 (in Spanish and Portuguese) and several additional resources are available from GOFC-GOLD (2009).

45. The most important carbon stock pool is tree biomass. To calculate carbon stocks in trees we need to know:
• total number of trees per ha,
• distribution of their diameter at breast height,
• and two parameters that relate biomass to stem diameter (‘allometrics’).

46. The devil is in the details. It is necessary to both (1) use the correct allometric equations (and to know when not to use the standard ones), and (2) to know the diameter frequencies, especially those for big trees. Using allometric equations from the literature can simplify the carbon stock calculations at the landscape level. Guidelines for choosing the right allometric equation(s) should be followed (see Table 5.2 for a description of the criteria). If any of the criteria are not met, it is recommended to develop local allometric equations. If there are several equations that meet the criteria, choose the one with highest value for R² (for a detailed procedure see Rugnitz et al., 2009, p.51-59). A list of allometric equations by species and type of forest is shown in the Appendix.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil and climate conditions</td>
<td>Similar climatic conditions within the sample area to that of where the equation was developed for:</td>
</tr>
<tr>
<td></td>
<td>- Annual mean temperature</td>
</tr>
<tr>
<td></td>
<td>- Annual precipitation</td>
</tr>
<tr>
<td></td>
<td>- Altitude</td>
</tr>
<tr>
<td></td>
<td>Wherever possible, similar soil conditions.</td>
</tr>
<tr>
<td>Harvested species</td>
<td>At least 30% are of forest species used in the equation are present in the sample area</td>
</tr>
<tr>
<td>Tree sizes</td>
<td>Similar diameter at breast height (DBH) and tree height</td>
</tr>
</tbody>
</table>

*Source: Adapted from Rugnitz, et al., 2009.*

**Box 5.6. Large trees, large roots... but not always**

Large trees tend to have large roots. For mixed tropical forests, the ratio of above to below-ground biomass is approximately 4:1. In very wet conditions the ratio can shift upwards to 10:1; under dry conditions it may decrease to 1:1 (van Noordwijk et al., 1996; Houghton et al., 2001; Achard et al., 2002; Ramankutty et al., 2007). As measurement of root biomass is not simple (although there is a method that uses the root diameter at stem base and allometric equations), we normally use default assumptions for the shoot:root ratio based on available literature (Cairns et al., 1997; Mokany et al., 2006).
From plot to land use

47. For calculating carbon stock changes at the landscape level, we need data of the typical carbon stock or time-averaged carbon stock of each land use - not the carbon stock of each plot under current conditions. Here, we refer to the spreadsheet provided with this manual. We use worksheet L for land use change according to land use category. We multiply typical carbon stock values by each land use change. A couple of examples to calculate time-average carbon stock for monoculture and diverse systems are shown in Appendix 2. Estimated values of time-averaged carbon stock of selected land-use systems from various countries are shown in Table 5.3 below.

Table 5.3. Time-averaged carbon stock (mean and range) of selected land uses

<table>
<thead>
<tr>
<th>Land use</th>
<th>Time averaged carbon stock, Mg ha⁻¹</th>
<th>Reference, remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary forest (Indonesia)</td>
<td>300 (207-405)</td>
<td>Palm et al., 1999</td>
</tr>
<tr>
<td>Selectively logged forest (Central Kalimantan, Indonesia)</td>
<td>132</td>
<td>Brearly et al., 2004</td>
</tr>
<tr>
<td>Shrub/crop rotation</td>
<td>15</td>
<td>Prasetyo et al. (2000)</td>
</tr>
<tr>
<td>Imperata grassland</td>
<td>2</td>
<td>Palm et al. (2004)</td>
</tr>
<tr>
<td>Oil palm (Indonesia)</td>
<td>60</td>
<td>Recalculated from Rogi (2002)</td>
</tr>
<tr>
<td>Rubber agroforest, 25 year old (Sumatra, Indonesia)</td>
<td>68</td>
<td>Averaged from Palm et al. (2004)</td>
</tr>
<tr>
<td>Rubber agroforest, 40 year old (East Kalimantan, Indonesia)</td>
<td>100</td>
<td>Rahayu et al., 2004</td>
</tr>
<tr>
<td>Coconut plantation</td>
<td>60</td>
<td>Adjusted from 98 Mg ha⁻¹ according to IPCC (2006) based on Rogi (2002)</td>
</tr>
<tr>
<td>Tea plantation</td>
<td>28</td>
<td>Adapted from Kamau et al. (2008)</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>9</td>
<td>Soejon 2004, modified</td>
</tr>
<tr>
<td>Coffee-based agroforestry system</td>
<td>51</td>
<td>Hairiah (2007, for shaded coffee)</td>
</tr>
<tr>
<td>Cacao</td>
<td>58</td>
<td>Lasco et al. (2002)</td>
</tr>
</tbody>
</table>

From land use to sub-national region

48. Once we obtain the time-averaged carbon stock per land use system as explained above, we need to calculate/estimate the time-averaged carbon by land cover in order to extrapolate to landscape level.

49. For example, in Figure 5.5, the “Plantation” land cover comprises five different land uses (pinus, agathy, mahogany, clove, and bamboo). Because it is not possible to distinguish these land uses at the land cover level (and the time-averaged carbon stock has relative small variation/deviation), then we obtain an average for the land cover.
50. Once the time-averaged carbon stocks per land cover have been estimated, use them to extrapolate by multiplying by the area in the landscape of analysis in year y using the results of a GIS analysis. Then repeat the procedure in the map of year y+10, and then calculate the difference in carbon stocks.

![Figure 5.5. Extrapolating carbon from land uses to land covers at the landscape level](source: Hairiah, et al, 2010.)

**From sub-national region to nation**

Scaling-up landscape carbon estimates to sub-national and national levels requires a combined effort of different government agencies, NGOs, and other institutions. Data related to land use is usually scattered and not publicly available. At the national level, the data available normally corresponds to land cover level. The availability of specific spatial national data sets varies from country to country and the information is often scattered among different Ministries (Agriculture, Fisheries, Environment, Mining and Energy) or specialized government agencies.

51. Within countries, different areas with similar conditions have often already been identified with respect to climatic, elevation or vegetation. These different classes should be used as the basis for the stratification process within sampling scheme (Box 5.5) and the development of a land use map. Such information may likely be sufficient to spatially differentiate areas of similar carbon content, especially within forests. However, some weaknesses of the approach derive from:

- Errors in classification of the pixels into land cover classes,
- uncertainty on the average carbon stock values per class,
- changes in carbon over time.
52. From the perspective of an opportunity cost analysis, the land use categories are key to identify and quantify the different land uses at the landscape and national level. Each land use should have a corresponding carbon content. By comparing and calculating the differences between carbon content of the different land uses in year \( y \) and year \( y+5, y+10 \) or the intervals defined, it would be possible to estimate the change in carbon stocks. Nevertheless, either using Tier 2 or Tier 3 data, weaknesses of the approach derive from:

- Errors in spatial classification by land use types, combining ‘land cover phases’ with on-the-ground characteristics and management styles,
- Uncertainty on shifts in time-averaged carbon stocks within the LU categories.

**Building a national monitoring system**

53. The UNFCCC (2009) has identified key elements and capacities for building national carbon monitoring systems for REDD+ as well as components and required capacities for establishing a national monitoring system for estimating emissions and removals from forests. These key elements include:

- Being part of a national REDD+ implementation strategy or plan,
- Systematic and repeated measurements of all relevant forest-related carbon stock changes,
- The estimation and reporting of carbon emissions and removals at the national level that either use or are in line with the methodologies contained in the IPCC good practice guidance for LULUCF due to the need for transparency, consistency, comparability, completeness, and accuracy that should characterize such systems.

54. The key components and required capacities for establishing a national monitoring system for estimating emissions and removals from forests are explained in detailed in UNFCCC, 2009, pages 8-10 and include:

- planning and design,
- data collection and monitoring,
- data analysis,
- reference emission levels, and
- reporting.

55. At a finer scale, the challenges about data collection (Tier 3) equally refer to data collected by ‘forest professionals’ and community members. Quality control measures that identify outliers and unexpected results need to be in place whoever collects the primary data. Unexpected results may indicate an opportunity to learn, if they are confirmed via cross-checking. Nevertheless, such results have an above average chance of being due to
error and may inappropriately leverage overall results if erroneously retained in the dataset.

Cost estimates of measuring carbon and capacity building

56. Building a national or sub-national carbon stock inventory is a time-consuming and costly exercise. Although many countries are familiar with conducting forest inventories, carbon accounting is a step further. Carbon accounting outside forests or in mixed land use systems also increases the complexity of this task. Therefore, one of the initial major costs of measuring carbon faced by some countries would be building the capacity to do it.

57. In the short term, initial capacity building at the national/sub-national level is desirable. In the medium to long term, some cost-effective approaches can be applied, such as: building institutional alliances, involving communities, and introducing specific carbon measurement topics and field practices in [tertiary] education curricula, and mainly, using available national skills.

58. There are numerous foresters, biologists, ecologists, etc., in countries where REDD+ schemes would be developed and who are familiar with biomass measurements. These professionals could transfer some of the basic skills for carbon measurement to communities living in the forest and forests margins, encouraging local community participation and reducing the costs in the long term.

59. Table 5.4 summarizes relative costs of using different data resolution, existing capacities for carbon accounting and building new ones for monitoring, reporting and verification (MRV). The involvement of international organizations also results in higher costs. This is why the focus of these organizations is on transferring skills to national and local levels through partnerships and alliances. Start-up costs are usually higher than maintaining and upgrading the capacities.

60. Costs will differ according to the country and extent of data gaps. Below are estimated costs for equipment and personnel for above-ground biomass sampling in Colombia (Table 5.5) and a national forest inventory in India (Table 5.6). The average cost of assessing forest cover and changes on a per unit area in India is US$ 0.60 per km². The cost per unit is derived from the total forest cover of the country, which is estimated at 677,088 km².
### Table 5.4. Relative costs of building a national carbon accounting inventory

<table>
<thead>
<tr>
<th>Issue</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data resolution</td>
<td>Tier 1: Global estimates</td>
</tr>
<tr>
<td>Description</td>
<td>Tier 2: National available data</td>
</tr>
<tr>
<td>Relative cost</td>
<td>Tier 3: Plot/watershed data</td>
</tr>
<tr>
<td></td>
<td>Freely available online but need expert knowledge to interpret data</td>
</tr>
<tr>
<td></td>
<td>$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capacities used</th>
<th>International expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>National expertise</td>
</tr>
<tr>
<td>Relative costs</td>
<td>Local expertise</td>
</tr>
<tr>
<td></td>
<td>Personnel from international organizations (WB, UN, NGOs, etc) with direct access to governments and normally involved in the start-up of the process</td>
</tr>
<tr>
<td></td>
<td>$$$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capacities that need to be built for MRV</th>
<th>Start-up</th>
<th>Maintain</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Initial set up, varies according to current in country capacity</td>
<td>Keeping up to date and implement quality assurance and quality control schemes</td>
<td>Specialized training, participation in international conferences or access to international standards</td>
</tr>
</tbody>
</table>
| Relative costs                          | $$$      | $        | $$-$-$-$ $$
Table 5.5. Equipment and personnel for above ground biomass sampling in Colombia

<table>
<thead>
<tr>
<th>Activity</th>
<th>Equipment</th>
<th>Personnel</th>
<th>Time (*per plot, **per tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling non-tree vegetation</td>
<td>1 GPS, 5 m nylon cord, 3 machetes, 1 25 kg or more scale, 1 scale of 1 to 5 kg with 0.1 g accuracy, Plastic bags, markers, pencil, forms</td>
<td>3 people</td>
<td>40 - 60 minutes*</td>
</tr>
<tr>
<td>Forest inventory</td>
<td>1 GPS, 1 50 meter tape, 1 hipsometer, 3 machetes, 1 2m long wood pole (can be obtained in the field), 30 m nylon cord, Markers, pencil, forms</td>
<td>3 people</td>
<td>120-150 minutes*</td>
</tr>
<tr>
<td>Trees and palms</td>
<td>1 chain saw, 1 metallic tape, 4 machetes, 1 scale 50 kg or more, 1 scale 1 to 5 kg capacity and 0.1 g accuracy, Plastic bags, Markers, pencil, forms</td>
<td>4 people</td>
<td>1-5 hours**</td>
</tr>
</tbody>
</table>

* Number of plots sampled in a day will depend on the transport time within sample points.
** Time varies according to the size (and hardness) of the tree.

Table 5.6. Cost of measuring forest cover and change using satellite imagery in India

<table>
<thead>
<tr>
<th>Components</th>
<th>Cost per 100 km² (US$)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human resources (cost of data interpretation by technicians, supervision and checking by professionals and ground truthing)</td>
<td>38.5</td>
<td>64</td>
</tr>
<tr>
<td>Cost of satellite data (IRS.P6- LISS III of 23.5 x 23.5 m)*</td>
<td>6.5</td>
<td>11</td>
</tr>
<tr>
<td>Equipment (cost of hardware/software with assumed life of 5 years plus day-to-day maintenance, air conditioning plant, network, etc.)</td>
<td>15.0</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>60.0</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

*Exchange rate used is 1 US$ = 50 Indian Rupees. In total, 393 satellite scenes using IRS P-6 LISS III cover the entire country. The area of each scene is about 20,000 km².

*Source: UNFCCC, 2009.*

References and further reading


Locatelli, B. 2007. Carbon pools slide. MSc course SA 507, CATIE.


UNFCCC, 2009. Cost of implementing methodologies and monitoring systems relating to estimates of emissions from deforestation and forest degradation, the assessment of carbon stocks and greenhouse gas emissions from changes in forest cover, and the enhancement of forest carbon stocks. Technical paper (FCCC/TP/2009/1). Online.


Chapter 6. Profits from land uses

Objectives

Show how to:

1. Develop an analytical framework to estimate the profits (net benefits) of land uses (forest, agriculture, ranching),
2. Estimate financial budgets of land uses,
3. Identify sources of cost and revenue information needed to calculate profits,
4. Develop multi-year profit analysis of land use trajectories,
5. Identify and critically review methodological and data assumptions.

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References and further reading .................................................................................................................. 6-33
1. Economics has many terms and phrases that are commonly used (Box 6.1). For definitions, see Glossary in Appendix A.

<table>
<thead>
<tr>
<th>Box 6.1. Economist speak</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discount rate</strong></td>
</tr>
<tr>
<td><strong>Net present value</strong></td>
</tr>
<tr>
<td><strong>Profit</strong></td>
</tr>
</tbody>
</table>

2. Avoiding deforestation often requires giving up the profits that new land uses would have provided. Reforesting lands may also reduce profits. To know what participating in carbon funds and markets will cost, we need answers to questions such as:

- *What profits are generated by forests?*
- *When forests are cut, what profits will be made from the other land uses?*
- *When forests are re-established what profits do they generate?*
- *What profit would have been generated from the now forested lands?*

3. Money can be made from forest products, such as timber, and from agricultural or ranching activities. The magnitude of profit, however, greatly depends upon:

- local management practices,
- land productivity, and
- market conditions.

4. This chapter shows how to estimate profits from forests and other land uses in order to estimate REDD+ opportunity costs. The procedures presented below are based on a bottom-up approach of data collection with analysis of revenues and costs for a range of land use activities.41

**Box 6.2. Profit is about more than just money**

We use the term *profits* as a convenient shorthand. Other terms, such as *net benefits, net revenues* or *net returns* could be also used. *Profit* is a concise and convenient way to describe the concept of benefits minus costs.

It is also important to note that especially in rural regions, the value of production is not always based on money. Many products and services have value despite not being purchased or sold (e.g., family labor inputs, household consumption of harvests, etc.). Imputing, or estimating, the value of these non-market goods and services are a challenge facing REDD+ opportunity cost analysis. (Other off-site non-market ecosystem services, such as watershed function and biodiversity co-benefits, are addressed in Chapter 7.) Thus *profit* is used in this manual to represent the general concept of net benefits after on-site costs that land users receive from a given land use.

---

41 Other less-precise REDD+ opportunity cost approaches are described in the introduction, Module I.
Why such detail?

5. The bottom-up approach provides a rigorous and transparent record of data collected and analysis, along with a review of methodological assumptions, that are essential for accurately estimating REDD+ opportunity costs. When coupled with carbon stock information, the profit analysis of land uses with enable policymakers to prioritize land uses and regions that minimize REDD+ opportunity costs.

6. This chapter helps develop analyst capacity to: (1) systematically estimate and compare profits generated from different production cycles using a common analytical framework. Similar to identifying land uses, the procedure of assembling financial budgets is based on a three-level hierarchy of activities within land uses:

   1. the enterprise (or activity) budget is the basic building block of information,
   2. land use budgets are constructed to address the multiple enterprises found within land uses,
   3. budgets of land use trajectories are developed to represent how a land parcel may undergo numerous land use changes.

Upfront issues – clarifying assumptions

7. Many types of data and procedures are needed to estimate the profitability of land uses. Here are some details worth mentioning now.

Whose perspective? (the accounting stance)

8. REDD+ programs involve different types of landowners. Such owners can be a country or individual groups (e.g., farmer, rancher, logging company, communities). The way costs and revenues are calculated – called an accounting stance – represents the viewpoint of individual groups or the country. Although an accounting stance does not affect productivity data (e.g., yield/harvest quantities), the difference in perspective determines the data collected, budget accounts, and profit analyses. Inappropriate mixing of data and methods is a common and potentially easy error, and can result in misleading estimates (Pagiola and Bosquet, 2009).

9. For the accounting stance of a country, costs and benefits should be valued at the social value of resources (their value in their next-best alternative use) rather than observed market prices. The social value of a resource may differ from that observed in markets because of either policy distortions (e.g., taxes, subsidies, import restrictions, etc.),

---

42 Often termed private or financial profitability.
43 Often called social or economic profitability.
or market imperfections\textsuperscript{44} (e.g., from a lack of property rights). In contrast, costs to individual groups are valued at actual prices, including any taxes (Pagiola and Bosquet, 2009).

10. Discount rates, and how they are affected by accounting stance, are discussed below.

**Which actual price to use?**

11. Actual prices can differ, often substantially, according to location: farmgate, local market, national market and international market. Because of transportation and intermediary costs (of merchants/middlemen), farm gate prices can be 20-95\% of a national or international market price. Analysts often use the following three types of price data, which represent different stages of a product within a product value chain:

- **Farmgate price:** the price a farmer receives for outputs or pays for inputs at the boundary of the farm. These prices are determined from field surveys with farmers or found in agricultural census data.
- **Wholesale or sub-national market price:** the price at which agricultural products are traded on various domestic markets. These prices include the cost of transportation between farm and market, and are available from surveys at market locations.
- **Border price:** the price at which agricultural goods are exported from the country. Such prices are available typically through official statistics.

12. Adjustments are needed when farmgate prices are expected to differ from prices from where data are collected (e.g., local markets). The recommendation is to use farmgate prices. Local agronomists and extensionists often know farmgate prices. Where not, an adjustment factor can be estimated – often related to distance to market and quality of road and river transportation.

**How to deal with prices distorted by policies?**

13. Prices can also differ due to government market interventions. Inputs subsidies (of e.g., agrochemicals, gasoline, fertilizer) can increase profitability; whereas input taxes can increase them. Similarly, profitability of farm and forest land use is decreased by export taxes which decrease farmgate prices, while output subsidies or import taxes and quotas increase prices and profitability.\textsuperscript{45} Therefore, such a basic assumption of what price to use can greatly affect REDD+ opportunity cost estimates.

14. Despite all these potential distortions to prices, governments are intervening less in markets than before. To enhance global competitiveness and fair trade, international agreements on tariffs and trade limit the use of such mechanisms. In addition, governments

\textsuperscript{44} A situation in which the market does not allocate resources efficiently. Market imperfections can occur for one of three reasons: (1) monopoly - when one party has power that can prevent efficient transactions from occurring, (2) a transaction has externalities (side effects) that reduce efficiency elsewhere in the market or the broader economy, and (3) nature of certain goods or services (e.g., public goods such as roads).

\textsuperscript{45} In some countries, cattle production and oil palm are land uses, for example, that have received subsidies.
typically have less financial capability to subsidize economic sectors as budget overspending and debt is being controlled by lending organizations (banks, International Monetary Fund, etc.).

15. If such distortions are apparent and important, the recommendation is to have separate estimates for costs to land users and budgetary costs to the government (using unadjusted prices) and for costs to the country (using prices that correct for the distortion).

16. A Policy Analysis Matrix (PAM) can be used to compare the results of different accounting approaches (or methodological assumptions) of economic analysis. For example, differences in agricultural and natural resource policies and factor market imperfections can contrast with multi-year land use system budgets calculated at private and social prices (Monke and Pearson 1989 is the basic reference).

