Estimating the Opportunity Costs of REDD+

A training manual

THE WORLD BANK

CARBON FINANCE ASSIST

FOREST CARBON PARTNERSHIP FACILITY

ASB Partnership for the Tropical Forest Margins

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The World Bank
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Foreword

Over the last years, reducing emissions from deforestation and forest degradation in developing countries, 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 land 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 (more than the size of Costa Rica), accounts for up to one-fifth of global anthropogenic carbon emissions.

Forests contain more carbon than the atmosphere and the world's oil reserves combined

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 debating how to integrate REDD+ into a future international climate agreement. The December 2010 Cancun decision on REDD+, under the Ad Hoc Working Group on Long-term Cooperative Action, represents an important milestone in this respect as it recognizes the climate change mitigating role of forests in developing countries and the corresponding need for international financial support.

REDD+ opportunity costs are the difference in net earnings from conserving or enhancing forests versus converting them to other, typically more valuable, land uses

The cost of REDD+ is crucial knowledge for forest countries, donors and buyers of emission reductions in the future. While the transaction and implementation costs of REDD+ can be more readily estimated from similar forest-related activities or when they actually occur, an important cost component may remain hidden: by conserving their present forests, countries and landowners forgo the benefits of potentially more lucrative alternative land uses, such as crops or livestock — this foregone revenue is known as the opportunity cost of REDD+.

This manual is a collective effort of (1) the Facility Management Team of the Forest Carbon Partnership Facility (FCPF), (2) 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) and (3) the Partnership for the Tropical Forest Margins (ASB) of the Consultative Group on International Agricultural Research (CGIAR).

The manual shares hands-on experiences from field programs and presents the essential practical and theoretical steps, methods and tools to estimate the opportunity costs of REDD+ at the *national* level. The manual addresses the calculation of costs and benefits of the various land use alternatives in relation to their carbon stocks. As required data are generally not readily available, the manual also includes information on data collection, analysis and evaluation techniques. Although sections of the manual are relevant for *sub-national* or *project* analysis, it is not intended to calculate compensation for farmers or landowners at a given site.

The target audience of the manual includes professionals within 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. As part of a capacity building objective, a series of training-of-trainer workshops is scheduled for countries participating in the FCPF and UN-REDD Programme in Africa, Asia and Latin America.

The cost of REDD+ is crucial knowledge for governments, donors and buyers of carbon credits

The manual was edited by Pablo Benitez, Marian de los Angeles and Gerald Kapp (World Bank Institute), Benoît Bosquet, Stephanie Tam, Alexander Lotsch (FCPF Facility Management Team), 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. In addition, external reviews from Erick Fernandes, Gregory Frey, Ken Andrasko, Loic Braune, Martin Herold, and Timm Tennigkeit are appreciated.

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This is a living document. Please send your comments to the following address:
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Abbreviations and acronyms

AFOLU	Agriculture, Forestry and Other Land Use
AWG-LCA	Ad Hoc Working Group on Long-term Cooperative Action of the UNFCCC
BA	Basal area
BAP	Bali Action Plan
BAU	Business as Usual
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CMP	Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
GHG	Greenhouse Gas(es)
GIS	Geographic Information System
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
LCCS	Land Cover Classification System
LU	Land Use
LULUCF	Land Use, Land-Use Change and Forestry
LUS	Land Use System
MAI	Mean Annual Increment
MRV	Measurement (Monitoring), Reporting, Verification
NBSAP	National Biodiversity Strategy and Action Plan
NAPCC	National Action Plans for Climate Change
NFI	National Forest Inventory
NPV	Net Present Value
POA	Program of Activities
REALU	Reducing Emissions from All Land Uses
REDD	Reducing Emissions from Deforestation and Forest Degradation
REL	Reference Emission Level
RPP	Readiness Preparation Proposal
RS	Remote Sensing
SESA	Strategic Environment and Social Assessment
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
SOM	Soil Organic Matter
tC	Metric ton of carbon (1tC = 3.67tCO_2)

tCO_2	Metric ton of carbon dioxide ($1tCO_2 = 0.27tC$)
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VHRI	Very high resolution imagery

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Chapter 1. Introduction

Objectives

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

Contents

What are REDD and REDD+?

1. Both REDD and REDD+ are intended to help reduce carbon emissions into the earth's atmosphere. 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. REDD 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+, an expanded version of REDD, was 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] For the purposes of this training manual, REDD+ is emphasized.

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

4. Financial flows from REDD+ programs could reach up to US$30 billion a year, in order to halve emissions between 2005 and 2030.[3] Besides reducing carbon emissions, the flow of funds, primarily North-South, could 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. With ratification, REDD+ will affect, and potentially benefit, a wide range of land users.[4] Stakeholders include farmers, ranchers, loggers, rubber tappers, private businesses, etc. – anyone who has land-based activities in rural regions. Since REDD+ funds will pass through national governments, countries will need to decide how to prioritize programs and share the benefits. To facilitate the process of developing a national REDD+ strategy, this manual helps policymakers identify the costs of participating in REDD+ programs at a

[1] Specifics for a single widely-accepted definition of forest degradation have not yet been generated, for more see Chapter 5 and 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 (CO_2) emissions, would require financial flows of US$17 to 28 billion per year. This would require a payment of US$10-21/t$CO_2$. A 10% emissions reduction over the same period would cost between US$0.4 and 1.7 billion annually and US$2-5/tCO2.
[4] This section has benefitted from the contributions of G. Frey (2010, personal communication).

national level, by focusing on the analysis of opportunity costs. Given the importance of benefit sharing, we briefly discuss some of the ways the benefits of REDD+ can be shared within a country.