Why use a discount rate?

17. A discount rate is the way economists account for time while estimating the value of goods and services. Simply put, a dollar today is worth more than a dollar tomorrow. Thus, for profit analyses that examine multiple years, the value of future profits must be properly discounted.

18. The discount rate used to assess costs to the country should be the social discount rate normally used by the government. In contrast, the discount rate used to assess the costs and benefits to individual groups should reflect their rate of time preference. If the costs to all individual groups (including the government) were added up and re-calculated based on social value of resources rather than observed prices, they should equal the costs to the country.

19. From a national perspective, the discount rate can be equated to the cost of borrowing money. The interest rate on loans (often between 5 and 10% annually) is a useful proxy. From an individual perspective, the costs of borrowing money are typically much higher. Interest rates in countries often range between 10 and 30% per year, or higher, if loans are available.

20. For the purposes of opportunity cost analysis, the real interest rate should be used. How to deal with inflation is discussed below.

Box 6.3. Understanding the potentially big effect of discount rates

In many developing countries, interest rates are high, reflecting perhaps unstable economic conditions or the inherent risk of loans not being repaid. Nevertheless, strong criticism arises from employing the use of high discount rates. Within a NPV analysis, the chosen discount rate can have strong effects. This is a result of compounding, where the discounting includes the cumulative effect of all previous years. For example, at a 10% discount rate, NPV of profits at the end of the first year (t=1) are valued 9.09% less. At the
end of year 2, the profits are valued 17.4% less. In other words, to account for the time value of money, the profits would need to increase by these discounted amounts in order for the future profits to be of the same value.

When a discount rate is applied over a long time horizon (15+ years), the NPV profits in the final years can be dramatically lower. The effects a 2, 5, 10, 15 and 20% discount rate are depicted below. At a 2% discount rate, the NPV profits in year 20 “lose” over 32% of their value (nearly 45% at year 30). At a 5% discount rate, the NPV profits in year 20 “lose” over 62% of their value (nearly 77% at year 30).

At higher discount rates, the effects are more severe. Use of a 15% discount rate implies that the NPV profit in year 20 have lost 93% of their value (in year 30, over 98%). With 20% discount rate, the year 20 NPV profit is down approximately 97% (in year 30, down over 99%).

How to estimate unstable and non-existent prices?

How to value inputs provided and outputs consumed by the household?
21. Labor inputs or inputs retained from previous harvests are used within farm households yet are not purchased. Therefore such input prices are not readily available. Some of the inputs may have multiple possible prices (e.g., seeds retained from harvest could be valued at the foregone income at time of harvest, or the cost at time of planting).

22. It is recommended to use the cost that farmers actually incur for such inputs. In the case of seed, the cost of storing seed may be minimal, therefore the seed should be valued
at the time of harvest. Although such non-market inputs can be valued in different ways, be
done justifiably, and produce different results, it is important to document the assumptions
and methods. Sensitivity analysis of the assumptions can be conducted to see the impact of
the assumption upon results of the analysis. With such comprehensive information, the
difference may turn out to be rather insignificant or worthy of discussion amongst peers to
decide the best, most relevant, option.

23. Smallholder farm households also may consume much of their harvests instead of
selling them. Such subsistence or semi-subsistence agriculture is common in many rural
regions. While the earnings are not realized, the value of the output should be recognized at
its market price.

How to handle prices and yields that are highly variable over time?

24. Agricultural production and product prices can be notoriously unstable. When
collecting data at one point in time, it is likely that the information is not representative of
yields and prices. Two basic types of variation exist (and their causes):

1. Prices and yields vary around a static mean (e.g., because of variable weather
   conditions, pest and disease outbreaks, exchange rate fluctuations, global supply
   shifts), and
2. Prices and yields vary around a changing (trending) mean (e.g., mean yields decline
   because of soil degradation; real prices trend up because of increased consumer
demand, energy costs; prices trend down because of demand shifts away for
   particular commodities or increasing supply associated with productivity growth).

25. It is therefore recommended that price information be examined over multiple years
   and the context of agricultural productivity and markets be examined. Past trends can
   provide us with important information on how parameters of profitability analyses may
develop in future years. For example, yields and input use of agricultural enterprises often
increase gradually over time as technology improves. Yields can decrease resulting from
soil degradation.

26. Likewise, prices may be subject to both positive and negative trends depending on
population and economic growth at local, national, and global levels. While trends do not
usually increase uncertainty, they can nevertheless lead to significant biases in opportunity
cost estimations, especially if longer time REDD+ contracts are at stake. If there is
reasonable evidence to expect major trends in key enterprise budget items, these items
need to be adjusted accordingly for each year of the planning horizon. The gradual
adoption of pest resistant corn varieties, for example, can be introduced in the analysis by
gradually increasing yields and reducing pesticide expenses in the corn enterprise budget
according to the expected trends in these parameters. Uncertainty and risk of parameter
estimates can be analyzed using stochastic analysis (Box 6.4).
Box 6.4. Risk and uncertainty analysis

Numerous computer programs are available to analyze the effects of risk and uncertainty (@Risk, Quametec, etc.). Using stochastic analysis methods within an Microsoft Excel spreadsheet, the programs can reveal the likelihood of a particular outcome. Such analyses help decision makers to better understand the potential implications of interventions within uncertain environments.

27. All parameters used in profitability analysis are subject to uncertainty as a result of data collection and processing errors. District averages of yields, for example, often overestimate actual yields (aggregation bias\(^{46}\)), and information from field surveys may be subject to recall biases. In addition, survey respondents tend to generalize recent year experiences, even if not representative of a longer period. To aid practitioners in understanding the process of assembling land use budgets, the accompanying spreadsheet workbook contains numerous notes. Sensitivity analysis of results can help analysts identify the most reasonable assumptions.

Profits are calculated in terms of what?

28. Profits in terms of returns to land (i.e. $/ha) typically makes most sense. It is a common measure understood by many.

Should the cost of land be included in calculations?

29. Including land costs in the analysis only makes sense from the perspective of an investor who is considering acquiring land (through purchase or rental) to undertake an activity. For a farmer or logging company that already owns/controls the land, the analysis considers the returns to the next-best land use alternative. Therefore, the opportunity cost of land is already being taken into consideration. In other words, since we are comparing the profitability of activity A to activity B, it makes little sense to include costs of land in these profitability estimates. The costs would cancel out.

And labor?

30. A more difficult question is whether profitability should be estimated in terms of returns to labor (i.e. $/workday). For many smallholder farm households, it could make more sense to express results in terms of return to land and family labor. In many forest frontier regions, the most limited factor of production is labor. Since land is relatively abundant, smallholder farmers most carefully allocate their scarce labor resources (along with their land resources).

31. Opportunity costs of REDD, however, are calculated in terms land. Fortunately, it is possible to impute the value of family labor in the farm activity costs, thus giving

\(^{46}\) Resulting from assuming relationships observed for groups necessarily hold for individuals. For forest margin areas, lower yields can be masked if average values include areas with higher inputs and productivity.
profitability in terms of returns to land. Since family labor can be reallocated to other uses if a different land use is chosen, the returns to land are the correct measure of the opportunity cost of land use change. Most important, in this case, household income from a given land use will include both profits and the implicit wage of their labor. REDD+ opportunity costs need to account for both the profits and implicit wages. Both types of earnings are foregone with REDD.

32. Another important issue with land use trajectories from the perspective of profitability analysis arises when different groups or individuals are responsible for different portions of the trajectory. This makes no difference when the analysis is from the country's perspective, but is very important when the analysis is from the perspective of an individual group.

Which profits from a land use should be analyzed?

33. A systematic profitability analysis starts with developing detailed budgets of simple activities (also called enterprises) of land uses. These budgets are a summary of cost and revenue information. Enterprise budgets typically describe activities that occur within a year's harvest season. Examples of enterprises include NTFP collection, timber harvesting, and annual crops. Enterprise budgets are an important building block to represent land uses and land use trajectories.

34. Budgets of land uses account for a combination of activities, such as agricultural and tree crops. These budgets are typically multiple year summaries representing all phases of an activity: preparation, production and, perhaps, fallow periods.

35. A budget of a land use trajectory is a longer-term summary of land uses and land use changes. Land use trajectories are developed as a basis for REDD+ opportunity cost estimates and analysis. Table 6.1 summarizes the three types of budgets and associated sources of information.
Table 6.1. Types of budgets

<table>
<thead>
<tr>
<th>Type of budget</th>
<th>Description</th>
<th>Information sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land activity/enterprise</td>
<td>A single year summary of costs and revenues from a single activity. Forest conversion, forest harvests, agriculture &amp; ranching activities within land use changes</td>
<td>Local experts</td>
</tr>
<tr>
<td>2. Land use</td>
<td>A multi-year summary of a single enterprise or linked enterprises of a land use Land use change cycles and transitions</td>
<td>Local experts</td>
</tr>
<tr>
<td>3. Land use trajectory</td>
<td>A summary of different land uses starting from current use. The basis for opportunity cost estimates.</td>
<td>Local experts, literature, remote sensing</td>
</tr>
</tbody>
</table>

Source: Authors

36. With land use trajectories, a profitability analysis often represents different groups or individuals who are responsible for different portions of the trajectory. For example, logging companies for forest degradation, settlers for deforestation and slash-and-burn agriculture. Budgets will be needed for each segment of the trajectory.

37. Although such a profit analysis with multiple components does not affect REDD+ compensation from a national perspective, it is important to recognize the REDD+ contribution from each individual group. Proper compensation for REDD+ depends on such knowledge of land use changes.

What to do when profits differ across sub-national regions?

38. The distribution of profits for a particular land use within a country can be highly variable. Consider cocoa land uses, a principal driver of deforestation and degradation that occupies more than 8 million ha in the Guinea rainforests of West Africa, coastal Atlantic rainforests of Brazil, rainforests on the Indonesian island of Sulawesi, and other areas.

39. Wide differences exist between the harvest yields of cocoa producers (Figure 6.1). The distribution of yields from nearly 5000 producers show that the mean is more than 100kg/ha greater than the median. Causes include significant differences fertilizer uses, and management practices. Thus although cocoa systems can be considered a land use system within an opportunity cost analysis, examination of yields and causes of differences is essential to improve the accuracy and precision of profit estimates. Moreover, at a national level different budget should be developed to accurate represent the difference within a land use system.
Enterprise budgets

Components and construction

Enterprise budgets estimate profit ($/ha):\

$$\Pi = pq - c$$

Where: $p =$ price ($/ton), $q =$ yield (ton/ha), and $c =$ costs ($/ha)

40. Revenues ($pq$) come from the output (e.g., crop, animals, timber) of a land use activity. Costs ($c$) arise from the use of three types of inputs: physical (or capital), land, and labor. These measures serve as adjustable parameters for subsequent scenario, sensitivity and tradeoff analyses. 47 A sample enterprise budget is presented in Table 6.2. For more detail on enterprise budgets, see Gittinger (1982).

41. Physical inputs include seeds, fertilizers and chemicals, which are typically used annually. Longer-term investments such as fences, tools, machinery, animals (cattle), etc. are also physical inputs.

42. Labor inputs can be estimated using wage rates. Two types of rate, however, are typically available: legal minimum wage and actual wage. Nationally-established minimum

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47 A parameter is a specific value of variable estimated or selected (e.g., mean, median) within an analysis.
wages may include social benefits: health and pension. In contrast, actual wages are often significantly lower, especially with informal arrangements in remote forest frontier areas. Actual wages should be used. Effects of different wage rates on opportunity cost estimates can be examined with sensitivity analyses.

A monthly labor calendar is helpful to discuss, identify and quantify workday activities in order to estimate total labor input. The type of labor activity may also receive a different wage rate, depending on skills required or scarcity of seasonal labor. The first task of the agricultural/logging season, typically land preparation, should determine the starting month of the calendar.

Table 6.2. A sample enterprise budget

<table>
<thead>
<tr>
<th>Activity</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
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<tr>
<td>Planting</td>
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<tr>
<td>Weeding</td>
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<tr>
<td>Harvest</td>
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<tr>
<td>Threshing</td>
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<tr>
<td>Transport</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Calendar: Workdays</td>
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<tr>
<td>Total</td>
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</tbody>
</table>

Careful consideration of the units of analysis within budgets is essential. Units of measure, such as kg, liters, tons, should be noted. While yields are usually available in the required per hectare units, cost information may come in different units, e.g., workdays per ton of product harvested. If farm inputs are used for more than one enterprise the cost of input should be shared and attributed to the other enterprises. For example, rental rates per hectare or day are convenient approximations for the use cost of tools and machinery (e.g., chain saws, machetes, machinery, etc.). Alternatively, prices and average lifetime values can be estimated to impute annual use cost per hectare.
45. Numerous methodological and data assumptions underlie the information within enterprise budgets. Parameters (e.g., of inputs, harvest yields and prices) can easily be adjusted to represent specific locations and contexts.

**Data collection**

46. Data needed to develop enterprise budgets can come from a variety of sources. Since budget information is basic to analyses of agriculture, ranching and logging activities, national research centers and universities may have budgets already available. If not, production data can be collected via interviews with farmers, or other experts (e.g., agronomists, extensionists, foresters) and via literature review of case study analyses of production systems. Although annual output is often available through producer surveys, many smallholder practitioners of slash-and-burn farming do not have precise measures of their field size. This is particularly common in regions where land markets and land titling are not developed. In such cases, accurate estimates of field size may be obtained by walking the field perimeter with a handheld GPS. Detailed secondary information on inputs is also rarely readily available. Essential to estimating costs, accurate data on enterprise inputs is best obtained via farmer and key informant interviews.

47. Given budgetary or time restrictions, precise measures for some items within an enterprise budget may not be readily available (e.g., workdays, inputs, prices). In order to quickly advance analyses, estimated measures can be used, based on expert opinion and other sources. In addition, information from other budgets and studies can be used in an IPCC Tier 1 or Tier 2 manner and adjusted to local conditions. For planning budgetary commitments, or estimating the compensation needed to get land users to forego clearing, etc, the most useful estimates are domestic currency. Estimates in domestic currency are also typically less vulnerable to exchange rate fluctuations. Therefore, any database should be expressed and maintained in domestic currency.

48. Conversion to foreign currency only occurring for those specific purposes in which it is needed. For example, at some later point countries will need to know how their REDD+ opportunity costs compare to possible REDD+ payments, which will be stated in US$/tCO\text{\tiny 2e} or other such terms. For this particular purpose, countries will need to convert results to US$ (or to convert US$/tCO\text{\tiny 2e} to domestic currency).

49. Prices, needed to calculate input costs and output values, can be one of the easiest or most difficult types of information to acquire. Although many types of prices exist, farm gate should be used if the objective is to estimate land user’s opportunity costs of REDD.

50. Budgets collected through field surveys can avoid most of these problems but are much more expensive to collect. Budget accuracy and reliability also depends on appropriate sample design and well-trained enumerators. Budgets collected through

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48 Prices of internationally-traded commodities such as cocoa or palm oil, may be less volatile.
surveys usually can only obtain reliable data for the current and previous years. (Data obtained for earlier years can be very inaccurate.) When yields and prices are very variable official budgets can also be very unreliable. Surveys are also difficult when the activities concerned are illegal (e.g., logging, bushmeat trade, coca production).

51. Many estimates within enterprise budgets will likely be imperfect. Bias, or inaccuracy, of such information can affect results of the profitability analysis. A systematic approach to data collection and reporting enables the process to be transparent, reviewed, revised and improved. Sensitivity analysis of changes in parameters is a useful way to understand how much an estimate affects the final results of an opportunity cost and tradeoff analysis (discussed in Chapter 7).

52. Table 6.3 summarizes the advantages and disadvantages of different data collection approaches. For details on data collection methods, see Holmes, et al. (1999), FAO (2001, 2002), and Pokorny and Steinbrenner (2005).

Table 6.3. Advantages and disadvantages of data collection approaches

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey (in-person)</td>
<td>-Expert-based</td>
<td>-Follow-up questions require second communication</td>
</tr>
<tr>
<td></td>
<td>-Timely</td>
<td>-Expensive for large sample</td>
</tr>
<tr>
<td></td>
<td>-Comprehensive, large sample size can increase statistical significance of results.</td>
<td>-Proper training of interviewers/enumerators essential.</td>
</tr>
<tr>
<td>Case Study</td>
<td>-Close discussion with land user</td>
<td>-Dependence on secondary information and knowledge by personnel</td>
</tr>
<tr>
<td></td>
<td>-Broader questions</td>
<td>-Limited representativity.</td>
</tr>
<tr>
<td></td>
<td>-In-depth questions and answers possible.</td>
<td></td>
</tr>
<tr>
<td>Experiment station</td>
<td>-Control over data quality</td>
<td>-Higher yields than field conditions</td>
</tr>
<tr>
<td></td>
<td>-Allows for the testing of alternate scenarios and ideas.</td>
<td>-Limited validity of extrapolation</td>
</tr>
<tr>
<td>Existing sources</td>
<td>-Cheap to collect</td>
<td>-Specific individual results</td>
</tr>
<tr>
<td></td>
<td>-Data already processed.</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from: Pokorny and Steinbrenner (2005); Pagiola (personal communication, 2010).
53. For example, all types of price data may be affected by market distortions, as a result of government subsidies, sales taxes or minimum price policies. In such cases, analysts will have to evaluate whether these distortions are likely to continue over their analysis horizon. If so, price effects of government policies should be taken into account throughout the analysis or considered with sensitivity analyses.

54. The following section is divided into two parts to address particular data aspects of (1) agriculture/ranching, and (2) forest land uses.

**Agriculture and ranching**

55. Many separate activities often occur in within a small patch of land. Although remote detection of individual crops is notoriously difficult, a subset of the major activities can be selected to represent a mixed land use, thereby reducing the need for detailed data collection. Similarly the productivity of pastures within a landscape is not possible to assess without on-site information.

56. Agricultural census and government statistical information at provincial or department level can confirm yield estimates. With estimates of total crop area, such sub-national production figures can be converted to a per hectare basis. Even if farm-level data is used within the analysis, government census statistical information is helpful to check data accuracy.

57. Local measurement units of land area and harvest weights can be used in order to facilitate discussion with farmers. Conversion to metric measures (e.g., hectares, kilograms), however, are needed to enable a standardized analysis. Local currencies should be used. These values can be converted later to a standard currency, typically € or US$.

58. Farmers can usually recall prices paid and received for the most recent season. In the absence of farm gate prices, other price data should be adjusted based on value-added marketing activities. For example, wholesale market prices of rice include the added value of milling and farm-to-market transportation costs. If market prices are used, the cost of milling and transport should be subtracted in order to arrive at farm gate prices.

59. Within markets, prices are established by exchanges agreed upon between buyers and sellers. Nevertheless, markets may not exist or function well in remote regions. For example, services such as wage labor could simply be unavailable for purchase. Since minimum wage rates are often poor approximations of actual rural wage rates, analysts are best advised to consult local experts about realistic wage rates. Even in remote areas, the hiring casual workers is common. The daily wage is often quite standardized and known within a given locality. Since minimum wage rates are often poor approximations of actual rural wage rates, analysts are best advised to consult local experts about realistic wage rates.
60. Alternatively, hired laborers are commonly paid on a piece-rate rather than a monthly, daily or hourly wage basis. This complicates wage rate sensitivity analysis as this labor cost is a lump sum payment and therefore requires a data transformation. Perhaps the simplest way is to divide the lump sum payment by the wage rate to estimate the equivalent quantity of wage labor that could have been employed. Sharecropping is another labor institution common to smallholder agriculture in developing countries that requires a similar treatment.

61. Slash-and-burn systems typically include a wide range of agricultural crops including rice, maize, beans, cassava, plantain, etc. To represent slash-and-burn agriculture in Peru for example, a rice-plantain-fallow cycle, which is common to the region, is used. The cycle can be adjusted according to age of forest frontier by changing the length of the fallow period. Similarly, pasture productivity is adjustable according to animal units (head of cattle per ha).

**Forests**

**Timber**

62. Since the logging industry is highly competitive and under the scrutiny of tax officials, acquiring financial information can be particularly difficult. In addition, most timber extraction (around 90%) in the Amazon is estimated to be illegal (Stone, 1998). Operations are often led by self-made managers who have little business management training, deficient bookkeeping practices, and limited financial control of forest operations (Arima and Veríssimo, 2002, Pearce, et al. 2003). Nevertheless, personal interviews, mail surveys and informal discussions with industry experts may provide needed information.

**Other forest products**


**Land use budgets**

64. Information from enterprise budgets is essential to estimating the profitability of land uses and land use trajectories. While enterprise budgets are a helpful building block, land use budgets are more than a simple adding together of separate enterprise budgets.

65. For land uses with more than one product, a more accurate representation of profit is
\[ \Pi = \left( \sum_{h=1}^{H} p_h q_h + \sum_{i=1}^{I} p_i q_i \right) - \left( \sum_{j=1}^{J} C_j y_j + \sum_{k=1}^{K} C_k y_k \right) \]

66. The above equation makes explicit not only the prices and multiple market goods and services of a land use, \((p_h \text{ and } q_h)\) but also the non-market prices \((p_i)\) of non-market goods and services \((q_i)\). Within a specific land use, the inputs may include both marketed inputs \((y_j)\) and non-marketed inputs \((y_k)\), which have distinct valuation challenges \((c_k)\). The use of shadow prices for non-marketed goods is common.

67. The enterprise budget example for rice above is a single year. Land uses, however, typically require a multi-year analysis, since annual profit levels can be very different (negative, zero or positive) depending on phase: establishment, fallow or production. Therefore, the above equation becomes:

\[ \prod_{\text{land use}} = \sum_{t=1}^{T} \prod_t \]

68. The computer spreadsheet workbook contains examples of land use budgets with different phases and products. These detailed budgets help analysts keep track of individual activities and enterprises as they change over time. Notes on how the costs and earnings change help analysts understand the assumptions employed.

69. For some land uses, complementary activities should be noted, if not included in estimates. Fodder production for feeding animals that provide transport or other farm activities, such as plowing, should be attributed a proportional use basis.

70. Details of such assumptions are discussed at the end of the chapter. A transparent presentation of information enables rigorous profit analysis of land uses.

**Agriculture**

71. Land use budgets address both land use change cycles and transitions. Distinct versions of land use budgets can also represent the different locations within a forest frontier. For example in Peru, swidden agricultural production typically has a three year production phase, but different fallow periods. Farmers in established settlements with higher population pressure commonly practice bush fallows of 2-6 years. In contrast, pioneer farmers employ land management practices with fallows of 6-15 years. Since both input (e.g., labor) and output (e.g., harvest) levels may be different between such systems, separate budgets are justified. Perennial systems, tree crops (cocoa, oil palm) and cattle include costs of establishment and production.
72. The workbook of land uses contains spreadsheet of cocoa, oil palm, cattle, rice-plantain systems. Cells, highlighted in yellow, represent parameters that should be adjusted to better represent local conditions and contexts. It is also important to note that the land use options may not be feasible for all farmers, issues of cash flow constraints (especially for cattle and perennial systems) may require land uses to be phased in as earnings compile and investments become more discretionary.

Forests

Timber

73. Different budgets for timber harvests are needed for each major variation that is observed in a country. Forest harvest operations are typically diverse, ranging from small-scale informal loggers to vertically-integrated harvest, transport and processing firms.

74. Timber cost analyses are typically divided according process stage: harvesting, transportation and milling. Harvesting comprises a set of activities undertaken to fell standing trees and extract trees or logs from the felling site to a landing or a roadside where they are processed into logs and consolidated into larger loads for transport. Logs are transported over unpaved and paved roads to the processing facility or other final destination. Milling refers to a variety of log sawing activities into different shapes and dimensions. Spreadsheet Timber is an example of an enterprise budget for logging company. The level of detail can be expanded per process stage, by including estimates for the costs of labor and equipment for example. For a comprehensive explanation of costing procedures, see Holmes, et al. (1999).

75. Forest uses and forest conversions are important to analyzing profits at the start of a land use trajectory. Forests can generate substantial profits or losses. Whether the profits are positive or negative, depend upon how forests are used and if products are sold. To understand the variety of forest uses and products, two aspects of forests need to be considered: forest quality and forest use.

76. Forest quality refers to the status of the forest with respect to previous human use. Many forests have already undergone a series of changes, including extractions of high-value tree species and selective logging. Hence, forest quality is also a measure of forest degradation. While degraded forests can still be forests, according to definition, the carbon content and future profits can be substantially different from natural forests. A previously-harvested forest will not generate the same profits as a pristine forest.

77. In order to enable a rigorous accounting of forests, distinct forest quality categories need to be developed. For the purposes of this training manual, general categories are

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49 Although specific definitions of forest quality (e.g., carbon content and canopy cover) will likely differ according to national contexts and perhaps differ within a country. Forest categories and their geographic identification can be linked with land uses discussion.
employed, consisting of: pristine or natural, selectively cut (highest value species extracted), and partially cut (high-mid value species harvested). In order to obtain more precise estimates of forest profitability, sub-categories with greater levels of distinction and detail may be required per country context and REDD+ program criteria.

78. **Forest use** refers to activities within the forest. Per forest quality category, Table 6.4 summarizes both previous and potential forest uses. Past activities that have led to the current status of a forest will affect future potential uses of the forest. Pristine or natural forests have had few human activities but a wide range of potential uses. Respective selectively and partially-cut forests have increasing levels of previous use, yet fewer potential uses. Fewer potential uses implies lower profitability.

### Table 6.4. Past and potential forest uses per status of forest quality

<table>
<thead>
<tr>
<th>Forest quality status</th>
<th>Past uses</th>
<th>Potential future uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pristine or natural</td>
<td>NTFPs</td>
<td>Tourism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highest-value trees extracted</td>
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<tr>
<td></td>
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<td>High-mid value trees extracted</td>
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<tr>
<td></td>
<td></td>
<td>Forest conversion (timber, charcoal)</td>
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<tr>
<td></td>
<td></td>
<td>Other land uses (agriculture, ranching)</td>
</tr>
<tr>
<td>Selectively cut</td>
<td>Highest-value trees extracted</td>
<td>NTFPs</td>
</tr>
<tr>
<td></td>
<td>NTFPs</td>
<td>High-mid value trees extracted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forest conversion (timber, charcoal, pulpwood)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other land uses (agriculture, ranching)</td>
</tr>
<tr>
<td>Partially cut</td>
<td>Highest-value trees extracted</td>
<td>NTFPs</td>
</tr>
<tr>
<td></td>
<td>High-mid value trees harvested</td>
<td>NTFPs</td>
</tr>
</tbody>
</table>

* can also include areas of slash-and-burn agriculture, depending on land use definitions and resolution of analysis.

Source: Authors.

79. All timber harvests affect forest quality. Select cut- or partial-timber harvests, for example, decrease carbon content, albeit less than clear cutting. Such selective forest harvest practices may not cause a land parcel to lose its distinction as a forest. Nevertheless, their effects on carbon and potential future profitability need to be assessed.\(^{50}\) For example, after thinning (e.g., selective harvest) remaining trees grow faster.

\(^{50}\) The opportunity costs of conserving selectively logged forests can be substantially lower and thus more affordable from a REDD+ point of view. “Log and protect” might thus become a way to avoid substantial emissions.
80. Often used to describe forest use are the words sustainable and unsustainable. For the purposes of estimating REDD+ opportunity costs, however, the distinction is not sufficiently precise. Sustainable use activities, such as from non-timber forest products (NTFPs) or tourism, do not affect the carbon content and forest quality. Yet, other "sustainable" practices, such as sustainable forest management, are likely to reduce carbon content and forest quality - although less than conventional logging practices.

81. Profits from forests can also be generated in other ways. A lesser-known forest use and income source is the production and sale of charcoal, which is used as a cooking fuel. As an enterprise activity of a smallholder farmer, for example, charcoal production in the Peruvian Amazon can generate substantial earnings. A whole-farm profitability analysis estimates that charcoal-producing farmers generate 17% higher net income from their farm than merely slashing and burning the forest (Labarta et al. 2007).

82. When trees are not sold, forest conversion costs are not offset by income, thereby causing profit losses. Especially in remote areas, many farmers, prefer to burn trees on-site since expensive transportation often erases potential earnings. In such cases, the cost of clearing land typically exceeds the initial years of revenue generated from agriculture or pasture activities (Kotto-Same, et al., 2001; Merry, et al. 2001; White, et al. 2005).

83. Numerous cost and revenue estimates exist from studies of logging operations. Profit estimates show significant variation – ranging from US$24/ha to US$1435/ha (Olsen & Bishop, 2009). Differences stem from a variety of sources, from estimating costs and revenues. Experiences from Brazil, the largest timber producing country in the tropics, are used to illustrate costs and revenues from the timber industry. In a review of 11 forest operation studies, Pokorny and Steinbrenner (2005) found that differences in cost estimates arose from contextual conditions of:

- particular forests (e.g., species composition, forest structure, topography),
- commercial enterprises (e.g., staff, machinery, work processes, and organization),
- cost calculation methods, and
- approaches used for data collection.

84. The cost studies examined the entire sequence of activities related to forest operations, including cutting, skidding, landing activities, and transportation. Also included were costs for construction and maintenance of infrastructure (landings, and primary and secondary roads) and the costs for capital items (e.g., capital costs, depreciation,

51 Although trees can used for many local uses, their estimated value is relatively small and therefore not included in an analysis of profits.
maintenance), labor, material, administration, and stumpage fees. Most studies also took into account transportation costs from the forest site to the sawmill along public roads.

85. Cost differences also result from how trees were harvested and costs calculated. Studies examined costs of conventional logging (CL) and reduced impact logging (RIL) practices. (See Box 6.5 for a description of the logging techniques and cost implications.) Also, while some of studies addressed overall costs, others estimated costs per specific sub-activity. In addition, studies differed in how costs for administration and technical coordination are included. Costs representing risks and administration salaries were largely ignored. Some studies used standard costs for labor and machinery, while others relied on data specific to the different activities.

86. The conversion rate from logs to sawn timber is a factor that greatly affects costs and is usually an assumption within many analyses. Stone (1990) considers a conversion rate woof of 47% while Stone (1995) considered a conversion rate of 34%. Barreto, et al. (1998) added a general surcharge of 25% to the costs of conventional logging for timber waste, whereas Holmes et al. (2000) estimated a potential value of the waste measured in the forest. According to Pokorny and Steinbrenner (2005), the different considerations of timber waste, rather than the different measurements of productivity in the field, resulted in greater differences in the cost estimates.

Box 6.5. Reduced impact logging

Reduced impact logging (RIL) can be more profitable than conventional logging (CL) practices. Benefits accrue in the both short and longer term. At an initial harvest, investments in forest worker training generate efficiency gains to skidding, recovery of potential marketable timber and log deck productivity. Longer term economic and ecological benefits of RIL include less damage to residual trees and disturbed soils.

In a case study analysis, wood wasted in the CL practices represented about 24% of the harvest volume but only 7.6% with RIL techniques. Less wasted wood and increased recovered volume of wood can reduce costs by 12% per cubic meter versus a typical CL operation. Investment costs (Holmes, et al. 1999).

The FAO model code of forest harvesting provides the basis for RIL system design, including many or all of the following activities (Dykstra and Heinrich 1996): pre-harvest inventory and mapping of trees, pre-harvest planning of roads and skidtrails, pre-harvest vine cutting (where needed), directional felling, low stump cuts, efficient use of felled trunks, optimum width of roads and skid trails, winching of logs to planned skid trails, optimal size of landings, minimal ground disturbance and slash management.

52 Stumpage fees are the cost of purchasing the rights to log a parcel of land. Payment is typically made on a m³ basis. Such fees can also be considered an opportunity cost, or value of the trees to the landowner.
53 The revised rate, reflecting less efficiency is one of the main factors behind Stone's conclusion that timber profits are decreasing (Bauch, 2010, personal communication).
54 Location to where logs are skidded stacked for subsequent loading onto trucks.
87. RIL techniques and guidelines are not fixed prescriptions, but adapt best harvesting techniques to existing biophysical and economic conditions. Pre-harvest, harvest planning and infrastructure costs of CL operations were $0.71 per m³ and $1.93 per m³ for RIL. In some cases, RIL can be more expensive or of similar cost to CL depending on sophistication of the CL (e.g., harvest planning) and particular practices of RIL (Winkler, 1997; van der Hout, 1999). Effects of RIL on carbon density stock and regeneration capacity of the remaining have not yet been estimated.

88. In another study of the Brazilian logging industry, other factors significantly affected costs of each activity, including labor wage, distance from the forest to the processing location, type of equipment, and the type of forest frontier (Bauch, et al. 2007).

89. Profit estimates of logging operations also differ from assumptions regarding timber quality and prices received. Since many forests within a country may have already been harvested, timber profits could substantially differ per region. An assessment of current forest quality and forest uses establishes a starting point of analysis for estimating potential profits. Box 6.6 presents a sub-national analysis of timber resources from Brazil.
Box 6.6. Identifying timber prices and harvest rates in Brazil

Para, Brazil has harvested large amounts of timber. Below is a provincial scale map of a forest inventory.

A geographic assessment of logging history (Para, Brazil)


Although a forest inventory provides an assessment of available timber and timber already harvested, analysis of current and future logging activities is conducted per geographic region. Within Para, four areas of logging activity are identified, Central, Estuarine, East and West.
Logging regions within Para, Brazil.


The location of a logging operation affects not only the amount and quality of available timber but also prices received. The figure below shows how timber quality of estuarine regions are of overall lower quality. The western region contains a higher percent of high and medium quality timber.

Regional estimates of timber quality (% timber; Brazil, 1998)


Prices received for timber differ per quality category and, to a lesser extent, logging region. The price differential between high and medium quality is significant greater than the difference between medium and low quality timber. The price of high value timber is approximately $2.5$ times more than prices of medium and low quality timber.
90. The potential profits generated from high value forests can be substantial. The case of mahogany in Brazil is an example of high profits with potentially low carbon impact (Box 6.7).

**Box 6.7. High-value mahogany but with what carbon effects?**

High value species extracted from forests generate large profits with relatively little effect on forest carbon. In Brazil, for example, mahogany trees are usually widely scattered in patches. On average, 5 m$^3$ of mahogany logs are extracted per hectare and generate $81 per hectare in profit, despite high ($150 per m$^3$) harvesting costs (Verissimo, et al., 1995). While this type of forest impact may be small, associated harvest practices can have greater effects on forest quality. Most logging operations use conventional harvesting techniques, sometimes termed high impact, that severely damage and degrade forests. Skidder road construction and damage to other trees during felling can affect both carbon and forest canopy. Yet such effects are not included in deforestation maps (Nepstad, et al., 1999). In addition, since only a portion of the tree is being harvested, substantial biomass is not of commercial quality, yet waste needs to be considered in carbon accounts of forests.

To account for selective logging, budgets should be estimated for the forest land with selective logging of mahogany (and any subsequent land uses in the trajectory) and for the same forest land without such logging. The profitabilities can be compared with differences in C stocks under the two land uses in order to estimate the REDD+ opportunity costs (details provided in Chapter 7).

**Other forest products**

91. Estimates of profits generated from NTFPs also vary widely according to study methods, products gathered and economic context. In a meta-analysis of NTFP studies, Belcher, et al. (2005) estimated the valued of three types of value of NTFP production (US$/ha): wild ($1.8), managed ($3.8), and cultivated ($25.6). Costs of collection, especially
labor inputs, are difficult to measure comprehensively and are not reported extensively in the literature.

Reforestation

92. Although no formal agreement was reached in Copenhagen, a broad consensus developed to also include enhancement of forest C stocks. This implies, for example, REDD+ eligibility would include changes from a particular non-forest land use (returning to forest) or deviations from a degraded forest trajectory already underway to a reforested trajectory.

93. NPV calculations begin with an established non-forest (or degraded forest) land use. The forest land use includes establishment and maintenance costs.

Profitabilities of land use trajectories

94. We now have an analytical framework and sufficient information to analyze the profitability of land uses. Where needed, the enterprise budgets have been combined into multiple year budgets representing a land use.

95. The length of the time horizon for analysis can be an arbitrary decision, yet should be guided by REDD+ policy. Common horizons range from 20 - 50 years, and perhaps more. Sample results of a 30 year profit analysis from Peru are in

96. Figure 6.2 and associated Table 6.5. For each land use in the Peru case, profits in the first year are negative. This is due to the high investment costs of preparing the land for subsequent agricultural or tree production.

97. Profits change annually for most of the land uses. Agriculture and pasture systems generate earnings earlier than tree-based systems. In the Peru example, both the short- and long- fallow systems have positive profits in year two and three. During the fallow periods of 4 and 8 years, respectively, no costs or earnings generate zero profit.

98. With ranching land uses, although the initial costs of seeding pastures can be low, other establishment costs such as cattle purchases and fencing are high. The costs of establishing an improved pasture are greater than a native pasture, generating double the profits after year 1.

99. The profits of perennial land uses depend on investments required to establish the system, intercropping activities and the number of years until production from the trees.

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55 The longest horizon of CDM project activities, other than Afforestation/Reforestation (A/R), is 21 years. For A/R activities the time horizon is 60 years (UNFCCC, 2010).
56 When timber can be sold, for example, first year profits can be high. Likewise, first year profits can be positive when clearing costs are low (e.g., using burning with little slashing) and first crops are obtained quickly (annual crops).
57 The rental rate of land is considered to be zero. Discussion on this assumption below.
The tree-based systems generate negative profits (losses) for one or two years, given that weeding and other investments are typically required before production.

100. These sample results are highly sensitive to yield, price and input assumptions. These parameters, within the enterprise or land use budgets, can be adjusted to represent different socio-economic and biophysical contexts. The interconnected information enables rapid review of how parameter estimates affect profitability of a land use. More on the topic of sensitivity analysis, in Chapter 7.

Figure 6.2. Sample multi-year profit analysis (undiscounted values, $/ha)
Table 6.5. Sample results of a multi-year profit analysis (undiscounted; years 1-15, 30)

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
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<tbody>
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<td>-70</td>
<td>-70</td>
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<td>(75)</td>
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<td>Charcoal+oil palm</td>
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<td>-70</td>
<td>-70</td>
<td>-70</td>
<td>46</td>
<td>57</td>
<td>69</td>
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<td>81</td>
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<td>81</td>
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<td>200</td>
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<td>158</td>
<td>115</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>-45</td>
<td>158</td>
<td>115</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timber+improved pasture</td>
<td></td>
<td>-183</td>
<td>38</td>
<td>38</td>
<td>38</td>
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</tr>
</tbody>
</table>
Net present value

101. The above multi-year profit analyses illustrate how profit levels change during a time horizon. Nevertheless, it is not easy to determine the most attractive land use with respect to overall profitability. A land use may generate the highest profits, but occurring at the end of a time horizon.

102. Net present value (NPV), or sometimes called present value, is a calculation commonly used to estimate the profitability of a land use over many years. NPV takes into account the time-value of money. Since waiting for profits is less desirable than obtaining profits now, the “value” of future profits is discounted by a specific percentage rate, often ranging from 2-20%.

103. With multi-year analysis, NPV is a discounted stream of profits (revenues minus costs of capital, land and labor inputs).

\[ NPV = \sum_{t=1}^{T} \frac{\Pi_t}{(1 + r)^t} \]

Where \( t = \) year, \( T = \) length of time horizon, \( \Pi = \) annual profits of the LU ($/ha), \( r = \) discount rate. The major assumptions introduced at the stage of NPV calculation are the discount rate (\( r \)) and the time horizon (\( T \)).

Which discount rate should be used?

104. For discount rates, NPV analyses typically use loan interest rates, which are set by a national bank or the government. Such rates can range from 10-30%. Although agricultural loans are rarely available, especially in remote forest margins regions, bank interest rates do serve as a good indicator of the time value of money.\(^{58}\) The interest rate reflects the opportunity cost of obtaining profits - not now - but in the future.

105. High discount rates can dramatically reduce the viability and attractiveness of long-term investments. These include enterprises such as forestry, agroforestry, and cattle systems where initial years require up-front investments and payoffs occur 5-20 years later. Costs are scarcely discounted, whereas the value of future earnings can be significantly lower.

106. Another interpretation of the discounting effect from high rates is that future values do not matter. Since future profits are heavily discounted, they are not important. This can also be translated into saying that the benefits to future generations do not matter. The context of high discount rates creates incentives to generate profits and benefits in the short term, since waiting for the long term is nearly worthless. For example, the use of high

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\(^{58}\) Furthermore, smallholder farmers rarely have title to their land or tangible assets to use for collateral to be able to borrow funds.
discount rates challenges the view of conservationists who consider current and future values of biodiversity to be high. Therefore, in order to value ecosystem services, a lower (social) discount rates could be more justifiable than higher discount rates used in a risky (private) business environment.

107. In sum, it is important to select a discount rate that reflects the transaction within the market and policy context. REDD+ programs are not based on the context of smallholders conservationists or businesses. The national accounting system of a country is likely intermediate and appropriate financial context of a REDD+ program. Therefore, within this training manual a 5% discount rate is employed. To see how NPV can be calculated in computer spreadsheets, examine sheet "30 year trajectory" in the example workbook. The combination of enterprises that comprise each land use has been defined in 0. Now, in sheet NPV, a function within is used to calculate the NPV of the profit stream for each of the enterprises in a given LUT. The sensitivity of results to this assumption is examined in detail below and within Chapter 7.