6. In some cases, countries may choose to make direct financial payments to individuals, businesses and communities to compensate them for their activities that protect and conserve forests. In other cases, countries may fund programs to finance capacity-building and investments for alternative livelihood strategies and/or other community development activities. Such an approach is a form of indirect compensation. The selection of national policies for benefit sharing is an important component of a REDD+ readiness process.[5]

7. Identifying effective and equitable benefit-sharing mechanisms can be a challenging task. For instance, land ownership and associated rights may be contested or not formalized (titled) making fair and adequate compensation difficult. Similarly, if a REDD+ intervention is to reduce illegal logging, a policy to compensate to 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 in this chapter.*)

8. If a REDD+ strategy limits livelihood activities (being legal or not), then opportunity costs arise. 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, which is a violation of international good practice standards (and World Bank Safeguards) of "doing no harm." (*See Chapter 3 for a discussion on safeguards.*)

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

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[5] From FCPF (2010): *Use clear and transparent benefit-sharing mechanisms with broad community support, so that REDD+ incentives are used in an effective and equitable manner with the objective to further tackle deforestation and forest degradation. In some cases, the national government can be the best actor to enact and implement the necessary policy changes and regulations. But many changes will also require the involvement of indigenous peoples, local communities and the private sector, in which case these stakeholders or rights-holders would expect to partake in the REDD+ activities and the corresponding carbon revenues (or alternative financing or support) in recognition of their contributions. In other cases, indigenous peoples, local communities and the private sector would be the primary actors implementing the ER [Emission Reduction] Programs and thus expect to be the principal beneficiaries of ERPA [Emission Reductions Payment Agreement] payments. These arrangements will have to reflect the assessment of the drivers of deforestation and forest degradation.*

Costs of REDD+

10. In order to receive REDD+ funding, countries must reduce deforestation and forest degradation, and/or enhance carbon stocks. To do so, however, generates costs. These costs can be grouped into three general categories:

(1) *opportunity costs* resulting from the forgone benefits that deforestation would have generated for livelihoods and the national economy,

(2) *implementation costs* of efforts needed to reduce deforestation and forest degradation, and

(3) *transaction costs* of establishing and operating a REDD+ program.[6]

11. Although some of the individual components of implementation and transaction costs can be interchanged, implementation costs are typically associated with reducing deforestation directly, whereas transaction costs are indirectly associated. Brief descriptions of these costs are provided below and are summarized in Figure 1.1.

Opportunity costs

12. Deforestation, despite all its negative impacts, can also bring economic benefits. Timber can be used for construction, and cleared land can be used for crops or as pasture. Reducing deforestation and preventing land use change means forgoing these benefits. Similarly, forest degradation also generates benefits from selective logging, fuelwood collection, or grazing of animals, for example. Avoiding forest degradation implies forgoing these benefits. The costs of the forgone benefits (net of any benefits that conserved a forest generates) are known as "opportunity costs" and can be the single most important category of costs a country would incur while reducing its rate of forest loss within REDD+.

13. Opportunity costs include, most obviously, the forgone economic benefits of the alternative land use, what we term direct, on-site opportunity costs. They can also include social-cultural and indirect costs:

> *Social-cultural costs.* Preventing the conversion of forests to other land uses, can significantly affect the livelihoods of many rural dwellers. Such an alteration in the way of life may bring about social and cultural costs that are not easily measured in economic terms.[7] Examples of such costs could include psychological, spiritual or emotional impacts of livelihood change, loss of local knowledge, and erosion of social capital. These costs can be minimized if alternative livelihoods are viable and readily accessible with the implementation of a REDD+ program.

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[6] These categories are not definitive, but provide an overview of the different REDD+ costs. For a discussion of REDD+ costs, see Pagiola and Bosquet (2009). Costs can be arranged in fewer or more categories.

[7] See Chapter 3 for discussion of involuntary resettlement policy of the World Bank. For a comprehensive review of social impact assessment, see Richards and Panfil (2010).

Indirect, off-site costs. Changes in economic activities, from timber and agriculture to other productive sectors, can also affect downstream actors of associated product supply chains. In addition, less economic activity could have an effect on national tax revenues. Similar to opportunity costs, these indirect costs are not total, but need to be estimated on a difference basis (that is, with vs. without REDD+).[8] Such indirect costs associated to REDD+ can be estimated by using multipliers or multi-market economic models.

Other indirect costs include global feedback relationships arising from REDD+ policy. Land uses within a country under a REDD+ policy scenario would be different than a non-REDD+ scenario. Since more land would be in forest with REDD+, the prices of timber, agricultural and ranching products would likely increase. 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 price changes could represent significant opportunity costs.[9]

14. This manual focuses on estimating direct, on-site opportunity costs. Along with other socio-economic information, the field-level economic data collected for this component of opportunity cost can be used to estimate indirect opportunity costs. The information and enhanced knowledge of farm, cattle and timber production and their performance within supply chains will help analysts understand potential REDD+ program impacts on the respective economic sectors. For the sake of brevity, the term *opportunity cost* will refer to direct, on-site opportunity costs throughout this manual.

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[8] In addition, the growth of other productive sectors needs to be estimated, as economic conditions are not static.

[9] 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+.