Results of profitability analysis

108. Results of a sample profitability analysis are in Table 6.6. NPV estimates for the 30 year timeframe and 5% discount rate range from $15 per ha for NTFP collection to $893 for a timber and improved pasture land use trajectory. The next lowest performing trajectory was traditional pasture. Low productivity and initial investment costs lower the NPV estimates. The inclusion of profits from either timber or charcoal sales significantly increase NPV estimates. Charcoal profits more than double the NPV of a rice-plantain swidden system. Similarly, the NPV of an improved pasture system nearly doubles with the inclusion of profits from timber.59

109. All these results are highly dependent upon yields, prices and cost of inputs. Adjustment to parameters of particular land uses can be made within the corresponding spreadsheets.

59 By law in Brazil, the minimum harvest cycle for tropical forests is 25 years. Although there no forest has been managed (and survived) for that long in order to be able to assess feasibility of another harvest in year 25, NPV could be higher based on a 2nd harvest; see van Gardingen, et al., (2006) for forest regrowth models.
Table 6.6. Profitabilities of land use trajectories (5% discount rate, 30 year analysis)

<table>
<thead>
<tr>
<th>Land uses</th>
<th>Average annual profit, undiscounted</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil palm</td>
<td>45</td>
<td>346</td>
</tr>
<tr>
<td>Cocoa</td>
<td>66</td>
<td>604</td>
</tr>
<tr>
<td>Rice+plantain 8y fallow</td>
<td>20</td>
<td>302</td>
</tr>
<tr>
<td>Rice+plantain 4y fallow</td>
<td>25</td>
<td>383</td>
</tr>
<tr>
<td>Improved pasture</td>
<td>50</td>
<td>464</td>
</tr>
<tr>
<td>Traditional pasture</td>
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<td>182</td>
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<tr>
<td>Charcoal</td>
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<td>360</td>
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<tr>
<td>Charcoal+oil palm</td>
<td>58</td>
<td>706</td>
</tr>
<tr>
<td>Charcoal+rice+plantain 8y</td>
<td>33</td>
<td>662</td>
</tr>
<tr>
<td>Timber</td>
<td></td>
<td>429</td>
</tr>
<tr>
<td>Timber+improved pasture</td>
<td>65</td>
<td>893</td>
</tr>
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<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

Source: Authors.

**Backend issues – more methods and assumptions**

110. Since the results of profitability analyses always depend on a series of assumptions (e.g., data accuracy or discount rate), results can and should be questioned. It is therefore crucial to review profit estimates with respect to their underlying methodological and data assumptions. In this section, we revisit important elements of profitability analysis and discuss the implications of assumptions.

**How to handle shared and long-lasting inputs**

111. If farm inputs are used for more than one enterprise, the cost of input should be shared and attributed to the other enterprises. If the cost were to appear within the budget of one enterprise, the profit would be incorrectly reduced while other benefiting activities become more profitable.

112. To account for shared inputs, it is recommended to use rental rates per hectare or day to approximate the cost of tools and machinery (e.g., chain saws, machetes, tractors, etc.). For long-lasting inputs, prices and average lifetime values can be estimated to impute annual use cost per hectare. Analysis can also depreciate the value of the input according to a depreciation schedule (for details, see Gittinger, 1982).

**How to estimate budgets for hypothetical land uses**

113. Countries may want to estimate hypothetical land use practices within a profitability analysis. Some practices are not currently observed but may have higher C benefits than
current practices (e.g., RIL). Also, other potential new land uses might not be used now but that could begin to be used (e.g., biofuel production).

114. Often prospective budgets make unrealistic assumptions in order to obtain funds for research and implementation. Careful review of the literature about possible yields and costs savings are recommended. Both socio-economic and bio-physical conditions of case studies should be comparable to the proposed locations.

How to deal with inflation

115. Do all calculations in real terms. In other words, inflation is accounted for in the analyses. The NPV analyses combines the discount rate with the inflation rate. (Real Interest Rate = Nominal Interest Rate – Inflation) Analyses using real rates are important as they tell you what the actual increase in value was, and how much of a return was just the effect of inflation.

Time horizon of a net present value analysis

116. For NPV estimates to remain comparable across enterprises and land uses, the same time horizon must be used in all analyses. This manual uses a 30 year timeframe. As we are interested in the opportunity cost of entering a REDD+ contract, the choice of the time horizon may have important implications for buyers and sellers of emissions credits. If the time horizon for NPV calculation exceeds the respective REDD+ contract duration, opportunity costs may be overestimated and vice versa.

117. The use of a higher discount rate and longer time horizon helps improve the methodological consistency when estimating the land use profits. Since harvest cycles of different land uses are likely to have differing periods lengths, discrepancies can result within a multi-year time horizon. Some land uses may end in the end or middle of a productive phase while other may be in fallow. (Note that in Figure 4.5, the agriculture-fallow cycles are not complete within the time horizon.) Fortunately, the discount rate can cause the contribution of later year profits to be less significant.

118. If a short time horizon is used, then substantial residual values may arise for many land uses. Using a long time horizon (long enough that, under whatever discount rate is chosen, any benefits or losses beyond the time horizon no longer matter) than to use a short horizon and have to compute and enter residual values.
References and further reading


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Vera Diaz, M.C. and S. Schwartzman,. 2005. Carbon offsets and land use in the Brazilian Amazon. In Moutinho and Schwartzman (eds.) Tropical Deforestation and Climate Change. IPAM (Instituto de Pesquisa Ambienta de Amazonia), Pará, Brazil; Environmental Defense Fund, Washington, D.C.


Chapter 7. Opportunity cost analysis

Objectives

1. Generate an opportunity cost curve of REDD,
2. Review effect of changes in policy, prices and technical coefficients on an opportunity cost curve (sensitivity analysis),
3. Create maps of opportunity costs,

Contents

Estimate opportunity costs .............................................................................................................7-2
Sensitivity analyses .....................................................................................................................7-4
Opportunity costs maps7-5

Analyzing results of the opportunity cost calculations in the GIS has several advantages:

- Future land use transitions are likely to be found adjacent to past transitions. The analysis team can overlay these areas on maps of protected areas, biodiversity hotspots, population distribution, the road network, indigenous reserves and other maps.
- Analysts can then visualize where different interventions may be necessary in a REDD program.
- Future analysis could use predictions of deforestation and land use change to better target REDD+ initiatives.

References and further reading ................................................................................................7-7
1. This chapter integrates the outputs from previous chapters. Here we combine different types of information about land use – land use change, carbon stocks, and profitability.

**Estimate opportunity costs**

2. An opportunity cost is a type of tradeoff. With REDD+, an opportunity cost is measured of a land use change expressed in terms of money and physical units – instead of only physical units, as tradeoffs are often compared. The opportunity costs of REDD+ are based on $ or € per ton CO₂e.

**An opportunity cost curve**

3. A REDD+ opportunity cost curve is a comparison of the opportunity costs of many different types of land use change. The height represents opportunity cost of each land use change. The curve also shows the quantity of potential emissions reduction per type of land use change. This is the width of the respective segments.

4. In a national abatement curve developed by *Dewan Nasional Perubahan Iklim* and McKinsey and Co. (Figure 7.1), the highlighted options are related to land use. In this example, some costs of abatement are negative meaning that reducing such activity generates net earnings not costs. Such options are located to the left of the graph and below the horizontal axis. Nevertheless, as the width of these bars is narrow, the quantity of abatement potential is relatively small.

5. Other abatement options have positive costs. Examples related to land use include four abatement options of REDD from smallholders, reforestation, REDD timber extraction and REDD – intensive plantation dryland forest. Although the costs range between €<1 and €15, the potential quantity for abatement is more substantial than less expensive abatement options.
6. Such a national analysis is a useful step in understanding the costs of carbon abatement. The results, however, are a simplification of a diverse reality. A broad range of national and sub-national contexts typically reveals considerable differences from generalized results.

Spreadsheet analysis exercise
7. The spreadsheet entitled OppCost is a simplified example of an opportunity cost analysis. It is important to note that opportunity cost analysis is based on land use changes. Therefore, in addition to the land use legend, information on current land uses and land use changes at the national level are required.

8. In this example, land use information is based on the percentages. The initial land use distribution is within a single column of cells. Whereas, the row of future land use is a result of numerous land use changes corresponding to a matrix of cells. Land uses changes produce carbon emissions in three instances (Figure 7.2). The opportunity cost of avoiding a change of logged forest to agriculture is the lowest at $0.44/tCO₂e. A land use change from logged forest to agroforestry has an opportunity cost of $1.14/tCO₂e; and a change from natural to logged forest has the highest opportunity cost of $1.36/tCO₂e. A land use change from agriculture to agroforestry would imply a negative opportunity cost of $0.84/tCO₂e. This result reflects how the land use change produces higher profits and stores more carbon.
9. As the number of land uses within an analysis increases, difficulties arise in discerning which factors matter most. A convenient way to identify major determinants is through sensitivity analyses. One (or more) parameters (e.g., input costs, wages, product prices) within an analysis can be changed sequentially or simultaneously in order to assess how much it influences the results. In addition, a structured sensitivity analysis, conducted by raising and lowering the value of a parameter by a certain percentage, is useful means to assess the potential implications of uncertain parameters.

**Sensitivity analyses**

1. Sensitivity analyses are conducted to check the robustness of a quantitative analytical model, such as the opportunity cost model presented in this manual. By using such an approach, it is possible to identify the variables that account for more variation in the model results. In short, the process of sensitivity analysis involves changing the value of input parameters of the model to capture and understand the effects that such changes would have on the results. Key steps thus include:

- Identifying the key input variable and assumptions that are likely to affect the results,
- Prioritizing variables for sensitivity analysis (e.g., inputs, yields, prices),
- Determining the realistic range of variation of the variable or assumption,
- Examining the results of low and high estimates of each variable in the model,
- Documenting, comparing, and discussing the results,
- Identifying priority scenarios to consider in policy discussions,
- Considering additional land use classifications in order to improve precision,
Identifying priority areas of research to clarify the range of specific parameters (e.g. inputs, yields, prices).

2. In the case of opportunity cost analysis, key variables for consideration are prices: carbon, food, inputs, energy and bio-fuel prices determine opportunity costs.

3. In addition, an appraisal of trends, locations, and behavioral dynamics relating to change in a given country can also help identify priority variables to examine. In some cases, it can be argued that the best way for determining priority variables and their likely range is via a participatory process. Sensitivity analyses can thereby become related to analysis of different scenarios of future conditions and pathways.

4. The choice of approach to use are dependent on the expertise and resources available. While expert knowledge of variables is likely to be easier, cheaper and faster at Tier 1 level, expensive and comprehensive scenario modeling may be more appropriate at a Tier 3 level.

5. Sensitivity analyses require interpretation and critique of results. Changes in results should reflect a “normal” difference, whereby “normal” is determined with discussion to ensure that the result make sense. In other words, sensitivity analysis requires skills of science and knowledge of the context. Since models are simplifications of a larger and more complex reality, the objective of sensitivity analysis is to ensure that the model behaves as expected.

**Opportunity costs maps**

6. Maps of opportunity cost estimates are useful for visualizing the economic cost of avoiding deforestation and benefits of increasing carbon stocks. The analysis team can use the results of opportunity cost estimates to analyze their spatial distribution.

7. Figure 7.3 shows results of the type of map that may be useful for determining a starting point in the development of a REDD+ compensation program. It shows the four largest areas of forest transition in a central Peruvian Amazon study site between 1990 and 2007. The values of net emissions and abatement costs, shown in the cost abatement bar graph, are derived from the opportunity cost spreadsheet calculations. These calculations can be converted to database or tabular files that can then be imported a GIS, where they are linked to the land use transition maps described above.
Figure 7.3 An opportunity cost map, central Peruvian Amazon 1990 – 2007.

8. Analyzing results of the opportunity cost calculations in the GIS has several advantages:

- Future land use transitions are likely to be found adjacent to past transitions. The analysis team can overlay these areas on maps of protected areas, biodiversity hotspots, population distribution, the road network, indigenous reserves and other maps.
- Analysts can then visualize where different interventions may be necessary in a REDD program.
- Future analysis could use predictions of deforestation and land use change to better target REDD+ initiatives.

References and further reading


Chapter 8. Co-benefits of water and biodiversity

Objectives

1. Explain water and biodiversity co-benefits and their importance within REDD+ mechanisms,
2. Summarize how to address co-benefits within opportunity cost analysis,

Contents

What are co-benefits? .......................................................................................................................... 8-2
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Biodiversity co-benefits .................................................................................................................... 8-8
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What are co-benefits?

1. It is important to put REDD+ programs into perspective. Forests generate other environmental or ecosystem services which have economic value. Such services, or co-benefits, include biodiversity and water of forests, which are addressed in this chapter.

2. When co-benefits are present, REDD+ programs can affect more than reducing emissions and mitigating climate change. In forests with high levels of co-benefits, say in upper water catchments with unique biodiversity, the value of all the benefits could be significantly greater than the value of carbon alone. When this higher forest value is taken into account (a benefit to the country – not the individual), the opportunity cost of foregoing alternative land uses is lower.

3. The relationships between biodiversity, water ecosystem services, and carbon stocks are rarely simple. Within countries, just as forests have different levels of carbon, the level of biodiversity and water ecosystem services that forests provide can also be very different. Furthermore, priority areas for reducing emissions may not be the same as those for generating forest co-benefits. For example, dryer forests may have higher biodiversity and less carbon content than moist forests (Stickler, et al. 2009). In order to achieve multiple forest benefits when implementing REDD+ programs, countries will need to identify potential synergies and trade-offs of benefit provision.

4. The objective of this chapter is to present an approach to consider the effects of two of the more substantial environmental co-benefits, water and biodiversity, on the opportunity costs of REDD+. It is important to note that the chapter is not a definitive analysis of water and biodiversity. Rather we discuss the potential importance of water and biodiversity services within a context of estimating opportunity costs.

What are ecosystem services?

5. Ecosystem or environmental services are the “benefits that people obtain from ecosystems.” Forests, and lands in general, provide numerous beneficial ecosystem services that can be grouped into four basic types: provisioning, regulating, cultural and supporting (Table 8.1). This comprehensive framework of the Millennium Ecosystem Assessment (2006) includes services that are the focus of:
   - **opportunity cost analysis**: most provisioning services,

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60 Poverty reduction, enhanced social equity, human and indigenous rights and governance are all important REDD+ related topics that also have been categorized as co-benefits. For more on these see Brown, et al. (2008) and Meridian Institute (2009). For example, Gold Standard CDM credits emphasize carbon benefits with sustainable development benefits. For a CDM project to generate Gold Standard CDM credits, specific sustainable development criteria more stringent than UNFCCC requirements must be met. Such credits are voluntary and receive a price premium. For more information see: www.cdmgoldstandard.org/
6. The more tangible and direct benefits come from supporting and provisioning services. Less tangible, yet still substantial benefits, are cultural services and associated social relations and livelihood security. Given that they are indirect, such benefits are often overlooked. Considering such a range of benefits helps to develop a better understanding of the many contributions the water makes to ecosystems and society.

Table 8.1. Forest ecosystem services

<table>
<thead>
<tr>
<th>Ecosystem service</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provisioning</strong></td>
<td>Production of food and water (the focus of opportunity cost analysis)</td>
</tr>
<tr>
<td>Food</td>
<td>Non-timber forest products such as fruits, berries, animals</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>Water supplies of domestic, industrial and agriculture</td>
</tr>
<tr>
<td>Fiber</td>
<td>Timber, hemp, silk, rubber</td>
</tr>
<tr>
<td>Fuel</td>
<td>Fuel wood, charcoal</td>
</tr>
<tr>
<td><strong>Regulating</strong></td>
<td>Control of natural processes</td>
</tr>
<tr>
<td>Climate</td>
<td>Regulation of the global carbon cycle; local and regional climate regulation (albedo effects, regional rainfall etc)</td>
</tr>
<tr>
<td><strong>Floods/drought</strong></td>
<td>Reduction of surface water runoff</td>
</tr>
<tr>
<td>Disease</td>
<td>Reduced breeding area for some disease vectors and diseases transmission, such as malaria</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>Hydrological cycle</td>
</tr>
<tr>
<td>Cultural</td>
<td>The non-material benefits obtained from ecosystems</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>Scenery and landscapes</td>
</tr>
<tr>
<td>Spiritual</td>
<td>Spiritual significance to forests</td>
</tr>
<tr>
<td>Educational</td>
<td>Genetic resources, biodiversity</td>
</tr>
<tr>
<td>Recreational</td>
<td>Tourism</td>
</tr>
<tr>
<td><strong>Supporting</strong></td>
<td>Natural processes that maintain other ecosystem services</td>
</tr>
<tr>
<td>Nutrient cycling</td>
<td>Nutrient flows through atmosphere, plants and soils</td>
</tr>
<tr>
<td>Soil formation</td>
<td>Organic material, soil retention</td>
</tr>
<tr>
<td>Pollination</td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from UN-REDD, 2009.

7. Ecosystem services are interdependent. The amount of one type of ecosystem service is often related to other services, especially with forest. High priority conservation areas tend to generate multiple services with strong inter-linkages. Nevertheless, studies have shown varying degrees of interdependence amongst services. In some cases, minor or inverse relationships exist, depending on the types of services. For example, co-costs or "dis-benefits" may arise from land management practices that increase carbon density. Biodiversity can be lower within monoculture forest plantations.
8. Identifying such potential negatives are important to consider within a national REDD+ strategy. Like co-benefits, co-costs are site-specific consequences and therefore best to analyze on a case-by-case basis.

**How to estimate co-benefits?**

A pragmatic approach

9. To effectively address ecosystem co-benefits at a national level requires both speed and accuracy.

**Tier 1: Participate and Identify**

10. A first step in evaluating co-benefits of forest ecosystems is specifying the ecosystem services to be examined. Given the wide array of potential services, priorities per country will likely differ. A broad cross-section of public agencies, NGOs, academia and civil society should be involved in the identification process to ensure national ownership.

*Examples: national gap analyses conducted by Parties to the CBD.*

**Tier 2: Prioritize and Locate**

11. A second step in evaluating co-benefits is to locate areas with high levels of ecosystem benefits. Such a process requires combining distinct opinions and diverse types of data. Global and regional analyses, presented below, can supplement or be adapted for national analyses.

*Examples: biodiversity hotspots, catchments above urban centers.*

**Tier 3: Quantitatively Estimate Economic Values**

12. A third step in estimating co-benefits is estimating their economic value. Such information will enable direct comparison across different ecosystem services. Nevertheless, economic values do not reflect all values of such services. Moreover, tradeoffs are often difficult to value. While economic values can guide policy decisions, other non-economic values, are likely to have influence.

*Examples: Environmental service valuation and compensation schemes*

**Water co-benefits**

13. Land use affects water and associated benefits in many ways. Table 8.2 summarizes a variety of water benefits drawn from two analytical frameworks: international river cooperation (Sadoff and Grey, 2005) and ecosystem services (Millennium Ecosystem  

---

Assessment, 2003). The ecosystem concept provides a comprehensive approach for analyzing and acting on the linkages between people and environmental services.

### Table 8.2. Water benefits and services

<table>
<thead>
<tr>
<th>Types of benefit</th>
<th>Water benefits / services</th>
<th>Type of environmental service (contribution to well-being)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing benefits to water</td>
<td>Water quantity, quality, regulation, soil conservation, ecology/biodiversity</td>
<td>Supporting/Regulating</td>
</tr>
<tr>
<td>Increasing benefits from water</td>
<td>Hydropower, agriculture, fishing, flood-drought management, navigation, freshwater for domestic use</td>
<td>Provisioning</td>
</tr>
<tr>
<td></td>
<td>Spiritual and religious, recreation and tourism, aesthetic, inspirational, educational, sense of place, heritage</td>
<td>Cultural</td>
</tr>
<tr>
<td>Reducing costs because of water</td>
<td>Cooperation instead of conflict, economic development, food security, political stability</td>
<td>Cultural</td>
</tr>
<tr>
<td>Increasing benefits beyond water</td>
<td>Integration of regional infrastructure, markets and trade, regional stability</td>
<td>(social relations and security)</td>
</tr>
</tbody>
</table>


### Identify benefits

14. Another way to look at water is from a watershed perspective. Such an approach also helps associate environmental services generated from a land use, especially forests. Land-use decisions can affect the provision of watershed environmental services. Bruijnzeel (2005) provides a review of forest-water linkages. Nevertheless, disagreements are common about the extent and nature of the effects (Calder, 2005; van Noordwijk, 2005). Forest – water linkages are also often debated with many scientific results countering common beliefs.62

15. Land use affects watershed services by affecting:

   - quantity or total water yield (streamflow)
   - regularity of flow (regulation)
   - quality of the water
     - lack of sediment from erosion
     - lack pollution from farm waste (e.g. manure) and fertilizer runoff.

16. The relative importance of the watershed service depends on the site-specific conditions, the type of land-use change, and on the type of water user located within the

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62 This section largely based on Porras, et al. (2008) and Pagiola, personal communication, (2010).
watershed. Different water users have different needs, thereby determining the type of water services required. For example, a domestic water supply system needs clean water and a regular flow. In contrast, water quality is much less of an issue for a hydroelectric power facility. Nevertheless, reducing sediment loads is important for storage reservoir.

**Quantity or total water yield**

17. Forests can reduce annual flows or quantity of water. Experiments based on observations and theoretical reasons confirm that increased evapotranspiration from forests reduces annual flows (Calder 1999). Forests lose more water through evaporation than other shorter vegetation, including crops. In dry conditions, the deeper roots of trees enable forests to access to water in the ground. Therefore, water losses from forests are higher in dry climates. Experiments show that evaporation from eucalyptus forests can be twice as much than from agricultural crops.

18. Forests can also increase total flows of water. In the case of cloud forests, evidence suggests that increased water yields from cloud interception (fog droplets on vegetation, sometimes called horizontal rain) offset higher rates of evapotranspiration, (Bruijnzeel, 2001)

**Regularity of flow**

19. The impact of forests on water flow regulation is also unclear. The common view that forests act as “sponges” soak up and gradually release water is widespread, although not supported by extensive evidence. In theory, forests have two opposing effects on base-level flows: (1) natural forests tend to have higher water infiltration, which enables higher soil water recharge and increased dry season flows, and (2) increased interception and transpiration during dry periods that increase soil moisture deficits and reduce dry season flows.

20. Instances of deforestation reducing seasonal water supplies tend to be site-specific and due to different factors. The type of tree species, new land uses and associated management practices affect outcomes of forest – water flow relationships. Upper catchment cloud interception can also contribute to increased dry season flows (Bruijnzeel, 2001). However, research from Costa Rica indicates that the added capture may be relatively small versus other land uses (Bruijnzeel 2005).

21. Common management practices of non-forest land uses is a primary cause of reduced water services. For example, where deforestation is associated with high soil compaction (from roads, paths or grazing land), water runoff may rise by more than evapotranspiration declines. Similarly, exposed soils from tillage and overgrazing often cause increased runoff along with soil erosion and downstream sedimentation.

22. Forest may help reduce flood risks in rain events of “regular-intensity.” The public perceives forests as having significant benefits in terms of reducing floods. In theory,
forests may help to reduce flooding by removing a proportion of the storm rainfall and by allowing the build-up of soil moisture deficits through increased evapotranspiration and rainfall interception. Expected effects are considered to be most significant for small storms and least significant for the largest storms.

23. On the other hand, logging activities may increase floods through high impact harvesting, drainage practices, and road construction, resulting in increasing stream density and soil compaction during logging. Some early hydrological studies show few linkages between land use and storm flow. Recent evidence supports a positive relationship yet only exist in smaller catchments and during small events. Forest type and management affect the extent to which forests absorb excess water during rainy periods. In larger catchments, flooding occurs in numerous basins allowing for an averaging of flood waters. For prolonged and heavy storms, even large catchments will generate floods, but will likely occur even in forested catchments (Bruijnzeel and Bremmer 1989).

Quality of water

24. The relationship between forest and reduced erosion is also not straightforward. A general belief exists that high water infiltration rates associated with natural and mixed forests will reduce surface runoff – and thus erosion. Moreover, tree roots can bind soils thereby reducing the susceptibility of soils to erosion, especially on steep slopes. Trees also help to reduce the impact of rain on soils, and thus reduce the dislodgement of soil particles. Evidence also suggests that forests are less important than other factors, such as ground cover, soil composition, climate, raindrop size, terrain and slope steepness, in determining erosion rates.

25. For any given set of conditions, however, a forested plot will typically cause less erosion. It is also important to note that water quality can also be affected by other factors unrelated to land use. Untreated effluents from urban centers or industries are a major source of contamination unrelated to forest conservation.

26. Forests reduce sedimentation in some circumstances. Sediment delivery depends on a range of site-specific factors, including: the size of catchments, local geology, topology, stability of river banks, and land uses and road networks (Chomitz and Kumari, 1998). Forests have two potential roles. One, forests tend to be less erosive than most alternative land uses. Degraded forests, however, can also be significant source of sediment. Two, forests located in riparian corridors can intercept sediment eroded elsewhere before it reaches waterways. Although changes in land use may have significant impacts on sedimentation, comparison is needed between existing levels and before land-use change. Very few empirical studies have taken account of all relevant variables.

63 This second role is un-mentioned in Porras, et al. (2008) review, but can be a very important one (Pagiola, personal communication).
27. The extensive root systems of forests is commonly believed to help hold soil firmly in place and resist landslides. Nevertheless, this notion only hold true mostly for shallow landslides. Large landslides are not necessarily correlated to the existence of forests.

28. Natural healthy ecosystems, including forests, help maintain of aquatic habitats. Forests positively impact the health of aquatic populations in rivers, lakes and along coasts through controlling sedimentation, nutrient loading, water temperature and water turbidity (Calder, 2005). In contrast, high sediment and nutrient loads from some agricultural land uses are particularly damaging, causing eutrophication and the development of algae blooms that starve aquatic life of oxygen and sunlight.

**Quantify benefits**

29. This section needs to end on a much more positive note, indicating the kinds of services that forests can generally be expected to be provide, compared to the most common alternatives of pasture and cropland. I would put reduced erosion and higher water quality at the top of that list, followed by reduced risk of flooding at the local level, and improved dry season flow with a question mark.

30. Benefits from water ecosystem services can be estimated in many different ways. These range from local participatory approaches to data intensive global analyses. The Rapid Hydrological Appraisal tool (Jeannes, et al. 2006; van Noordwijk, 2006) mixes the two. The approach brings together knowledge of land – water linkages from computer-based landscape-hydrological simulation models with stakeholder perceptions of watershed functions. Using participatory rural appraisal techniques the tool explores stakeholders’ perceptions on:

   - severity of watershed problems in relation to land use
   - positive contributions generated from specific land-use practices
   - the potential of compensation for supporting positive actions upstream.

31. The appraisal is developed over a six month period, and has five steps:

   - month 1: inception and reconnaissance of stakeholders and issues;
   - months 2–4: baseline (desktop) data collection of existing literature and reports;
   - months 3–4: baseline (fieldwork) data collection: spatial analysis, participatory landscape analysis, surveys of local and policymaker ecological knowledge;
   - months 3–5: data processing into modeling and preparation of scenarios;
   - month 6: communications and refinement of the findings.

**Biodiversity co-benefits**

32. What happens to the opportunity costs of REDD+ when forests have a high biodiversity value? Since biodiversity of forests can generate economic benefits, the difference between the profits from forest and non-forest land uses is lower. Thus, the
opportunity costs of a REDD+ program are less. Assuming that the landowners earn profits from biodiversity, fewer funds need to be invested in order to compensate them for conserving the forest (and biodiversity).

33. Biodiversity can alleviate the need for REDD+ projects. In some high-profile biodiverse forests, the value of the forested habitat could exceed the value generated from any other land uses.\textsuperscript{64} Tourists, for example, are often willing to pay to see mountain gorillas or jungle wildlife in national parks. If biodiversity benefits are reflected in the returns that landholders generate from a given area, such benefits are not considered co-benefits as they can be included within opportunity cost estimates. Nevertheless, land tenure arrangements can complicate such calculations as many forests are protected areas, whereby locals have rights ranging from none to limited use.

34. Should a country consider biodiversity a co-benefit to itself or not? With water services generated by avoiding deforestation, associated improvements provide benefits within the country (e.g., cleaner water, lower flood risk, etc).\textsuperscript{65} Thus, it makes sense for a country to try to foster these benefits. In contrast, biodiversity is different. Most benefits are enjoyed outside the country. Much like the case of carbon sequestration, biodiversity is a primarily a global benefit. Therefore, a country would be unlikely to devote efforts to securing these benefits unless compensated for doing so.

35. Fortunately most countries have already prepared elaborate biodiversity conservation priority analyses, under their National Biodiversity Action Plans and other programs. Thus, REDD+ planners can utilize these existing plans by adapting associated maps to land use analyses of REDD+.

36. The range and complexity of plants and animals within a forest creates problems of biodiversity identification and quantification. Since the 1950s, debates on the measurement of biodiversity have remained at the center of substantial part of the ecological literature. This lack of consensus also has important implications for the estimating the value of biodiversity conservation. Any measure of cost-effectiveness used to guide investments in conservation must have some index or set of indices of biodiversity change (Pearce and Moran, 1994). Similarly, without accurate biodiversity co-benefit measures, REDD+ investments based on opportunity costs may not be justified. Issues of biodiversity measurement and valuation are discussed below.

**Identify biodiversity: What is biodiversity?**

37. Biological diversity, or biodiversity, is the variety of living plants, animals and microorganisms on Earth. Biodiversity is used to describe a wide range of life: from genes to ecosystems. Biodiversity is different from the global stock of biological resources, a more...
anthropocentric term for forests, wetlands and marine habitats. Biological resources are typically known elements of biodiversity that maintain current or potential human uses.

38. Biodiversity is important for ecosystem stability and function. Ecosystem stability has two components: resistance and resilience. Resistance is the “shock-absorbing” capacity of an ecosystem, the ability to withstand environmental change. In contrast, resilience is the ability of an ecosystem to return to its previous condition or “bounce back” after it has been severely disturbed. Loss of biodiversity typically affects both ecosystem resistance and resilience.

39. Alteration or conversion of natural habitats into agricultural lands is a primary cause of rapid biodiversity loss. Conversion of forests severely changes or simplifies an ecosystem. Modern agricultural practices, often monocultures of crop production, are an extreme case of simplification.

40. The potential impacts of accelerated extinction and depletion of biodiversity may be discerned sooner and later. In the long term, processes of natural selection and evolution may be affected by a diminished resource base, simply because fewer species are being born. The implications of species depletion for the integrity of many vital ecosystems are not known. The possible existence of depletion thresholds, associated system collapse, and huge impacts in related social welfare, are potentially the worst outcomes in any time horizon. More immediately, the impoverishment of biological resources in many countries might also be regarded as an antecedent to a decline in community or cultural diversity (Harmon, 1992).

Quantify biodiversity

41. Finding measures of biodiversity that can be used for policy decisions remains challenge. A number of factors cause difficulties. Determining the presence of a species or ecosystem in a specific location is not a straightforward task. Neither species or ecosystems have clear distinguishing boundaries. Although numerous species have been and continue to be identified, at times the definition of a particular species or boundary between

66 Losses can also be caused by:
- excessive harvesting of particular species, especially of high economic value,
- consequence of invading alien species including diseases,
- impacts of pollutants,
- extinction of essential companion species (e.g., pollinators, fruit or seed dispersers),
- climate change.

These causes of loss are outside the scope of REDD.

67 Between about 1.5 and 1.75 million species have been identified (Lecointre and Le Guyader, 2001). Scientists expect that the scientifically-described species represent only a fraction of the total number of species on Earth. Many additional species have yet to be discovered, or are known to scientists but have not been formally described. Scientists estimate that the total number of species on Earth could range from about 3.6 million up to 117.7 million, with 13 to 20 million being the range most frequently cited (Hammond, 1995; Cracraft, 2002).
species is debated and subject to revision (Gaston and Spicer, 1998). Similar difficulties challenge ecosystems. While the identification of ecosystems has improved with geographic information system technology (World Resources Institute, 2009), distinctions between ecosystems can be difficult to determine. Furthermore, ecosystems can be a moving target as climate change can have widespread effects (UNEP, 2008).

In sum, measurement of biodiversity is complex. Biodiversity is a multi-dimensional in scale (ranging from genes to ecosystems) and has different characteristics or attributes. Three features of biodiversity are often used to measure biodiversity: structure, composition and function, each at a different scale (Box 8.1). Structure is the pattern or physical organization of the biological components. Composition is their identity or variety. Functions refer to the ecological and evolutionary processes.
### Box 8.1. Measurement approaches of biological diversity at different scales

(adapted from Putz, et al., 2000)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Measurement approach</th>
<th>Structure</th>
<th>Composition</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landscape</strong></td>
<td></td>
<td>Areas of different habitat patches; inter-patch linkages; perimeter-area relations</td>
<td>Identity, proportions and distribution of different habitat types</td>
<td>Patch persistence (or turnover); inter-patch flows of species, energy and other resources</td>
</tr>
<tr>
<td>Regional mosaics of land uses, ecosystem types</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ecosystem</strong></td>
<td></td>
<td>Vegetative biomass, soil structural properties</td>
<td>Bio-geochemical stocks</td>
<td>Processes, including bio-geochemical and hydrological cycling</td>
</tr>
<tr>
<td>Interactions between members of a biotic community and environment</td>
<td>Vegetation and trophic* structure</td>
<td>Relative abundance of species and functional groups</td>
<td>Flows between patch types, disturbances (such as fires and floods), succession processes, species interactions</td>
<td></td>
</tr>
<tr>
<td><strong>Community</strong></td>
<td></td>
<td>Population age structure or distributions of species abundance</td>
<td>Particular species **</td>
<td>Demographic processes such as death and recruitment</td>
</tr>
<tr>
<td>Functional groups (e.g., guilds) and patch types occurring in the same area, and strongly interacting through biotic relationships</td>
<td>Heterozygosity or genetic distances between populations</td>
<td>Alleles and their proportions</td>
<td>Gene flow, genetic drift or loss of allelic diversity</td>
<td></td>
</tr>
<tr>
<td><strong>Species/population</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variety of living species and their component populations at the local, regional or global scale</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gene</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variability within a species: variation in genes within a particular species, subspecies or population</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* the position that an organism occupies in a food chain.

** can address issues of safe minimum standard.

### Measurement indices

43. Species richness and species evenness are commonly used as measures of diversity (Magurran, 1988). Both indices are based on identifying and counting species. Besides the drawbacks of identification mentioned above, use of the index assumes that all species present in a plot can be counted. The total number of species, however, is too high and there is no assurance that each one has been found. To illustrate the difficulty, one cubic centimeter of soil contains so many microbes that years of analysis would be required to fully characterize them.

44. Since comprehensive biodiversity measurement is not feasible, an ongoing debate surrounds the question of which groups of organisms to sample. These subsets of biodiversity are considered a surrogate for overall biodiversity. Plants are important, as
they are the primary producers in an ecosystem and animals depend on them for food, shelter, etc. Vascular plant species\textsuperscript{68} are relatively well known (e.g., compared to fungi).

45. Certain animal groups (e.g., birds and butterflies) have been well studied and are commonly used as indicator taxa. The choice of these animals, however, has usually been due to practical considerations like their visibility (and audibility in the case of birds), and the fact that their taxonomy and biology has been relatively well studied. Care should be taken when counting the number of animal species within a plot, whichever group has been chosen. Some individuals may be temporary visitors rather than actually resident in the plot. Furthermore, land uses with different vegetation can affect the visibility (e.g., more birds can be seen in an open grassland than in a densely-vegetated complex agroforestry system).

Compositional diversity

46. Species richness is the simplest measure of biodiversity. Richness (or diversity) refers to the presence or absence of species in a plot and the total numbers of species for a particular group. The Simpson Index is a measurement that accounts for the richness and the percent of each subspecies from a biodiversity sample within an area. The index assumes that the proportion of individuals in an area indicate their importance to diversity.

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**Box 8.2. Plant species richness in tropical forest margins**

ASB scientists used a minimum standard of data collected in all sites: the number of plant species per standard plot (40 x 5 m). The results from forest and forest-derived land covers in three continents are found in the below Table.

**Plant species richness in different land uses types in three ASB sites**

<table>
<thead>
<tr>
<th>Land use</th>
<th>Number of plant species within a 200 m(^2) plot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brazil</td>
</tr>
<tr>
<td>Natural forests</td>
<td>63</td>
</tr>
<tr>
<td>Managed forests</td>
<td>-</td>
</tr>
<tr>
<td>Logged forests</td>
<td>66</td>
</tr>
<tr>
<td>Extensive agroforests</td>
<td>47</td>
</tr>
<tr>
<td>Intensive agroforests</td>
<td>-</td>
</tr>
<tr>
<td>Simple tree systems</td>
<td>25</td>
</tr>
<tr>
<td>Long fallow agriculture</td>
<td>36</td>
</tr>
<tr>
<td>Short fallow agriculture</td>
<td>26</td>
</tr>
<tr>
<td>Continuous annual crops</td>
<td>33</td>
</tr>
<tr>
<td>Pasture/grasslands</td>
<td>23</td>
</tr>
<tr>
<td>Intensive pasture</td>
<td>12</td>
</tr>
</tbody>
</table>

\textsuperscript{68} higher plants that have lignified tissues (e.g., ferns, bushes, trees).
47. Forests typically have significantly higher levels of plant species richness. Nevertheless, disturbances to forests can increase diversity. After logging, new comers species can cause biodiversity estimates to be greater that estimates in pristine forests (Cannon, et al., 1998).

Structural diversity
48. Species evenness is a measure of structure. Evenness is the relative abundance with which each species are represented within a specified area. The Shannon-Wiener index takes into account subspecies richness and proportion of each subspecies. The index increases either by having additional unique species, or by having a greater species evenness. The index is also called the Shannon or the Shannon-Weaver index.

49. A species richness index can account for evolutionary differences amongst species by assigning weights to species taxa. Differences in genetic composition are determined by the family tree. Nevertheless, taxonomic analysis is data demanding and may not be a feasible approach for biodiversity assessments.

Functional diversity
50. Measuring only species is often considered inadequate in estimating biodiversity. Examining functions, or how plants and animals have adapted to their environment, is a useful concept in measuring biodiversity. Plant and animal are classified according to their functions: what they do and how do it. For example, the classification of below-ground organisms can be based on groups of animals that perform decomposition functions within an ecosystem, turning fallen leaves into other soil organic matter. Birds can be classified into functional groups (guilds) depending on their eating habits (trophic interactions). Species pertain to certain ‘diet guilds’ depending on what they eat (e.g., fruit, nectar, insects or seeds), or into certain ‘foraging guilds’, depending on where they eat (e.g., in the tree canopy, understorey vegetation, or on the ground). Land uses can be compared according to the percentage of species falling into each guild.

51. Plants can also be classified into functional groups. Adaptive traits (i.e. characteristics that plants have developed to exploit or cope with the conditions of a particular environment) are likely to be similar within similar ecosystems - on whichever continent. Therefore, similar functional types may conduct the same activities (and fill the same type of niche) in the forests of the Africa, Asia or Latin America. For example, although actual species are different across continents, the first trees (pioneers) to grow in an open patch of land have very large leaves, yet they belong to different plant families. Yet, the functional types of plants are comparable across continents in different parts of the lowland tropics.
Box 8.3. The V-index to estimate biodiversity

The V-index estimates the similarity of a land use to natural forest. It is a vegetation index calculated using a set of plant-based variables that are highly correlated with land uses, plant and animal richness and soil nutrient availability (Gillison, 2000b). The index can be also used as an indicator of land use impact on biodiversity and is based on key vegetation structural, plant taxonomic and functional types (PFTs). The index is not a direct measure of biodiversity, but more an indicator to characterize habitats or sites. Nevertheless, the V-index does include measures of vegetation structure, which is important in determining biodiversity. The component measures used to calculate the V-index are:

- mean tree canopy height,
- basal area (m2 ha-1),
- total number of vascular plant species,
- total number of PFTs or functional modi
- the ratio of plant species richness to PFT richness (species/modi ratio)

The index is calculated using a technique called multi-dimensional scaling. Results are scaled between 0.1 and 1, with 1 being the value of natural forest. Therefore, each value of the index representing a land use indicates how much that land cover differs from the local natural forest, which serves as the reference point. An advantage of the V-index approach is that measurements are easy to make in the field (with no hi-tech equipment). Nevertheless, a computer is needed to convert the individual measurements into an index measure. Step by step instructions regarding which data to collect, how, and how to analyze with the software are found in the VegClass manual (Gillison, 2000b).

The V-index was calculated for a range of forest margin land uses in Cameroon, Indonesia and Brazil. The index corresponds closely with observed impacts of land use on biodiversity, crop production and associated time since tree clearing. For example, in all sites, the V-index tends to be highest for primary forest, decreases through secondary and logged-over forests, then complex agroforestry systems, tree plantations and fallow systems and is lowest in annual agricultural crop systems, grasslands and pasture. Complex agroforestry systems based on economically-valuable tree crops have a much greater similarity to forest than monoculture plantations of the same tree crops. In Cameroon, jungle cocoa has a larger V-index value than plantation cocoa (Figure 8.1). Similarly in Indonesia, the V-index value of jungle rubber is greater than that of plantation rubber (Figure 8.2).
Figure 8.1. V-index values of land uses in Cameroon.