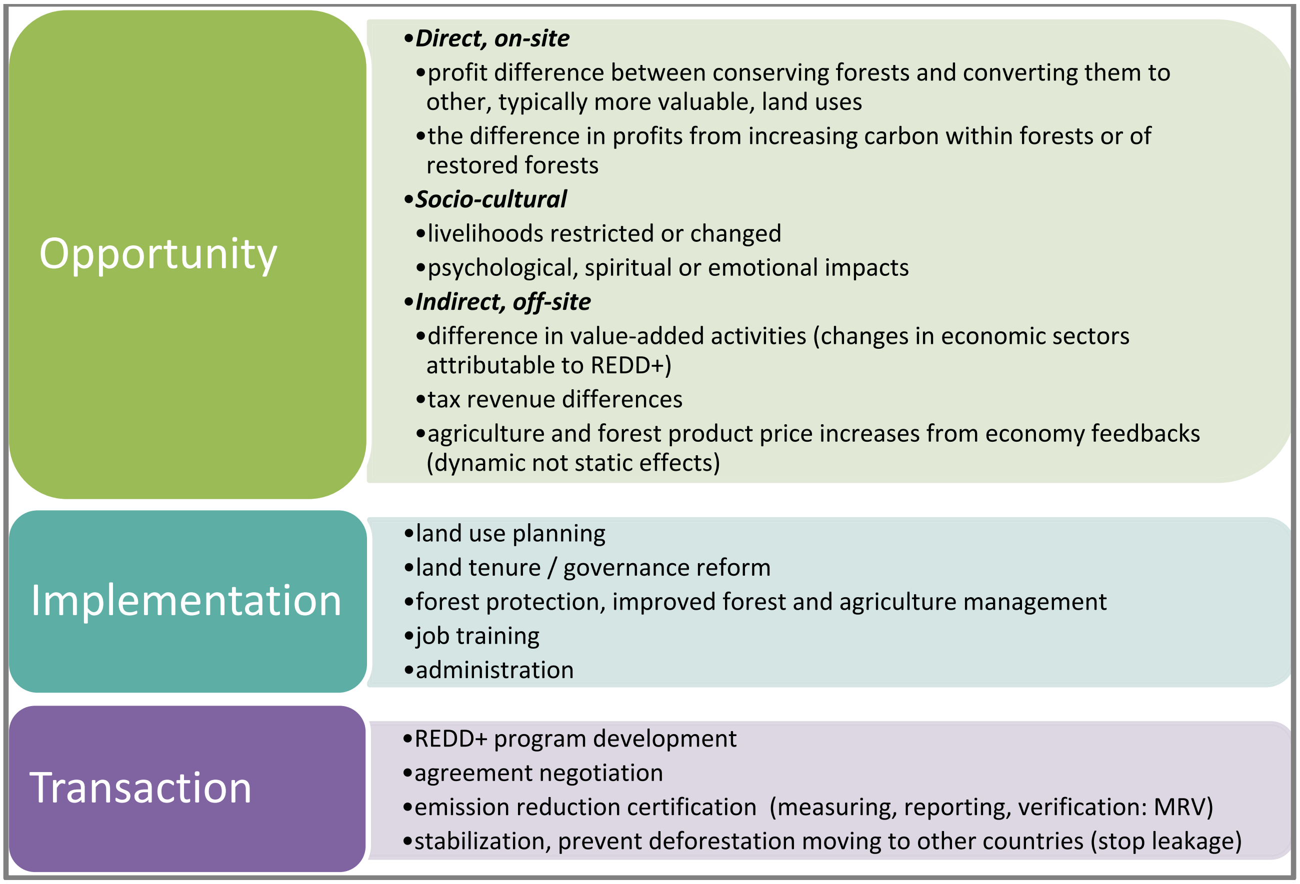


Figure 1.1. The costs of REDD+

Source: Authors.

Implementation costs

15. 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. Examples include the costs of:

- guarding a forest to prevent illegal logging,
- replanting trees in degraded or logged forests,
- relocating timber harvesting activities away from natural forests to degraded forests scheduled for reforestation,
- intensifying agriculture or cattle ranching so less forest land is needed 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 indigenous and settler 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 up-front investment and perhaps recurring costs for 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 costs include the expenses associated with the goods, training, research, and the political, legal and regulatory processes, including consultations and government decision-making processes.

Transaction costs

18. Over and above opportunity costs and implementation costs, REDD+ also comes with transaction costs. Transactions costs are incurred throughout the process: REDD+ program identification, transaction negotiation, monitoring, reporting, and verifying the emission reductions. Transactions costs are incurred by the implementers of a REDD+ program and third parties such as verifiers, certifiers, and lawyers. To illustrate, transactions 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 oversee compliance of stated emission reductions. Such activities and associated costs are nevertheless necessary to the transparency and credibility of the REDD+ program.

19. Transactions costs are typically considered separate from implementation costs, since by themselves they do not reduce deforestation or forest degradation. 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.[10]

Examples of REDD+ cost estimates

20. Opportunity costs can be high (e.g. when forests are converted to establish lucrative oil palm plantations), low and even negative (e.g. when forest conversion is for low productivity pastures). A global review of 29 empirical studies by Boucher (2008a) found

[10] 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.

an *average* opportunity cost of US$2.51/t$CO_2$. Eighteen out of the 29 estimates of land use change were less than US$2/t$CO_2$, and 28 out of 29 were less than US$10/t$CO_2$.

21. For other REDD+ costs, US$1/t$CO_2$ was estimated to represent transaction, implementation and administrative costs (Boucher 2008b).[11] These costs somewhat overlap, possibly making this a conservative overestimation. Since these estimates were largely based on a project basis, cost efficiencies may be possible to achieve with larger REDD+ programs. Nevertheless, the estimate could be substantially higher in specific national contexts, thus impacting viability of some REDD+ program options.

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 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, however, will not necessarily be true for all countries. 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 areas, may be less than transaction and implementation costs.

Two, estimating opportunity costs provides insights into the drivers and causes of deforestation. Forests are not cut out of malice—they are cut because of the economic benefits generated. 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). Here too, there is considerable variation; in some cases, forests are converted to very low-value uses (Chomitz, et al., 2006). By helping to better understand drivers of deforestation, opportunity cost estimates can thus help policymakers identify and develop appropriate responses.

Three, opportunity costs can help to identify the likely impacts of REDD+ programs across social groups within a country. Land uses are often associated with specific social groups. Knowing who would likely gain or would lose from a REDD+ program can help identify potential moral/ethical consequences – if losses were borne by marginalized groups. Possible hidden challenges of national REDD+ program strategies may also be apparent, such as losses being incurred by

[11] Transaction: $0.38/t$CO_2$ (Antinori and Sathaye, 2007), implementation: $0.58/t$CO_2$ (Nepstad, et al. 2007) and administration: $0.04/tCO2 (Grieg-Gran, 2006). In per hectare terms: a lower bound for annual administration costs is US$4 per ha and upper bound of US$15 per ha.

politically powerful groups able to prevent adoption of REDD+ policies or resist their implementation. With the insights gained from REDD+ opportunity cost 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 activities, 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, opportunity costs are an estimate the loss of income to nearby communities arising from use restrictions. Even if these communities are not directly compensated, the cost information is important for policymakers to understand the impacts of a REDD+ conservation policy in order to develop other types of compensation.

Five, the information gathered to estimate opportunity costs is a basis for improving estimates of other REDD+ costs. Opportunity and other REDD+ costs are likely to significantly differ within a country – even for similar land use changes. The process of gathering sub-national information, increases knowledge of local biophysical and socioeconomic contexts, which can also improve understandings needed to refine estimates based on generic values. For example, models of indirect opportunity costs, which typically employ average opportunity cost estimates, can become more accurate by taking into account sub-national information. Similarly, implementation and transactions costs can also be estimated on a spatially differentiated basis.

Risks and limitations of REDD+ opportunity cost estimates

Risks

23. Opportunity cost analysis can help inform the development of national REDD+ policies. Nevertheless, some serious risks can arise. Below are two risks associated with opportunity cost estimates, along with remedies to reduce possible harm.

One, inaccurate application of opportunity cost estimates. Seemingly similar land use changes may have very different opportunity costs. Many factors determine opportunity costs, both biophysical and socio-economic. Therefore, opportunity costs should never be applied uncritically. For example, opportunity costs may differ due to distinct soil fertility or market access contexts. ***Remedy:*** *Estimate and identify valid sub-national areas to which site-specific results can be extrapolated. This process is a crucial discussion topic within this training manual. In* *addition, to foster a process of timely improvement (i.e. precision and accuracy)*[12] *of 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.)*

Risks of opportunity cost estimates:

- inaccurate application
- considering opportunity costs to be equal to all REDD+ costs

Two, opportunity cost is considered to be the only component of REDD+ costs. Opportunity costs are only one piece of the REDD+ cost puzzle. If transaction and implementation costs are also taken into account, different conclusions regarding viable national REDD+ strategies could be reached. ***Remedy:*** *Analysis and policies should not only focus on opportunity costs, but also address other REDD+ costs (implementation and transaction) that are important in developing nationally-appropriate REDD+ strategies.*

Limitations

24. Opportunity cost analysis in general, and the approach specifically presented here, both have limitations that should be considered while estimating REDD+ costs:

One, opportunity cost analysis does not account for the cost of lost employment that could arise from wide-scale change in land use. To obtain alternative employment, time and training is often required. Moreover, in many rural contexts where REDD+ is likely to be implemented, high levels of under- and un-employment prevail. Therefore, jobs forgone, from agricultural to forest land uses for example, could lead to substantial costs. In addition, many classes of people may not be eligible for compensation, yet their livelihoods would be affected, including people without land title, rural laborers, illegal loggers and potentially other groups of affected people. ***Remedy:*** *Estimate employment impacts per type of land use change associated with a REDD+ program. Examine tradeoffs and scenarios (Chapter 9). Magnitude of costs will depend on the size of the REDD+ programs and their effect on the landscape. Results from analysis will enable policymakers to identify priority areas and efforts to generate jobs (a type of implementation cost). The success of REDD+ programs (i.e., sustainably diverting forest adverse activities) depends on creating lucrative alternative activities in intensified agriculture, forestry or other sectors of the national economy.*

Two, direct, on-site opportunity costs underestimate total opportunity costs. REDD+ could substantially alter forestry and agriculture economic sectors, input and output prices, and patterns of land use. Thus, other components of opportunity

[12] Accuracy is how close the estimates are to the "true" value, whereas *precision* is how close the estimates are to each other.

costs, socio-cultural and indirect off-site costs, also need to be considered within REDD+ policy analyses. ***Remedy:*** *Direct on-site opportunity costs can approximate the effect of such cost components within sensitivity and scenario analyses (Chapter 9). For example, a multiplier or additional socio-cultural costs can be estimated for specific land use changes. Similarly, additional costs arising from economic changes (e.g. prices) can be included with multipliers. These initial analyses can be used as a basis for discussion and justification for subsequent multi sector economic modeling.*

25. Despite these risks and limitations, the authors consider the analytical approach as a useful and essential step to understanding opportunity costs. The manual strives to illustrate a process of data collection and analysis to transparently estimate REDD+ opportunity costs and avoid calculation and interpretation pitfalls.

Important issues not addressed by opportunity cost analysis

One, off-site environmental impacts (externalities) of land uses. Although opportunity cost analysis of land uses is based multi-year time horizons, associated environmental impacts (e.g. negative downstream effects, biodiversity loss) are not explicitly taken into account. ***Remedy:*** *Such negative impacts can be discussed when reviewing opportunity costs at sub-national and national levels. Adequate costing of negative effects can be accomplished within a country accounting stance (defined in Chapter 3). On-site impacts, such as land degradation, can be examined with sensitivity and scenario analysis of the opportunity cost estimates (Chapters 7 and 9). For example, yield estimates from agricultural activities can decrease over the time horizon of the analysis.*

Other important REDD+ issues:

- environmental impacts
- governance
- illegal forest activities

Two, land and resource governance. Since legal and customary rights may not coincide, especially where land and resource rights are not well defined or enforced, determining the opportunity costs and who bears them may not be possible. An opportunity cost analysis 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. ***Remedy:*** *As part of a national REDD+ strategy development process, discussion of governance is essential. Participation in discussions (and analysis) should go beyond government and include affected stakeholders in civil society.*

Three, 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 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. In this case, 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 undertaken by low-income groups, a country may decide to compensate for opportunity costs (either directly or indirectly). ***Remedy:*** *Like the above limitation, a national REDD+ strategy development process should include discussion of legal and illegal forest activities. Participation in discussions should also include affected stakeholders in civil society. In this case, compensation should be given in form of creating legal jobs as an alternative to illicit forest depleting activities.*

REDD+ safeguards

26. Advances in social and environmental safeguards include defining and building support for a higher level of social and environmental performance from REDD+ programs. As REDD+ policy moves forward, the participation of local and indigenous communities 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.