RF: Rainforest; Raff. palm: Raffia palm; J. cocoa: jungle cocoa; Chrom: *Chromolaena odorata* (fallow); Cocoa PL: cocoa plantation (monoculture).

Figure 8.2. V-index values of land uses in Indonesia.

RF: Rainforest; Jung. rub: jungle rubber; Log.'83: Logged rainforest in 1983; Rub plt.: Rubber plantation; Log. ramp: Logging ramp; Para. plt: *Paraserianthes falcataria* plantation; Chrom.: *Chromolaena odorata*.

52. In summary, the V-index is a measure of the complexity of vegetation. Biodiversity is positively correlated with structural complexity and the number of ecological niches available for plants and animals.

**Comparing biodiversity estimates at different scales**

53. While diversity measures can be expressed per unit area, they cannot be converted easily to other units of area (Rosenzweig, 1995). In other words, estimates of biodiversity at the landscape level are not calculated by simply adding across a series of plot estimate. The same species may be found in a number of plots, and such a procedure would lead to multiple counting. As biodiversity is sampled over larger and larger areas of a particular ecosystem, the number of additional species observed will increase, but at a decreasing rate (Figure 8.3). Eventually the curve levels off, meaning that even though the area may increase, any new species will not be found.
Figure 8.3. Species-area curve

54. Another way to examine scalar relationships of biodiversity is to associate three types of diversity (Figure 8.4).

- **Alpha diversity** – is species richness within a particular area, community or ecosystem, measured by counting the number of taxa within the ecosystem (typically species).
- **Beta diversity** – is species diversity across ecosystems, comparing the number of taxa that are unique to each of the ecosystems.
- **Gamma diversity** – is species richness of different ecosystems within a region.

Figure 8.4. Biodiversity at different scales

55. For analysis of tropical forest margins, ASB contrasted the biodiversity of land uses. To obtain results comparable across the sites, standard protocols were used. The methodology for choosing plots can be found in Gillison (2000b). The studies were complemented by a detailed baseline study in Indonesia, which collected detailed information on vegetation, birds, insects, soil animals and canopy dwelling species (Gillison, 2000a).
Box 8.4. A cautionary note with species-area curves

Scaling relations (the shape of the species-area curve) may differ between types of vegetation (Figure 8.5), or between types of species. This may be due to fundamental differences in the ecology of the species or vegetation type. Therefore, comparison of species richness per plot is valid only for plots of the same size in two different land uses.

Figure 8.5. Species area curves for three land uses in Cameroon

Biological resources and conservation priorities

56. Given the data requirements and difficulty of measuring biodiversity, biological resources (e.g., species and ecosystems) are often used as a surrogate in the development of conservation priorities and strategies. The species-area relationship in regions of high species richness is one rapid approach to identifying conservation priorities (Brooks, et al. 2006). When such hotspot areas are under threat of land conversion priorities can become urgent. Nevertheless, the cost of conservation efforts may be high and chances of success low, thereby further confounding biodiversity conservation challenges.
Box 8.5. Gap analysis

In a conservation context, gap analysis is a method to identify biodiversity (i.e., species, ecosystems and ecological processes) that are inadequately conserved within a protected area network or through other long-term conservation measures. Although the number and size of protected areas continue to grow, a large number of species, ecosystems and ecological processes are not adequately protected. Gaps come in three basic forms:

Representation gaps: a particular species or ecosystem does not exist within a protected area, or examples of the species/ecosystem insufficient to ensure long-term protection.

Ecological gaps: although the species/ecosystem is represented in an area, the occurrence is either of inadequate ecological condition, or the protected area(s) fail to address the changes or specific conditions necessary for the long-term species survival or ecosystem functioning.

Management gaps: protected areas exist but management (objectives, governance, or effectiveness) do not provide adequate security for particular species or ecosystems.

Gap analysis is a process that starts by setting conservation targets. Next, biodiversity distribution and status are evaluated and compared with the distribution and status of protected areas. The CBD Program of Work on Protected Areas (PoWPA) gap analysis can provide mapping data and tools for REDD. For more on gap analysis and recent research results see Dudley and Parish (2006), Langhammer, et al. (2007) and IUCN publications.

Value biodiversity

57. Despite the importance of biodiversity, economic valuations are often complex, expensive and likely imprecise. Non-economic methods exist to examine public concern for biodiversity. Insights gained from public participation can complement benefit-cost approaches for policy decisions. The annex includes details on estimating the value of biodiversity also the references below contain numerous sources.

Co-benefits and opportunity costs

58. Benefits of forests can be divided into three categories:

- on-site benefits (e.g., fuelwood, timber, non-timber forest products, tourism)
- off-site benefits
  - within-country (e.g., protection of water services).
  - Outside-country (e.g., carbon sequestration and biodiversity habitat).

59. Within REDD+ discussions, off-site within-country benefits are typically termed: co-benefits of conserving, improving or establishing forests.
Here we present two sample “Tier 2” studies. Pagiola, et al. (2006), for example, identify areas within the highlands of Guatemala that are important for water and biodiversity services. Such information can be used in conjunction with opportunity cost estimates to determine whether particular areas should be prioritized within a REDD+ program (Box 8.6). A second example of co-benefits maps comes from Tanzania (Box 8.7).

**Box 8.6. A national analysis of water and biodiversity benefits**

Spatial analysis of water and biodiversity can help identify priority conservations. For example, Pagiola et al. (2007) developed maps of water supply and biodiversity conservation priority areas in Guatemala. Maps contain a simple but useful amount of quantification, and could be made more complex if and when data become available. Figure 8.6 shows a relationship between municipal water supply systems and associated supply systems. Darker red areas highlight areas that serve more households per area of catchment. This calculation can serve as a potential indicator of water co-benefit.

![Figure 8.6. Municipal water systems and supply areas, Guatemala.](source)

**Figure 8.6. Municipal water systems and supply areas, Guatemala.**

*Source: Pagiola, et al. 2007.*

**Box 8.7. National analysis of multiple benefits: An example from UN-REDD**

An effective way to identify and document co-benefits is through maps. One example of a recent effort is from UN-REDD+ Program at the UNEP World Conservation Monitoring Centre (WCMC) and the Tanzania Ministry of Natural Resources and Tourism. A national-
scale analyses of co-benefits and other factors was conducted, including population density, honey-beeswax-gum production, and mammal and amphibian species richness (Figure 8.7). In addition, a revised combined soil and biomass carbon map for Tanzania was produced (UN-REDD+ Program, 2009).

![Figure 8.7. A combined soil-biomass carbon map of Tanzania and priority NTFP areas](image.png)

**Source:** Miles, et al. 2009.

61. Naidoo et al. (2008) reviewed theory, data, and analyses needed to produce ecosystem services maps. Data availability allowed the quantification of imperfect global proxies for four ecosystem services: carbon sequestration,\(^69\) carbon storage,\(^70\) grassland production of livestock and water provision. Using this incomplete set as an illustration, ecosystem service maps were compared with the global distributions of conventional targets for biodiversity conservation.

62. Preliminary results show that regions selected to maximize biodiversity provide no more ecosystem services than regions chosen randomly. Furthermore, spatial concordance varies widely amongst different services, and between ecosystem services and established conservation priorities. Nevertheless, “win–win” areas of ecosystem services and biodiversity can be identified, both among eco-regions and finer scales. An ambitious

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\(^69\) Net annual rate of atmospheric carbon added to existing biomass carbon pools.

\(^70\) Amount of carbon stored in vegetation both aboveground and belowground.
interdisciplinary research effort is needed to fully assess synergies and trade-offs in conserving biodiversity and ecosystem services. Comparisons of these attributes of land use changes can reveal tradeoffs and synergies useful for understanding the potential role of REDD+ policy to foster desired outcomes.

63. Although the value of co-benefits is very difficult to estimate and even more challenging to convert into per hectare values, opportunity cost analysis guide where

   a. quantification and perhaps valuation efforts are priority,

   b. the identification of land uses to include in a REDD+ program.

64. Figure 8.8 contrasts four emission abatement options that correspond to different land use change contexts. Options A and B have similar, REDD+ opportunity costs less than the price of carbon. Although option B has a slightly higher costs, it is a priority for REDD+ given the higher estimated water co-benefits. Options D and E have higher REDD+ opportunity costs. Given that option D has a lower opportunity cost and has substantial estimated water co-benefits, it is also a priority for REDD+ program inclusion. Option E, which has REDD+ costs greater than the price of carbon, would normally not be included in a REDD+ program. With consideration of co-benefits, however, the option should be included.

65. Quantification of benefits is only important for the case where the REDD+ costs exceed the price of carbon. In all other cases, the carbon costs are less than carbon benefits so quantification of co-benefits is not needed.

![Figure 8.8. Identifying priority co-benefit analyses](source: Pagiola, 2010.)
Conclusion

66. The value of co-benefits can be substantial and greatly affect the opportunity cost estimates of REDD+ projects. Whether to or how to recognize water and biodiversity benefits within REDD+ policies is still being discussed (Ebeling and Fehse 2009; Pagiola and Bosquet, 2009). Though a REDD+ mechanism offers opportunities to achieve both carbon and other co-benefits, the limitations of a REDD+ mechanism to act as a panacea for biodiversity loss or water problems needs to be challenged. Overemphasis on non-climate change objectives within a REDD+ mechanism comes with a risk of raising transaction costs, potentially reducing the ability to conserve forests.

67. Specific suggestions for policy-makers include the following:

- **Biodiversity**
  
  o Develop a national information base on national biodiversity to increase the likelihood of achieving and maximizing a range of biodiversity co-benefits in REDD. Biodiversity-targeted funding can then have better understanding of biodiversity and aim to complement REDD+ financing, such as focusing in areas with high biodiversity and low carbon benefits.

  o Link on-going REDD+ demonstration activities with biodiversity performance assessments of monitoring, reporting and verification. This will enable the analysis, comparison, and evaluation of different approaches and methods used to promote biodiversity co-benefits in a REDD+ context. Lessons learned during the implementation of these REDD+ demonstration activities can ultimately feed into the international and national level policy-making processes.

  o Establish a technical working group on REDD+ biodiversity co-benefits to develop best-practice guidelines and principles, including indicators for biodiversity. Such a group could also help guide the policy decisions and implementation REDD+ activities at the national, regional and/or local levels.

- **Water**

  o Establish an national information base (e.g., inventories, maps) of water resources to increase the likelihood of achieving and maximizing water co-benefits in REDD. Water-targeted funding can then work within a REDD+ context, in order to focusing on areas of important water services (e.g., upper catchments).

71 Adapted from Karousakis (2009).
o Support and review efforts in modeling water ecosystem services and link government decisions with national REDD+ policy development and implementation. The clarification of diverse water services (e.g., flow regulation, water quality, etc.) will help policymakers prioritize government investments and actions.

o Establish a technical working group on REDD+ water co-benefits to develop best-practice guidelines and principles, including indicators for water services. Such a group could also help guide the policy decisions and implementation REDD+ activities at the national, regional and/or local levels.

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Chapter 9. Tradeoffs and scenarios

Objectives
1. Discuss tradeoff and synergies associated with REDD+ policy
2. Present methods to conduct scenario analyses to address uncertain future policy and economic contexts.

Contents
Tradeoffs ................................................................. ................................................................. 9-2
Scenarios ................................................................. ................................................................. 9-4
**Tradeoffs**

1. A tradeoff is a situation involving a loss of one thing with a gain in another. Win-lose situations are tradeoffs. They are often depicted with two dimensional graphs, by an inverse relationship (or downward slope of points) displaying the tradeoff. The axes of the graph are in typically in physical units of the good or service.

2. The relationship between profits from and carbon within different land uses is an example of a tradeoff (Figure 9.1). The horizontal axis represents carbon content of a land use (t/ha); the vertical axis corresponds to profits of a land use ($/ha). Natural forests, in the lower right-hand section, have high carbon stocks but low profitability. Agricultural crops, in contrast, have low carbon and high profitability. Some land uses, such as extensive cropping and cattle raising in this example, do not represent a tradeoff since they have both low carbon and profitability. More importantly, there are no apparent “win-win” high-carbon with high-profit land uses, as evidenced by no examples in the upper-right portion of the graph.

![Figure 9.1. NPV profit vs. carbon stock tradeoff of land uses](image)

3. Many other REDD-related tradeoffs exist, for example, between profits and biodiversity co-benefits and profits and water co-benefits. Table 9.1 summarizes likely relationships, tradeoffs (−) or complementarities (+), between profits, employment, carbon, biodiversity and water. Instead of being tradeoffs, relationships between carbon, water and biodiversity are likely to be positive, also between profit and employment. A larger amount of one of these goods and services is likely to be linked with larger amounts of the other.
Generally, the human goods/services of profits are inversely related to the natural goods/services of carbon, biodiversity and water.

Table 9.1. Likely tradeoffs and complementarities of goods & services from land uses

<table>
<thead>
<tr>
<th></th>
<th>Employment</th>
<th>Carbon</th>
<th>Biodiversity</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Employment</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carbon</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

4. A well-known tradeoff exists between profitability and biodiversity conservation. Farmer efforts to increase crop productivity often decreases biodiversity. Consequently, farmers may be unwilling to tolerate plant diversity and will remove trees and weeds in order to improve profit margins. Such productivity gains often occur in both agricultural monocrops and mixed land use systems. In rubber agroforests of Indonesia, for example, the number of rubber trees per unit area increased rubber production. Meanwhile, the number of other tree species decreased correspondingly (Lawrence, 1996). Extreme, yet common, cases are where economically-important agricultural crop and tree species are grown as monocultures.

Box 9.1. Land use tradeoffs: segregate or integrate land uses for biodiversity?

How does landscape uniformity and diversity affect estimates of biodiversity? The spatial arrangement of land uses types raises the question of how to achieve optimal levels of biodiversity within a landscape. If a specific conservation function is the objective, other functions will likely occur, but probably to a lesser degree.

Let’s illustrate this point with an example. An entire landscape of monoculture oil palm has a different potential value for biodiversity than a landscape containing a mixture of different-aged forests within a mosaic of smallholder farms. A ‘segregated’ option is to keep agriculture and forest completely separate: the forest untouched (with high biodiversity), and intensive agricultural production using monocultures e.g., oil palm, rubber, foodcrops with high intensity use of inputs (very low biodiversity).

An ‘integrated’ option incorporates/conserves as much biodiversity as possible in the farms within the landscape e.g., in fallows, complex cocoa agroforests, or multistrata agroforestry systems (including Brazil nut, mahogany, peach palm etc.). The consequences for biodiversity of the segregate-integrate choices are of a mixed nature. On the agricultural side of a ‘segregated’ landscape, the main benefits of agrobiodiversity may focus on the prevention or control of outbreaks of pests and diseases along with pollination. At the same time, forest animals can damage crop harvests.
Biodiversity benefits from segregated or integrated landscapes

<table>
<thead>
<tr>
<th>Segregated - Agriculture</th>
<th>Segregated - Natural forest</th>
<th>Segregated landscape with Ag + Forest</th>
<th>Integrated - Agroforestry mosaic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agrobiodiversity mainly relevant for pest and weed control</td>
<td>Large reserves desirable to maintain viable populations</td>
<td>Sharp (fenced) boundaries reduce conflict but create isolated and potentially unviable populations</td>
<td>Agrodiversity provides benefits or has relatively little negative impacts on human activities</td>
</tr>
</tbody>
</table>


5. Although tradeoffs may exist, the magnitude of the losses versus the gains can reveal opportunities for beneficial, and perhaps optimal, compromises. In some instance, it is possible to achieve a substantial gain with a small loss. Such insights into relationships help reveal likely consequences of policy decisions.

Spreadsheet analysis exercise

6. In the XL workbook, we have an opportunity to examine a number of tradeoffs and complementarities. The worksheet entitled Tradeoffs is a simplified version containing four land uses and compares three attributes of the land uses: profits, carbon and employment. Data inputs are per ha estimates for carbon, profit and workday per land use. Outputs are three tradeoff graphs: profitability vs. carbon, profitability vs. employment and employment vs. carbon. Adjustments to the data within the land use legend will affect the associated graphs.

7. While profitability and employment reveal a complementary relationship, both comparison of profitability vs. carbon and employment vs. carbon are tradeoffs. Agriculture and agroforestry land uses generate more profits and have less carbon than logged and natural forests. In this example, agroforestry generates both greater profits and has higher carbon content than agricultural land uses. Therefore, given these criteria agroforestry would be a preferable policy option. Nevertheless, such broad conclusions are based on two specific criteria. Many others exist that make agriculture a valuable land use, such as the importance of staple food produced and ability to generate earnings with a lag time. (See Chapter 6 for further explanation.)

8. Tradeoffs2 is an extension of the previous worksheet whereby additional characteristics of land uses (biodiversity and water co-benefits) are added. Given the data, both tradeoffs and complementarities become apparent.

Scenarios

9. In simple terms, scenarios are logically-consistent and realistic stories about the future. Scenarios can account for a variety of possible futures and their associated uncertainties. Scenarios encourage us to open our minds in order to consider the range of
changes or surprises that could occur in the future and think about their impacts. They go far beyond a “business as usual” approach, where we anticipate the future by looking at the past. Thus, scenarios can help to improve the understanding of decision-makers about the potential consequences of decisions taken today.

10. While sensitivity analysis (in Chapter 7) considers the effects of marginal changes in specific economic parameters (e.g., prices of outputs, efficiency of production, costs of inputs) on the net present value of alternative land uses, scenario analysis considers changes in groups of parameters due to overall economic changes, the introduction or prohibition of specific land uses, or alternative rules regarding the eligibility of land uses and land use changes for mitigation payments. Possible scenarios include:

- Large shifts in relative prices due to changes in the world commodity markets. An example contrasts is a high price scenario (2008), and a low price scenario (2006). Such scenarios need to be translated into sets of adjusted price parameters.
- Shifts in relative prices due to domestic or international policies. For example, biofuel policies have potential to shift prices for oil palm or sugar cane.
- Changes in property rights. Uncertainty in property rights can be captured in NPV analysis through explicit adjustments to NPV estimate, where expectations explicitly recognize the probability of a land user being able to invest and capture increased future revenues. In the Sumberjaya area of Indonesia, for example, farmers are less than certain that they will be able to benefit from land investments.
- Policy-induced changes in returns to alternative land uses. Policies can foster technology change and thereby affect production efficiency. Examples include improved access to fertilizers in Africa, export taxes (cocoa in Ghana) and subsidies (e.g., Malawi’s agricultural input subsidy programs)
- Carbon market scenarios. A possibility exists for farmers to be compensated for the carbon value of all or some land use types (e.g. AFOLU, all land use changes).
- Different national land and forest use policies. Avoided deforestation policies may decree and enforce the protection of certain land types (e.g., primary forests) that can be reflected in changes in the land use transition matrix.
- Increased accuracy or removal of systematic bias in carbon measurements (e.g., improved allometric equations or wood density estimates).
11. Scenarios introduce creative thinking about driving forces of land use change and their potential impact. Scenarios can create awareness about current and future land use, as well as serving as a synthesis tool, where different types of knowledge are combined in different formats, using both quantitative and qualitative information/methods. For example, local knowledge on the driving forces of deforestation is key for scenarios to be credible and plausible. Scenarios can also help identify potential threats, uncertainties, conflicts, as well as opportunities that a community could be facing in the future. Key steps in scenario analysis include:

1. Identification of actors involved (stakeholders) and selection of participants to the participatory scenarios exercise,

2. Start the participatory scenarios process: Identification of focal questions including the goal / objectives of the analysis,

3. Identification of context and driving forces of change,

4. Develop the scenarios (storylines),

5. Description of the scenario, possible causes and implications for parameter values (changes in C, P, or elements of the land use transition matrix)

6. Analysis across scenarios, Derivation of the opportunity cost estimate based on different scenarios

7. Map the results of the scenario and compare the map results for the base case.

8. Interpretation of results and implications.

12. A combination of tools and methods, quantitative and qualitative can be used at any of the stages in scenario development above. The process could be based on expert knowledge or be developed as a participatory process in which all actors are involved. The choice of methods depends on each country given the skills, capacity and the resources available.

Exercise: the effects of different REDD+ eligibility rules

13. The spreadsheet Eligibility presents a quick analysis of how REDD rules will affect eligibility of compensation for opportunity and other associated costs. Changes to the yellow highlighted cells reveals REDD+ policy effects on 11 categories of land use.

14. Given that no clear rules exist for REDD+, examining their potential effect is useful for national policy planning. Although discussions point toward agreement on conservation, sustainable management of forests and enhancement of forest carbon stocks as being eligible within REDD+, clarification on what is meant by a forest and changes in forests is still needed.