27. Besides the World Bank safeguards presented in Chapter 3, an international review is in process 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. The following principle addresses cost analysis:

Principle 2: The benefits of the REDD+ program are shared equitably among all relevant rights holders and stakeholders.	
Criteria	***Framework for indicators***
2.1 The projected costs, potential benefits and associated risks* of the REDD+ program are identified for relevant rights holder and stakeholder groups at all levels using a participatory process.	2.1.1 Projected costs, potential revenues and other benefits and associated risks of the REDD+ program are analyzed for each relevant rights holder and stakeholder groups at all levels using a participatory process.

**All analysis of costs, benefits and risks should include those that are direct and indirect and include social, cultural, human rights, environmental and economic aspects. Costs should include those related to responsibilities and also opportunity costs. All costs, benefits and risks should be compared against the reference scenario which is the most likely land-use scenario in the absence of the REDD+ program.*

28. International 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+ (e.g., illegal logging/conversion on public or private lands). Principles of good governance include transparency, participation, accountability, coordination and capacity (World Resources Institute, 2010). To address these and other challenges, reviews and reforms of legal, political, and institutional framework for carbon finance are typically required (see Richards, et al., 2010, The Forests Dialogue, 2010).

An important question

29. With REDD+ programs, lost are the potentially larger profits from future agriculture and logging activities.[13] So we need to ask:

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

30. The quick reply: it depends on the international carbon price, the type of land use change and the different types of REDD+ 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 greatly differ 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 per location.

31. It is quite likely that every country will find many locations in which REDD+ would not be justified by any realistic payment per ton of carbon emission reduction. Conversely, it is also very likely that every country will find that it has many areas in which even modest payments for avoided emissions would render efforts to reforest or 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 the opportunity costs of land use changes is a critical step (but not the only step) in answering this question.

32. Let's first examine three typical land use changes, from forest to:

High-value agriculture

Examples: soybean, oil palm or cattle on productive lands

probably no

33. Compensation 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 potential income from a REDD+ program. Carbon prices would need to be very high in order

[13] The term agriculture also includes ranching and tree-based or perennial cropping activities.

for REDD+ to be attractive, 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

maybe

34. Income from a REDD+ program may be more than the profits of mid-value agriculture. Compensation from REDD+ is slightly more 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

probably yes

35. Most likely, income from a REDD+ program is more than the profits from low productivity agricultural activities. In this situation, it is worthwhile for a landowner to accept compensation associated with REDD+ and maintain land as a forest (instead of converting it to agricultural use).

36. 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 degraded forests, 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.

Reforestation or afforestation

Examples: Native timber tree plantations on low-productivity agricultural or pasture lands

maybe

37. The investment costs to re-establish forests may be compensated by REDD+ programs. Earnings from the reforested areas may be greater than from low productivity agricultural, ranching uses, especially if timber is selectively harvested in the future.

What about the value of wood and timber?

38. The above deforestation examples only recognized the value of agricultural production after the land use change from forest. 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 enhanced forest management. When these profits exist, accurate REDD+ opportunity costs estimates should include the contribution of these forest products as well.

An opportunity cost example

39. 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.[14] (*Procedures on how to estimate the tC/ha stock value per land use is in Chapter 5.*) The estimated profits from agriculture are $400/ha, while forest profits are $50/ha, expressed in Net Present Value (NPV) terms.[15] *(An explanation of how to estimate NPV profits is in Chapter 6.)*

40. 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.

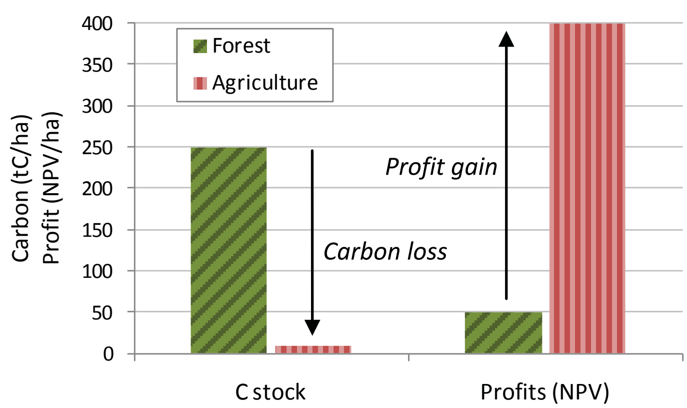


Figure 1.2. Carbon loss and profit gain from converting forest to agriculture

41. The opportunity cost of not changing forest to agriculture is equal to the $350/ha of profit difference ($400–$50=$350/ha) divided by the 245 tC/ha not emitted (250–5=245tC/ha). Thus, the opportunity cost, per ton of carbon, is $1.43/tC (=$350/245tC).

42. REDD+ compensation, however, is not based on carbon (tC), but rather on emissions of carbon dioxide equivalents (CO_2e). A conversion factor of 3.67 is needed to translate tC

[14] These figure are illustrative. Significant variation can arise within landscapes and across countries.
[15] Net present value is the summing of a stream of annual profits, whereby future profits are reduced by a factor (i.e., discount rate) that reflects the inherent preference for money now, rather than profits generated in the future.

to tCO_2e. (*See Box 1.1 for further explanation.*) So, the potential emissions of the land use change is $899tCO_2e/ha$ ($245tC/ha * 3.67\ tCO_2e/tC = 899tCO_2e/ha$).

43. With an estimate of the difference in profits ($350/ha) and the emissions avoided (899 tCO_2e/ha), an opportunity cost of avoided emissions can be estimated. The opportunity cost is $0.39/$tCO_2e$ of not converting a forest into agricultural land.

44. This per ton carbon equivalent estimate is one way of expressing opportunity costs. Yet 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. In other words, by not converting a forest to agriculture, the farmer forgoes $350/ha in NPV profits.

Two versions of opportunity cost:

- per unit carbon (tCO_2e)
- per unit land area (ha)

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

46. It is important to note that opportunity costs are 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 1.1. 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*16))/12)=3.67).

Deforestation and degradation also produce other greenhouse gases (GHGs) including nitrous oxide (N_2O) and methane (CH_4). N_20 has 231 times higher global warming potential than CO_2. Whereas, CH_4 has 23 time the warming potential. To standardize the effect of different gas emissions, international convention measures greenhouse gas loading in terms of CO_2 equivalents, represented by CO_2e.

Source: IPCC, 2006.

Carbon – profit tradeoffs

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

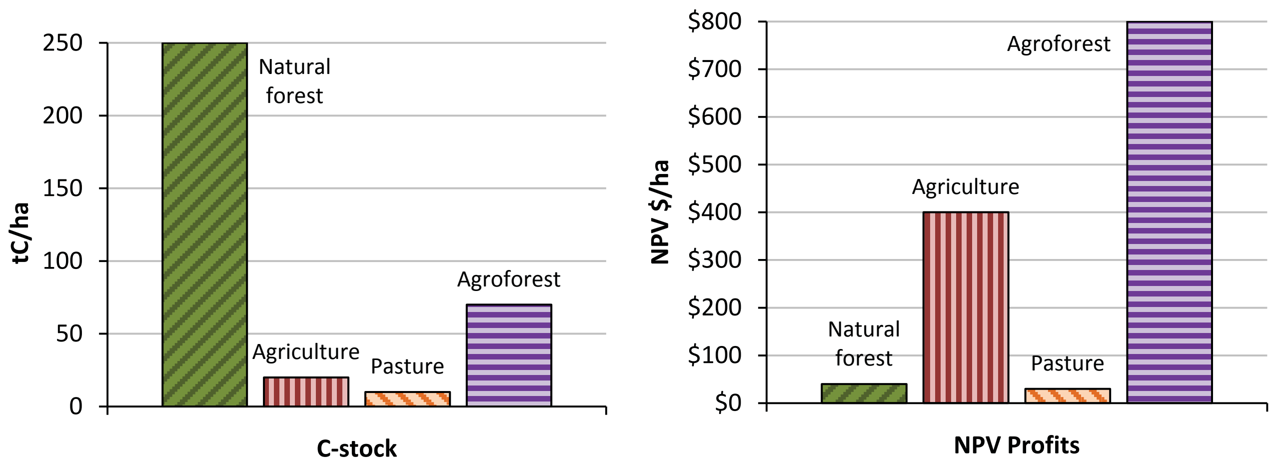


Figure 1.3. Carbon and profits of four land use categories

48. 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.
- Low-productivity pastures have low carbon content (5tC/ha) and low profits ($40/ha). Therefore, unlike conversion to agriculture, conversion to pastures would not be a carbon-profit tradeoff.
- Although agroforestry has lower carbon stocks than forests, the carbon content of agroforestry is substantially (80tC/ha) more than agriculture (5tC/ha). Of particular interest is the high NPV profit ($800/ha).

Comparing opportunity costs

49. Figure 1.4 presents the opportunity costs of three types of land use change (forest to pasture, agriculture, and agroforestry). Each has a different opportunity cost. Both changes to agriculture and agroforestry land uses have higher opportunity costs. Since agriculture has lower NPV profits and lower carbon content than agroforestry, the opportunity costs of avoiding the emissions from changes to agriculture are less than those of agroforestry.

50. 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 – which can be considered a potential benefit.* Landholders could realize an economic gain by not deforesting for producing cattle on low-productivity pastures. Profits would increase from $40 to $50/ha reflecting the lack of a carbon-profit tradeoff. In terms of the associated CO_2e, the opportunity cost is negative, that is -$0.01/$tCO_2e$. This is example of so-called low-hanging fruit – where REDD+ compensation may not be necessary in financial terms, but may be available and needed, to avoid such a land use change or restore a forest.

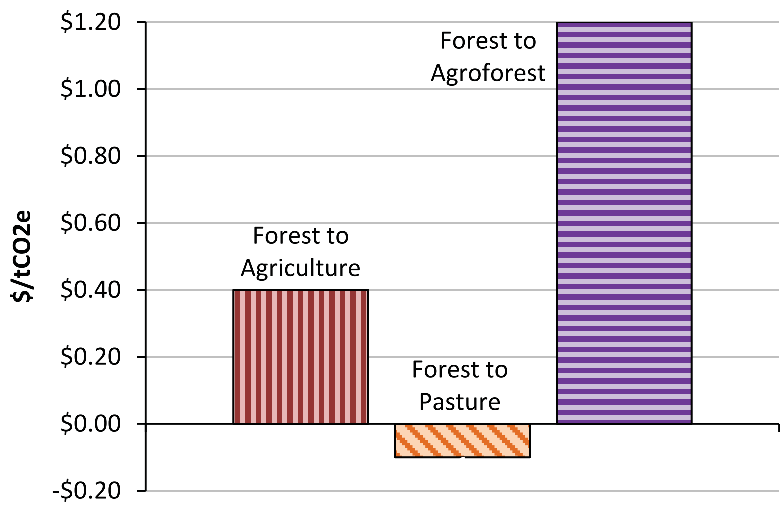


Figure 1.4. Example opportunity costs of three land use changes

Tradeoffs within a national landscape

51. People use land in many ways. Table 1.1 presents 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.

52. Land uses with trees tend to have higher carbon, but with lower profits and employment. Throughout this training manual, these eleven land use categories and associated estimates will be used to illustrate how to estimate opportunity costs of REDD+ policies and their associated effects on countries, economic sectors and citizens.

Table 1.1. Example carbon, profits and employment of land uses, Peruvian Amazon

Land use	**C stock** time-averaged (tC/ha)	**CO_2e stock** time-averaged (tCO2e/ha)	**Profitability** (NPV*, $/ha)	**Rural employment** (workdays/ha/yr)
Natural forest	250	918	31	5
Logged forest	200	734	300	15
Heavily logged forest	120	440	500	25
Agroforest 1	80	294	300	120
Agroforest 2	60	185	120	100
Cocoa	50	147	604	135
Oil palm	40	183	245	84
Improved pastures	3	11	618	7
Low-productivity pastures	2	7	336	5
Agriculture 8yr fallow	5	18	302	27
Agriculture 3yr fallow	3	11	409	43

* Estimated using a 5% discount rate.