15. Other issues include whether or not REDD+ will be part of National Appropriate Mitigation Actions (NAMA). If REDD+ becomes part of NAMA, then REDD+ policy would be
equivalent to REDD++, AFOLU – Agriculture Forestry and Other Land Use or REALU – Reduced Emission from All Land Use, as described in the literature.

16. Thus, four types of approaches, RED, REDD, REDD+ and REALU are possible outcomes of a UNFCCC policy agreement. The implication of eligibility conditions under these four versions can be illustrated by identifying appropriate parts of a land cover change matrix (Figure 9.2).

   o RED = Reducing emissions from (gross) deforestation: only changes from ‘forest’ to ‘non-forest’ land cover types are included; details depend on the operational definition of ‘forest’
   o REDD = RED + (forest) degradation, or the shifts to lower C-stock densities within the forest; details depend on the operational definition of ‘forest’
   o REDD+ = REDD, + restocking within and towards ‘forest’; in some versions RED+ will also include peatlands, regardless of their forest status; details still depend on the operational definition of ‘forest’
   o REDD++ = REALU = REDD+, + all transitions in land cover that affect C storage, whether peatland or mineral soil, trees-outside-forest, agroforest, plantations or natural forest. No dependence on operational definition of ‘forest’

17. The approach to estimate opportunity costs within this manual could be selectively applied to any of the four versions. The main filter for this in the approach would be the land cover change matrix that is used in the opportunity cost estimation.
Figure 9.2. Comparisons of eligible land cover changes per form of RED - REALU rules
Estimating the opportunity costs of REDD+  
A training manual

Chapter 10. Conclusions and next steps

Objectives

1. Identify and discuss how to review and update the opportunity cost analyses,
2. Discuss how to communicate the results,
3. Present the next steps related to opportunity cost analysis and REDD+.

1. This manual has presented a bottom-up approach for estimating the opportunity costs of REDD+. The steps include:
   - Analyzing land use change and generating land use change matrices,
   - Estimating time-averaged carbon stocks of land uses,
   - Estimating the profitabilities of land uses,
   - Calculating opportunity costs and generating opportunity costs curves
   - Interpreting the cost curves and conducting sensitivity analysis
2. In addition, the manual has presented how to:
   - Examine water and biodiversity co-benefits,
   - Identify and prioritize specific abatement options (land use change contexts) where co-benefits can substantially affect opportunity cost estimates,
   - Estimate the economic value co-benefits,
   - Review possible tradeoffs amongst carbon sequestration, biodiversity and water priorities.
   - Develop scenarios of future national development and conservation paths,
   - Examine the effects of different REDD+ eligibility rules,
3. In this chapter we explain how to review and update an opportunity costs analysis, effectively communicate results and identify next steps for opportunity cost analysis within national REDD+ efforts.

What opportunity costs reveal, and what not?

Opportunity costs are only one part of REDD+ costs

4. Opportunity costs are only part of the costs of REDD+. For many countries, opportunity costs could be largest of REDD+ costs (see Figure 1.1). Hence, getting a full picture of costs requires estimating all other associated costs and constructing REDD+ supply curve. Nevertheless, the opportunity costs estimates of land use changes, described
above, is a significant step to understanding the cost implications that come with REDD+ participation.

The analysis is retrospective

5. The methodology presented is based on actual land uses. Although these land uses may not adequately represent future, higher-value land uses, estimates of their opportunity costs provide a useful starting reference for further analysis and estimation. Profits from land uses depend largely on soil fertility, management practices and market access, each of which can be adjusted to reflect likely future circumstances. Furthermore, the effect of new technologies and associated land uses can also be explored. Such information will become available as more countries estimate opportunity costs. Countries can use such Tier 1 type of information to develop “new” land use trajectories within scenario analyses.

No partial or general equilibrium effects are included

6. The above method of opportunity cost analysis generates simple, tractable estimates of the cost of REDD+ programs to landowners. The approach, however, does not account for global feedbacks of REDD+ that will likely affect prices and costs across a broad spectrum of land uses and economic sectors.

7. Additional analysis is required since the reach of REDD+ could be far. For example, global food and energy prices could be affected as the value of land rises. Such intersectoral linkages between forestry, agriculture and energy (especially with respect to biofuels) will likely impact opportunity costs. While partial and general equilibrium models deal can better estimate such complex and indirect effect, the method in this manual can provide useful first approximations via scenario analyses, whereby prices of timber and agricultural products are raised in order to estimate the effect on opportunity costs.

A qualitative valuation of co-benefits

8. This study limits the valuation of co-benefits to qualitative measures within an analysis of trade-offs. Sophisticated and expensive valuations of water, biodiversity, scenic beauty, and other co-benefits would provide potentially more accurate estimates of REDD+ opportunity costs. Nevertheless, methods to quantitatively estimate such co-benefits are not without substantial limitations and costs. Qualitative assessments of co-benefits can help policymakers identify priority areas and land uses for special consideration within REDD+ programs.

Next steps

Updating an opportunity cost analysis

9. Since opportunity cost information can be time-sensitive, analyses should be updated periodically. National REDD+ analysis teams should review land use changes, technologies,
management practices, carbon estimates and prices in order help ensure the validity of opportunity cost estimates.

10. A second reason for updating the opportunity costs is related to the availability of analytical methods and data quality. For example, countries may start either at Tier 1, 2 or 3 have. Depending on where a country starts, updates and improved accuracy may be achieved accordingly. Consider the following examples:

1. A country begins an opportunity cost analysis at Tier 1, using default values and simple tools. The uncertainties of estimates are likely to be much higher, requiring that more data collected over time to improve accuracies. This is likely to be the case for most data-scarce developing countries within the FCPF and UN-REDD+ program.
2. A country starts estimating opportunity costs using a combination of default values and representative data from the area / country concerned, thereby achieving Tier 2. Such countries will need to continue collecting more data on the ground in order to improve accuracies and build models in order to achieve Tier 3.
3. A more developed country estimates opportunity costs at Tier 3 using complete and detailed data sets. Such countries will still need to update the estimates using updated prices, land use changes and policy changes.

11. One question that arises is: when or how often should opportunity costs be updated? A quick answer would be it depends on the rate of change within the given analytical context (i.e., landscape or a country). Although some may argue for regular updates, the associated expenses, however, could be prohibitive. In addition, such a procedure could also lead to revisions of only a sub-set of data required (e.g. land use, carbon, profits). The mixing of newer with older information could bias a comparisons across opportunity cost estimates. Therefore, updates should be comprehensive.

12. REDD+ policy and/or carbon markets may reward or even require updates of deforestation drivers and opportunity cost estimates. Such revised analyses could help identify pressures on forests potential areas of concern, such as where opportunity costs become significantly higher. These areas may require extra policy measures to assure compliance.

**Communicating the results from opportunity costs analysis**

13. Effective communication tactics can help assure the use of opportunity cost estimates within the policy and decision-making arena. Since analytical methods and even the concept of opportunity costs itself can be difficult to understand, particular approaches within a range of options may be more effective. Such options include:

1. Writing, printing and disseminating an executive summary of an opportunity cost report;
2. Synthesizing the study into a policy briefs, which are published and widely-distributed;
3. Presenting results at different science-policy and stakeholder forums;
4. Sharing results and their potential implications with popular media (newspapers, trade magazines, radio, television)
5. Involving policy makers in the opportunity cost analysis. (Within a Tier 3 context, modeling approaches of various policy scenarios can be collaboratively explored. For either a Tier 1 or 2 approaches, demonstrations and reviews of analytical results improve mutual understanding and help identify priority policies to develop and implement.)

14. In the communication process, key discussion questions are important to identify and address, such as:
   a. Who are the likely winners and losers from REDD+?
   b. How large are the other costs of REDD+? How do they differ within the country and per land use change?
   c. At what price could most deforestation in the area be averted?
   d. Which areas and land uses will be most / least affected by REDD+?
   e. What aspects of the environment or the economy are likely to be most impacted by REDD+?
   f. What national policies are needed to achieve reference emission levels in the future?

15. The sharing of results and discussion of implications can help both policymakers and public understand the potential benefits and costs of REDD+ participation. Feedback from stakeholders could also improve the accuracy, precision and relevance of results.
Chapter 11. Appendices

A. Glossary
B. Answers to common questions
C. Allometric equations
D. Required capacities for a national monitoring system of emissions
E. Steps to calculate time-averaged C: from plot to land use
F. Methods to estimate the economic value of biodiversity

A. Glossary
Definitions to important words and terms:

**Above ground biomass.** Biomass above the soil surface: trees and other vegetation.

**Accounting stance.** The viewpoint from which costs and benefits are calculated. Typical accounting stances for analyzing REDD+ initiatives are that of: an entire country, individual groups within a country, the government, and global community.

**Additionality.** The reduction in emissions by sources or enhancement of removals by sinks attributable to a project/program activity. (Modified from Climate Change 2001: Mitigation. http://www.grida.no/climate/ipcc_tar/wg3/454.htm).

**Attribute table.** A database or tabular file with information linked to distinct features shown on maps; can refer to points, lines or polygons in a vector GIS or grid cells in a raster GIS.

**Baseline.** A reference scenario, the basis for comparison, against which a change in carbon stock/greenhouse gas emission or removal is measured (IPCC Special Report on Land Use, Land Use Change and Forestry. http://www.ipcc.ch/pdf/special-reports/spm/srl-en.pdf).

**Below ground biomass.** Biomass below the soil surface: plant roots and other soil biota.

**Allometric equation.** Scaling rule or equation that relates tree biomass (or similar properties) to stem diameter and/or tree height.

**Attribute table.** A table that is joined or related to map features, storing quantitative and descriptive information about these features and permitting queries and symbolization according to variables in the table.

**Biomass.** The total mass of living organisms including plants and animals for a given area usually expressed as dry weight in g m⁻² or kg ha⁻¹. Organic matter consisting of or recently derived from living organisms (especially regarded as fuel) excluding peat. Includes products, by-products and waste derived from such material.

For most ecological research and for the purposes of this manual, "biomass" is a vegetation attribute that refers to the weight of plant material within a given area.
Another commonly used term for biomass is "production" which refers to how much vegetation is produced in an area.

**Capital.** Also financial capital. Money and savings.

**Carbon budget.** The balance of the exchanges of carbon between carbon pools or within one specific loop (e.g., atmosphere–biosphere) of the carbon cycle.

**Carbon dioxide equivalent.** A measure used to compare different greenhouse gases based on their contribution to radiative forcing. The UNFCCC (2005) uses global warming potentials (GWPs) as factors to calculate carbon dioxide equivalent.

**Carbon stocks.** Total carbon stored (absolute quantity) in terrestrial ecosystems at a specific time, as living or dead plant biomass (above and below-ground) and in the soil, along with usually negligible quantities as animal biomass. The units are Mg ha⁻¹.

**Carbon pool.** A reservoir or subsystem which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, soils and the atmosphere. The units are mass (kg ha⁻¹ or Mg ha⁻¹).

**Carbon sequestration.** The process of increasing the carbon content of a carbon pool other than the atmosphere.

**Charcoal.** Blackish residue, porous, consisting of impure carbon (about 85-90% C) obtained by removing water and other volatile constituents of animal and plants substances. It is usually produced by heating wood in the absence (or at low levels) of oxygen.

**Classification system.** A framework to arrange objects into groups, called classes, on the basis of characteristics. Classifications are based on criteria used to distinguish classes and the relationship between them. The definition of class boundaries should be clear, precise, possibly quantitative, and based upon objective criteria (FAO LCCS handbook, 2000).

**Country-specific data.** Data for either activities or emissions that are based on research carried out on sites either in that country or otherwise representative of that country.

**Discount rate.** A rate reflecting a time-preference at which the value future profits are reduced in a multi-period model.

**Emissions.** The release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time (UNFCCC Article 1.4).

**Good Practice.** A set of procedures intended to ensure that greenhouse gas (GHG) inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that uncertainties are quantified and reduced so far as possible. *Good Practice* covers choice of estimation methods appropriate to national circumstances, quality assurance and quality control at the national level, quantification of uncertainties and data archiving and reporting to promote transparency.

**Ground truth.** A remote sensing term referring to the actual condition of the Earth surface as determined by field visits.
**Land cover.** The classification of the biophysical surface of the Earth, comprising vegetation, soils, rocks, water bodies and areas built by humans.

**Land use (LU).** The classification of human activities, occupation and settlement of the land surface; e.g., annual crops, tree crops, plantations, urban, conservation area, etc.

**Land use legend.** The key to features in a classification system on a map, expressing each class as distinct colors, patterns or descriptions. In this manual, classes and sub-classes in a land cover legend to are matched with LUs.

**Land use classification system.** A framework for organizing land uses according to characteristics that differentiate them and make them unique (forests, agriculture, pastures, urban, etc)

**Land use system (LUS).** Dynamic characteristics and interactions in activities across space and time on the Earth surface. The word *system* refers to sequential cyclical changes that are part of a land use, such as the crop/fallow rotation in shifting cultivation systems. For the sake of brevity, the term *land use* is employed throughout the manual.

**Landscape.** A non-exact area of land. A portion of land or territory which the eye can comprehend in a single view, including all the objects it contains.

**Leakage.** Changes in emissions and removals of greenhouse gases outside the accounting system that result from activities that cause changes within the boundary of the accounting system. There are four types of leakage: activity displacement, demand displacement, supply displacement, and investment crowding. If leakage occurs, then the accounting system will fail to give a complete assessment of the true aggregate changes induced by the activity. (IPCC Special Report on Land Use, Land Use Change and Forestry. http://www.ipcc.ch/pdf/special-reports/spm/srl-en.pdf)

**Minimum mapping unit (MUU).** The smallest homogeneous area, or unit, that can be distinguished from remote sensing data and associated map. The MMU is dependent on the resolution of the imagery. Higher image resolution enables smaller, precise MMUs.

**Mixed mapping unit.** A mapping unit that represents a combination of LUS units. Because of insufficient spatial resolution, units are combined into a class that represents two or more land covers or land uses.

**Mortality/ Tree mortality.** Dead trees per area.

**Necromass or Dead Organic Matter.** The weight of dead organisms, usually expressed as g m⁻² or kg ha⁻¹. Necromass consists mainly of plant litter. It is usually on the soil surface or in the soil, but some may take the form of standing or attached dead material. Much of the transient or lag in response to rapid climate change by forest ecosystems can be estimated by the difference between tree regeneration (tree natality) and tree mortality. Annual necromass increments result from individual tree mortality within stands and from larger-scale disturbance and dieback events (fires, insect infestations, disease infestations, wind throw). In addition, a significant portion of the carbon stocks which comprise stored terrestrial carbon of forest and non-forest communities is in the form of necromass.

**Net present value (NPV).** The present value of an investment’s future net cash flows minus the initial investment.
**Net returns.** See profit.

**Organic matter** (or **organic material**). Matter that has come from a once-living organism; is capable of decay, or the product of decay; or is composed of organic compounds.

**Peatland.** Peatland is the land rich in partly decomposed plant remains, with organic C of >18% and thickness of >50 cm. Peatland is intrinsic to many wetlands around the world. The tropical peat is about 1 to 7 m thick and at places it can be 20 m thick. Moss, grass, herbs, shrubs and trees may contribute to the buildup of organic remains, including stems, leaves, flowers, seeds, nuts, cones, roots, bark and wood. Peat forms in wetlands or peatlands, variously called bogs, moors, muskegs, pocosins, mires, and peat swamp. Through time, the accumulation of peat creates the substrate, influences ground-water conditions, and modifies surface morphology of the wetland.


**Profit.** Net returns, or revenues minus costs.

**Raster GIS.** represents the Earth surface as a grid of cells of uniform area, each holding information on characteristics of its respective geographic area; useful for continuous data such as satellite imagery or climate and elevation surfaces.

**Removals.** Removal of greenhouse gases and/or their precursors from the atmosphere by a sink.

**Rent.** Also known as economic rent or producer surplus. The value that producers obtain when actual price exceeds the minimum price sellers will accept. In a REDD+ context, rent is the different between the international price of carbon and REDD+ costs.

**Resolution.** See spectral and spatial.

**Sink.** Any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere. (UNFCCC Article 1.8). Notation in the final stages of reporting is the negative (-) sign.

**Soil organic matter** (SOM). Mass of soil organic matter in a unit dry mass of soil. It’s often expressed in % by weight.

**Soil organic carbon.** Mass of carbon in a unit dry weight of soil, often expressed in % by weight. Unless measured directly, soil organic carbon is assumed 1/1.724 of soil organic carbon.

**Soil bulk density.** Oven-dry mass of soil in a unit volume of bulk soil (including the volumes of solid soil and soil pores).

**Source.** Any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere (UNFCCC Article 1.9). Notation in the final stages of reporting is the positive (+) sign.

**Spectral resolution.** Refers to the capacity of airborne or satellite remote sensing systems to detect surface features across a range of the electromagnetic spectrum. High spectral resolution generally improves the capacity to characterize the surface.
**Spectral signature.** The unique way in which a given type of land cover reflects and absorbs light.

**Spatial resolution.** The size of pixels or grid cells that represent areas on the Earth surface. High spatial resolution permits the identification of more detailed objects on the surface.

**Standing litter.** The amount of litter weight at a given time. Usually refers to the amount of litter found at soil surface.

**Understory.** Any plants growing under the canopy formed by other plants, particularly herbaceous and shrub vegetation under a tree canopy.

**Vector GIS.** represents geographic features on digital maps as points, lines or polygons.

**Wood density.** Wood density is the oven-dry weight of a given volume of wood, usually expressed as kg dm$^{-3}$.

**Wetland.** Land where an excess of water is the dominant factor determining the nature of soil develop.

### B. Answers to common questions

**What are opportunity costs?**

1. Opportunity costs are the costs resulting from not doing something. We all encounter opportunity costs and tradeoffs in our daily lives – working more instead of playing soccer, spending time with family, or sleeping that extra hour. Opportunity costs are an economic interpretation of a tradeoff – a gain of one thing, but with a loss of another. Increased carbon stocks but lost timber harvests, for example.

2. An opportunity cost is a comparison between options. Within the context of REDD, an opportunity cost is *not* just the foregone profits from not cutting trees and converting forest to another productive land use. The economic value of the current land use, forest for example, also needs to be taken into account. An opportunity cost is the difference between profit foregone and the current profit.

3. In sum, a REDD+ opportunity cost is *not* just the foregone profits from not cutting trees and converting forest to another productive land use. The economic value of the current land use, forest for example, also needs to be taken into account. Thus, an opportunity cost of REDD+ is the difference between economic profit not realized and the current profit from land.

**What are REDD+ tradeoffs?**

4. REDD+ is full of tradeoffs: benefits and but costs. Benefits include less carbon emitted in the air; thriving natural plants and animals; clean water flowing in streams and rivers. But, there is another side – the costs of REDD. For landowners$^{72}$ of forests, not being able to

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$^{72}$Landowners could be private citizens, communities, corporations or the national government.
cut trees for timber sales, cultivating crops and raising cattle are all examples of costs. Opportunity costs analysis of REDD+ is the comparison between land options, each and their associated with benefits and costs.

**Why estimate opportunity costs?**

5. Opportunity cost analysis helps make the often-unrecognized costs apparent. Many people could benefit from REDD, and many could lose. Opportunity cost analysis provides money-based estimates of how different stakeholders and sectors of the national economy would be affected by REDD+ policies and compensation. Therefore, opportunity cost analysis is an important part of a national REDD+ planning process.

6. Knowledge of opportunity costs is important within for designing a national REDD+ strategy, design of informing decisions while developing appropriate policy incentives and informing decisions. Opportunity cost analysis can help national decision makers to understand how REDD+ payments may affect their national forests, other land natural resources, economy and citizens.