Sources: Palm, et al. 2004; White, et al. 2005.

53. To illustrate a wide range of carbon-profit relationships, Figure 1.5 plots eleven land uses of Indonesia 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).

54. 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.

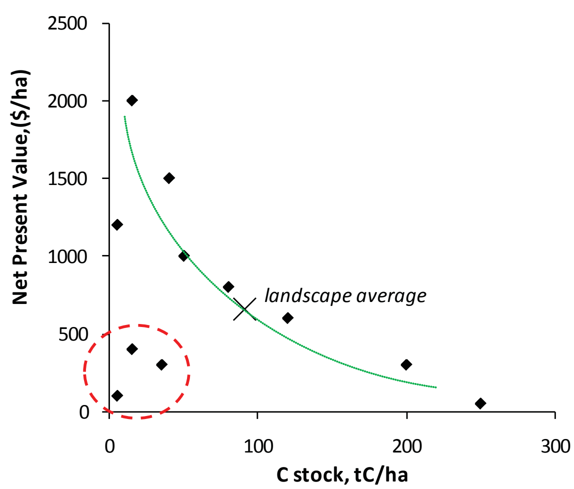


Figure 1.5. Tradeoffs and low-level conditions of NPV profit and carbon stocks

Source: Swallow, et al. 2008.

What is an abatement cost curve?

55. An abatement cost curve compares the quantity of potential emission reductions with their costs (i.e., opportunity, implementation and transaction). The vertical axis represents the abatement cost of the emissions reduction option (in monetary units per tCO_2e), while the horizontal axis depicts the corresponding quantity of reduction (often measured in million tCO_2e per year).

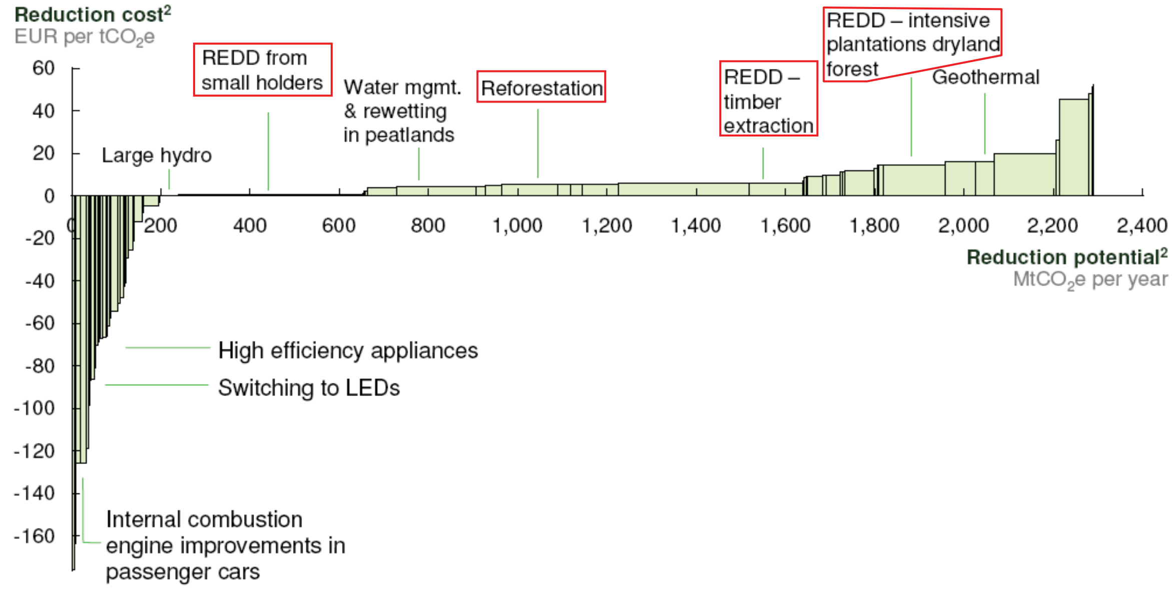
56. Besides representing potential REDD+ transactions, an abatement cost curve also helps to:

- summarize the attractiveness and feasibility of REDD+ options in a given region or country,
- clarify potential gains from REDD+ carbon trading.

57. Abatement, and opportunity, costs can be estimated at different levels: sub-national, national, and global, depending upon the scale of a REDD+ program. Figure 1.6 is a supposed example of a national abatement cost curve, for Indonesia, which includes abatement costs from both agricultural and industrial activities. Nevertheless, this "abatement cost curve" only considers direct, on-site opportunity costs (Dyer and Counsell, 2010). The fact that such a widely shared and well-publicized analysis is not actually of REDD+ abatement costs highlights the importance of reviewing methodological assumptions. Despite actual abatement costs being higher, arising from implementation and transactions costs, the graph is useful for illustrative purposes.

58. Reduction options associated with REDD+ are highlighted by 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 $MtCO_2e$ per year, whereas avoiding timber extraction would reduce about 90 Mt CO_2e per year. Reforestation could reduce emissions by approximately 100 $MtCO_2e$ per year (Dewan Nasional Perubahan Iklim and McKinsey & Co., 2009).

59. The differences in opportunity costs 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 tCO_2e, the opportunity cost of reforestation is approximately €10 per tCO_2e and reduced forest conversion to intensive agricultural production can cost over €20 per tCO_2e. Such cost differences affect feasibility of abatement options within national REDD+ programs.



1 Societal perspective implies utilizing a 4% discount rate

2. The width of each bar represents the volume of potential reduction. The height of each bar represents the cost to capture each reduction initiative

Figure 1.6. A national opportunity cost curve (Indonesia)

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

60. By representing both the amount of emission reduction and cost per type of land use change, an abatement cost curve (representing opportunity, implamentaion and transactions costs) can help answer the question: *what quantity of CO_2 emissions reduction may be possible at a carbon price of $X/$tCO_2e$?* It can also help to answer the question: *which emissions reduction options are attractive to the country at a carbon price of $X/$tCO_2e$.*

A training manual for estimating REDD+ opportunity costs

61. Opportunity costs can greatly differ per country and within countries. For example, the value of timber and agricultural activities depend upon numerous factors including market access, soil fertility and rainfall patterns. Production factors such as labor and machinery inputs also need to be taken into account when estimating costs.