7. During international climate negotiations, results from opportunity cost analysis can also support countries during international climate negotiations. Many details of REDD+ policy, such as procedures on land use eligibility and reference emission levels, have not yet been clarified or agreed upon. Many of these procedures and definitions may be left to the discretion of participating countries. Knowledge of the benefits and cost, enables decisionmakers improve national welfare

8. Finally, big money is at stake. Estimates of the REDD+ market range from US$1.2 to 10 billion per year, based on a relatively low carbon price of US$10 per ton and estimates of individual countries ability to slow deforestation (Niles, et al., 2002; Dutschke and Wolf, 2007).
## C. Required capacities for a national monitoring system of emissions

<table>
<thead>
<tr>
<th>Phase</th>
<th>Requirement</th>
<th>Capacities</th>
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<tbody>
<tr>
<td>Planning and design</td>
<td></td>
<td><em>Knowledge of international UNFCCC process on REDD+ and of guidance for monitoring and implementation</em>&lt;br&gt;<em>Knowledge of national implementation strategy and objectives for REDD+</em></td>
</tr>
<tr>
<td></td>
<td>2. Assessment of existing national forest carbon monitoring framework and capacities, and identification of gaps in existing data sources</td>
<td><em>Understanding of estimation and reporting guidance provided in the IPCC Good Practice Guide and any other relevant guidance under the Convention</em>&lt;br&gt;<em>Synthesis of previous national and international reporting, if any (i.e. national communications and the Food and Agriculture Organization of the United Nations Forest Resources Assessment)</em>&lt;br&gt;<em>Expertise in estimating terrestrial carbon stocks and related human induced changes, and monitoring approaches</em>&lt;br&gt;<em>Expertise to assess usefulness and reliability of existing capacities, data sources and information</em></td>
</tr>
<tr>
<td></td>
<td>3. Design of a forest carbon monitoring system driven by UNFCCC reporting requirements, with objectives for historical period and future monitoring</td>
<td><em>Detailed knowledge of the application of methodologies in the IPCC Good Practice Guide and any other relevant guidance under the Convention</em>&lt;br&gt;<em>Agreement on definitions, reference units, and monitoring variables and framework</em>&lt;br&gt;<em>Institutional framework specifying roles and responsibilities</em>&lt;br&gt;<em>Capacity development and long-term improvement planning</em>&lt;br&gt;<em>Cost estimation for establishing and strengthening institutional framework, capacity development, and actual operations and budget planning</em></td>
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<tr>
<td>Data collection and monitoring</td>
<td>4. Forest area change assessment (activity data)</td>
<td><em>Reviewing, consolidating and integrating the existing data and information</em>&lt;br&gt;<em>Understanding of deforestation drivers and factors, and management practices</em>&lt;br&gt;<em>If historical data records are insufficient, particularly with the use of remote sensing, the following capacities are required:</em>&lt;br&gt;- Expertise and human resources in accessing, processing and interpretation of multi-date remote sensing imagery for forest area changes&lt;br&gt;- Technical resources (hardware/software, Internet, image database)&lt;br&gt;- Approaches for dealing with addressing technical challenges (i.e. cloud cover, missing data)*</td>
</tr>
<tr>
<td></td>
<td>5. Changes in carbon stocks (emission factors)</td>
<td><em>Understanding of human-induced processes influencing terrestrial carbon stocks</em>&lt;br&gt;<em>Consolidation and integration of existing observations and information, that is, national forest inventories or permanent sample plots involving:</em>&lt;br&gt;- National coverage and stratification of forests by carbon density and threat of change&lt;br&gt;- Conversion to carbon stocks &amp; estimates of carbon stock change&lt;br&gt;<em>Technical expertise and resources to monitor carbon stock changes, including:</em></td>
</tr>
</tbody>
</table>
- In situ data collection of all the required parameters, and data processing
- Human resources and equipment to carry out fieldwork (vehicles, maps of appropriate scale, global positioning system, measurement units)
- National inventory & sampling (sample design, plot configuration)
- Detailed inventory of areas of forest change or REDD+ action.
- Use of remote sensing (stratification, biomass estimation)
  - Estimation at sufficient IPCC tier for:
    - The estimation of carbon stock changes due to land-use change
    - The estimation of changes in forest land remaining forest land
    - The consideration of the impact on five different carbon pools
  - Understanding of national fire regime and related emissions of different greenhouse gases
    - Understanding of slash slash-and and-burn cultivation practices and knowledge of the areas where this is being practiced
    - Fire monitoring capabilities to estimate areas affected by fires caused by humans and associated emission factors
    - Use of satellite data and products for active fire and area burned
    - Continuous in situ measurements (particularly emission factors)
    - Separating fires leading to deforestation from degradation

7. Accuracy assessment of activity data and uncertainty analysis of emission factors
- Understanding of sources of error and uncertainties uncertainty in the assessment process of both activity data and emission factors, and how errors propagate
- Knowledge of the application of best efforts using appropriate design, accurate data collection processing techniques, and consistent and transparent data interpretation and analysis
- Expertise on the application of statistical methods to quantify, report and analyze uncertainties for all relevant information (i.e. area change, change in carbon stocks, etc.) using, ideally, a higher-quality sample

8. National greenhouse gas information system
- Knowledge of techniques to gather, store, archive and analyze data on forests and other data, with the emphasis on carbon emissions and removals from changes in forest area
- Data infrastructure, information technology (suitable hardware/software) and human resources to maintain and exchange data, and quality control
- Data access procedures for (spatially explicit) information presented in a transparent form
- Understanding and availability of data for spatial-temporal processes affecting forest change, socio-economic drivers, spatial factors, forest management and land-use practices and spatial planning
- Expertise in spatial and temporal analysis and use of modeling tools

9. Analysis of drivers and factors of forest change
- Data and knowledge of processes relating to REDD+, associated greenhouse gas emissions, drivers and expected future developments
- Expertise in spatial and temporal analysis and modeling tools
- Specifications for a national implementation framework for REDD+

10. The establishment of reference levels of emissions, which is regularly updated
- Consideration of uncertainties and understanding procedures for independent international review and verification

Source: UNFCCC, 2009.
### D. Allometric equations

#### Table 11.2. Tropical allometric equations

<table>
<thead>
<tr>
<th>General classification</th>
<th>Species</th>
<th>Group Equation</th>
<th>Source</th>
<th>Data originating from</th>
<th>Max dbh</th>
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</thead>
<tbody>
<tr>
<td>Dry (900–1500 mm rainfall)</td>
<td>General</td>
<td>Biomass = 0.2035 x dbh(^{2.3196})</td>
<td>Brown (unpublished)</td>
<td>63 cm</td>
<td></td>
</tr>
<tr>
<td>Dry (&lt; 900 mm rainfall)</td>
<td>General</td>
<td>Biomass = 10(^{(-0.535+\log_{10}(\text{basal area})})</td>
<td>Brown (1997)</td>
<td>Mexico</td>
<td>30 cm</td>
</tr>
<tr>
<td>Moist (1500–4000 mm rainfall)</td>
<td>General</td>
<td>Biomass = \exp(-2.289+2.649 \times \text{ln(dbh)}-0.021 \times \text{ln(dbh})(^{2}))</td>
<td>Brown (1997, updated)</td>
<td>148 cm</td>
<td></td>
</tr>
<tr>
<td>Wet (&gt; 4000 mm rainfall)</td>
<td>Cecropia</td>
<td>Biomass = 12.764 + 0.2588 \times \text{dbh}(^{2.0135})</td>
<td>Winrock</td>
<td>Bolivia</td>
<td>40 cm</td>
</tr>
<tr>
<td>Palms</td>
<td>Palms (motacu)</td>
<td>Biomass = 23.487 + 41.851 \times (\ln(\text{height}))(^{2})</td>
<td>Winrock</td>
<td>Bolivia</td>
<td>11 m height</td>
</tr>
<tr>
<td>Lianas</td>
<td>Lianas</td>
<td>Biomass = \exp(0.12+0.91x\log(\text{BA at dbh}))</td>
<td>Putz (1983)</td>
<td>Venezuela</td>
<td>12 cm</td>
</tr>
</tbody>
</table>

*Source: Pearson et al, 2005.*
Table 11.3. Agroforestry allometric equations

<table>
<thead>
<tr>
<th>General classification</th>
<th>Species</th>
<th>Group Equation</th>
<th>Source</th>
<th>Data originating from</th>
<th>Max dbh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agroforestry Shade Trees</td>
<td>All</td>
<td>(\text{Log}<em>{10}\text{Biomass} = -0.834 + 2.223 \text{ (log}</em>{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>44cm</td>
</tr>
<tr>
<td>Agroforestry Shade Trees</td>
<td>Inga spp.</td>
<td>(\text{Log}<em>{10}\text{Biomass} = -0.889 + 2.317 \text{ (log}</em>{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>44cm</td>
</tr>
<tr>
<td>Agroforestry Shade Trees</td>
<td>Inga punctata</td>
<td>(\text{Log}<em>{10}\text{Biomass} = -0.559 + 2.067 \text{ (log}</em>{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>44cm</td>
</tr>
<tr>
<td>Agroforestry Shade Trees</td>
<td>Inga tonduzzi</td>
<td>(\text{Log}<em>{10}\text{Biomass} = -0.936 + 2.348 \text{ (log}</em>{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>44cm</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>Juglans alnanchama</td>
<td>(\text{Log}<em>{10}\text{Biomass} = -1.417 + 2.755 \text{ (log}</em>{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>44cm</td>
</tr>
<tr>
<td>Agroforestry Shade Trees</td>
<td>Cordia alliadora</td>
<td>(\text{Log}<em>{10}\text{Biomass} = -0.755 + 2.072 \text{ (log}</em>{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>44cm</td>
</tr>
<tr>
<td>Shade grown</td>
<td>Coffea arabica</td>
<td>(\text{Biomass} = \text{exp}(-2.719 + 1.991 (\ln(\text{dbh})) \text{ (log}_{10}\text{dbh}))</td>
<td>Segura et al.</td>
<td>Nicaragua</td>
<td>8cm</td>
</tr>
<tr>
<td>Pruned coffee</td>
<td>Coffea arabica</td>
<td>Biomass = 0.281 \times \text{dbh}^{2.06}</td>
<td>van Noordwijk et al. (2002)</td>
<td>Java, Indonesia</td>
<td>10cm</td>
</tr>
<tr>
<td>Banana</td>
<td>Musa X paradisiaca</td>
<td>Biomass = 0.030 \times \text{dbh}^{2.13}</td>
<td>van Noordwijk et al. (2002)</td>
<td>Indonesia</td>
<td>28cm</td>
</tr>
<tr>
<td>Peach palm</td>
<td>Bactris gasipaes</td>
<td>Biomass = 0.97 + 0.078 \times \text{BA} - 0.00094 \times \text{BA}^2 + 0.0000065 \times \text{BA}^3</td>
<td>Schroth et al. (2002)</td>
<td>Amazonia</td>
<td>2–12cm</td>
</tr>
<tr>
<td>Rubber trees</td>
<td>Hevea brasiliensis</td>
<td>Biomass = -3.84 + 0.528 \times \text{BA} + 0.001 \times \text{BA}^2</td>
<td>Schroth et al. (2002)</td>
<td>Amazonia</td>
<td>6–20cm</td>
</tr>
<tr>
<td>Orange trees</td>
<td>Citrus sinensis</td>
<td>Biomass = -6.64 + 0.279 \times \text{BA} + 0.000514 \times \text{BA}^2</td>
<td>Schroth et al. (2002)</td>
<td>Amazonia</td>
<td>8–17cm</td>
</tr>
<tr>
<td>Brazil nut trees</td>
<td>Bertholletia excelsa</td>
<td>Biomass = -18.1 + 0.663 \times \text{BA} - 0.000384 \times \text{BA}^2</td>
<td>Schroth et al. (2002)</td>
<td>Amazonia</td>
<td>8–26cm</td>
</tr>
</tbody>
</table>

Source: Pearson et al., 2005.
E. Steps to calculate time-averaged carbon stock: from plot to land use

Main output: Time-averaged C stock per land use (Mg ha\(^{-1}\)).

**For monoculture systems**

- Select plots of different ages of trees.
- **Tree level:** Measure trees by following the sample protocol/methods in Hairah et al, 2010. Calculate tree biomass by using the right allometric equation by species if possible, using the criteria described in this module.
  
  Output 1: Biomass per tree (Kg), extrapolate to Mg C ha\(^{-1}\)
  
  Output 2: Root biomass estimated using default value 4:1 (shoot/root ratio)
  
  Output 3: C biomass (Output 1 + Output 2) \(\times 0.46\) = C (Mg C ha\(^{-1}\))

- **Plot level:** Measure necromass and soil organic matter as explained in Hairah et al, 2010.
  
  Output 4: C Necromass (Mg ha\(^{-1}\)) \(\times 0.46\) = C (Mg C ha\(^{-1}\))
  
  Output 5: C Soil organic matter (Mg ha\(^{-1}\)) \(\times 0.46\) = C (Mg C ha\(^{-1}\))

- Sum up outputs 3, 4 and 5 to calculate total C stock per hectare. (Mg ha\(^{-1}\))

- **Land use:** Develop the total C stock equation for the monoculture per life cycle (see Figure 2-1). Find the value of the median C stock. This is the time-averaged C stock for the species (in the monoculture).

**For Mahogany plantation**

Example: 20 trees of mahogany of different ages (5, 15, 25 and 30 years old) are found in one plot of 200m\(^2\) of land use type A. The farmer informed us that Mahogany is harvested when it is about 50 years old. What is the time-average C stock for Mahogany in this case?

Step 1. Use the most suitable allometric equation for Mahogany and calculate the biomass (Mg ha\(^{-1}\)) for each tree.

Step 2. Transform biomass to total C by multiplying it by 0.46. Calculate the value per hectare.

Step 3. Add the necromass and soil organic matter estimations to the biomass per hectare. Transform them to total C by multiplying them by 0.46.

Step 4. Calculate total C by age (biomass, necromass and soil organic matter).

Step 5. Calculate the total C regression curve for Mahogany-monoculture system as in Figure 11.1. Note that it includes biomass, necromass and soil organic matter for each age group.

Step 6. If the trees would be harvested when 50 years old as expressed by the farmer, then we take the median of total C calculated with the equation at year 25 as the time-average carbon stock for this monoculture. This value is about 150 Mg C ha\(^{-1}\).
**For mixed systems such as agroforestry**

- Select plots of different stages within the same land use after forest conversion.
- **Tree level:** Measure all trees within the sampling plot by following the sample protocol/methods in Hairah et al, 2010. Calculate tree biomass by using the right allometric equation by species if possible.
  - Output 1: Biomass per tree (Kg per tree), extrapolate to (Kg ha\(^{-1}\))
  - Output 2: Root biomass estimated using default value 4:1 (shoot/root ratio), (Kg ha\(^{-1}\))
  - Output 3: C biomass (Output 1 + Output 2) \times 0.46 = C (Mg C ha\(^{-1}\))
- **Plot level:** Measure necromass and soil organic matter as explained in Hairah et al, 2010.
  - Output 4: C Necromass (Mg ha\(^{-1}\)) \times 0.46 = C (Mg C ha\(^{-1}\))
  - Output 5: C Soil organic matter (Mg ha\(^{-1}\)) \times 0.46 = C (Mg C ha\(^{-1}\))
- **Land use level:** Sum up outputs 3, 4 and 5 to calculate total C stock per hectare in the mixed land uses per age of plot after forest conversion:
  - 3 years
  - 15 years
  - 40 years
- Calculate the average of total C stock of the three ages. This would be the time-averaged C stock of a mixed land use. The reason we do not use total C curves as per the monoculture case is the diversity of species and ages found in mixed systems.

For example: The total C in an agroforestry system of 3 year old is 15 Mg C ha\(^{-1}\), for 15 year old is 40 Mg C ha\(^{-1}\) and 40 years old is 80 Mg C ha\(^{-1}\). Time-averaged C stock would be \((15+40+80)/3 = 45\) Mg C ha\(^{-1}\).
**F. Methods to estimate the economic value of biodiversity**

1. The Convention on Biological Diversity (CBD) recognizes the importance of economic valuation, and states that *economic valuation of biodiversity and biological resources is an important tool for well-targeted and calibrated economic incentive measures* (CBD, 1998). Economic valuation, based on sound theoretical foundations, can help clarify tradeoffs facing public policy decisions. Nevertheless, exceptions exist for prioritizing economic values over other cultural, traditional and spiritual values. Since numerous methodological limitations and moral questions regarding the rigor of economic valuation persist, non-economic values need to be recognized and addressed.

2. At the core of the debate are conflicting views regarding the concept of value. Philosophies clash. For some, the wants of the people are morally justified – costs are little or not even considered. Priorities are to be identified through political process. For others, costs are relevant since they represent alternative use of funds. (Prioritization of alternative uses also have moral implications.) For people of such a perspective, priorities are best clarified through procedures such and benefit-cost analysis and multi-criteria analysis in order to inform decisions. Whichever viewpoint, a consensus prevails on the importance of conserving biodiversity while considering the associated costs (OECD, 2002).

3. Achieving cost-effectiveness is not straightforward. Conservation policies are often weighted down by attempts to deliver multiple outcomes. Two approaches are commonly used to identify priorities: (a) the use of money or price weights, which define benefit-cost relations, or (b) the calculation of scores, typically derived from experts or public opinion.

4. Both types of analysis produce measures to reveal the importance of biodiversity. Nevertheless, the determination of monetary values enables biodiversity conservation to compete on the same standardized basis against other demands for public funding. Below are outlined numerous approaches to estimate the economic value of biodiversity.

5. Despite the role of important economic measures, the participation of numerous stakeholders is often central to public decision-making processes. Deliberative and inclusive approaches that identify social preferences are an increasingly popular approach as governments respond to calls citizen involvement, consultations and recognition in policy decisions. Scientific information is typically provided in order to inform the participants in deliberation and decision processes. Resulting negotiation and/or consensus can be perceived as a better or fairer reflection of social preferences than benefit-cost analysis. Although results from public participation can reflect biases, insights gained from wider discussion and involvement can permit a more comprehensive socio-economic analysis for policy decisions when combined with benefit-cost approaches (OECD, 2002).
6. Efforts to estimate the economic values of biodiversity at spatial scale are being advanced (Wünsher, et al. 2008; Wendland, et al. 2009), including those by Conservation International (CI) and other NGOs. Future maps on biodiversity benefits can incorporate the total economic value, with an assessment of direct and indirect use values (concept presented below). Benefits transfer methods, which involve taking economic values from one context and applying them to another, could potentially be used to help establish these values, where site-specific analyses do not exist. Nevertheless, analyses are still likely to be a data and time-intensive (Karousakis, 2009). Furthermore, the validity of benefit transfer methods can be suspect.

7. Economic values of biodiversity are derived from the preferences that people have for the functions of biodiversity. Since market prices rarely exist for biodiversity function, preferences are estimated via willingness to pay (WTP) in order to secure or retain functions. One advantage of this approach is that the benefits of biodiversity are expressed in monetary units, thereby enabling direct comparison with alternative actions.

8. The sum of the WTPs, of all relevant people affected by a due to a policy or project, is the total economic value representing the change in well-being. Total economic value consists of use values and non-use values (Figure 11.2). Use value refers to the value arising from an actual use of a given resource. Examples include use of forest for timber, or of a lake for recreation or fishing, and so on. Use values are further categorized into three types. One, direct use value, which refers to actual uses such as fishing, timber extraction, etc. Two, indirect use value, which concerns the benefits deriving from ecosystem functions. For example, the function of forests in protecting watersheds. Three, future option values represent an individual’s willingness to pay to safeguard an asset for the option of using it at a future date.

9. Non-use values are more problematic in definition and estimation. Non-use values are comprised of bequest value and existence value (see Arrow et al, 1993). Bequest value is the benefit accruing to any individual from the knowledge that others might benefit from a resource in future. Existence value derives simply from the existence of any particular asset, and is unrelated to current use or option values. An example is individual’s concern to protect the snow leopard although he or she has never seen one and is never likely to. Just knowing that leopards exist is the source of value. Altruistic value reflects the concern that the biodiversity is available for others.
Differentiating between use and non-use values is helpful for estimating the value of biodiversity. Non-use values are can be much larger than use values, especially when the species or ecosystem is rare and widely valued (e.g., charismatic species and ecosystems). Nevertheless, estimates of non-use values can be controversial, therefore it is beneficial to separate these values for presentational and strategic purposes.

An array of methodologies are available for eliciting and estimating economic values. They can be divided into three broad approaches. One, the stated preferences or direct approach comprises techniques that attempt to elicit preferences directly by the use of surveys and experiments, such as the contingent valuation and choice modeling methods. People are asked directly to state their strength of preference for a proposed change.

Two, the revealed preferences or indirect approaches are techniques which seek to elicit preferences from actual, observed market-based information. Preferences for the environmental good are revealed indirectly when an individual purchases a marketed good to which the environmental good is related. In other words, revealed preference methods use observed behavior to infer the value. Since these techniques do not rely on people's direct answers to questions about how much they would be willing to pay for an environmental quality change, value biological resources instead of biodiversity.

Although much of the world's threatened biological diversity is in the developing world, the theory and practice of economic valuation has been developed and applied mainly in the industrialized world. Consequently, it is important to assess if rich country methodologies can be applied in poor country contexts (Pearce and Moran, 1994).
13. Three, benefit transfer borrows an estimate of WTP from one site or species for use in a different context. Although fraught with methodological difficulties (e.g., reliability and validity), transferring benefit estimates is appealing. Avoidance of a detailed benefit study can save considerable resources for funders and agencies implementing environmental projects. Developed countries, such savings are motivating interest in an analysis of appropriate conditions for transferring estimates (Boyle and Bergstrom, 1992).

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