62. To address these challenges, the manual provides a systematic approach to identifying and analyzing data required to estimate the opportunity costs of REDD+ programs. To illustrate the process, 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

Countries estimate opportunity costs of REDD+ to help guide national policy.

Objectives

1. To provide methods and tools to estimate the opportunity cost of forgoing land use changes and fostering enhancements of forest carbon at a national level,[16]
2. To document case study examples that enable professionals (governmental, university, non-governmental) to learn, adapt and use the analytical methods, interpret results, analyze different land use scenarios and identify optimal 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.

63. Within this manual, we provide guidance on how to gather and analyze the necessary information to address questions of the economic viability and other decision criteria related to REDD+ programs at a national level. Such non-economic decision criteria include effects on biodiversity, water and livelihoods. Central to the analysis is the comparison of

[16] And also acknowledging and including the wide range of forests and other land use types found in those landscapes.

opportunity costs arising from preventing land use changes (e.g., forest to agriculture, forest to pastures), or fostering land use changes (e.g., degraded land to forest).

64. In order to inform national level decisions, the current land uses are identified throughout the country along with drivers of land use change. Since carbon and profit levels of all land uses can differ according to bio-physical (e.g., soil quality) and socio-economic (e.g., distance to markets) conditions, sub-categories of land uses are also identified. This also ensures accuracy of the information required to estimate REDD+ opportunity costs. With knowledge of the types of land uses, likely future changes in land use and the related opportunity costs, REDD+ programs planners can review the implications of reducing carbon emission per type and sub-national location of land use. The results from these analyses enables countries to become informed of the potential costs linked to REDD+ program commitments and thereby identify optimal national development strategies.[17]

Who else may be interested in opportunity costs?

65. 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:

A government policymaker

66. 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

67. 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?

[17] Optimal is defined as having the most positive qualities, with respect to national objectives. Objectives can be numerous, including economic, social, cultural and environmental considerations.

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

68. 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?

69. 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.

Box 1.2. Managing big numbers used with C accounting

Since REDD+ at national or global scale addresses large quantities of carbon, the scientific notation frequently 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). The below table summarizes the common notation.

Useful scientific notation for weight measures

Prefix	Abbreviation	Scientific notation	Equivalent Value
-	t	10^0	1000 kg
kilo	kt	10^3	1,000t
mega	Mt	10^6	1,000,000t
giga	Gt	10^9	1,000,000,000t
tera	Tt	10^{12}	1,000,000,000,000t
peta	Pt	10^{15}	1,000,000,000,000,000t

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

70. Despite intense efforts of including 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.

71. 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)

72. 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.

73. 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.

74. 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.

75. 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).

76. 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.

77. 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.

78. The three global models produce an array of results (Figure 1.7). 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/tCO_2e in Latin America (GTM) to \$38/tCO_2e 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/tCO_2e. Differences across the continents, however, were not statistically significant (Kindermann, 2008).

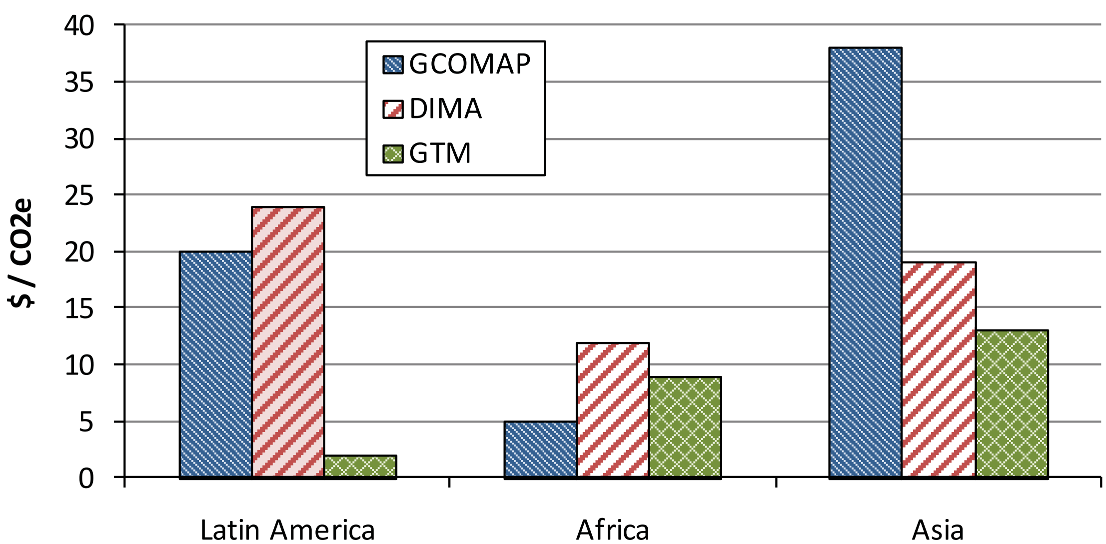


Figure 1.7. Carbon price needed to reduce deforestation by 50% in 2030

Source: Kindermann, 2008.

Bottom-up approach (regional-empirical models)

79. 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.

80. 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.[18] 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).[19]

81. 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)

82. 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.[20] 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). [21]

83. 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

[18] Borner and Wunder (2008) base their analyses largely on official government statistics, possible in Brazil because of their availability.

[19] The effect of changing prices and costs can be addressed with sensitivity analysis (Module T).

[20] Termed *global-empirical models* by Wertz-Kanounnikoff, 2008.

[21] To convert estimates based on area ($/ha) to emissions ($/Co2e), Boucher (2008b) used a conversion factor for mean carbon density: 3.94 billion tCO_2 of emissions from 10.1 million hectares deforested, from Strassburg, et al. (2008).

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.

84. In the other approach, a recent GIS-referenced global map of potential economic returns from agriculture and pasture (Figure 1.8; Naidoo and Iwamura, 2007) was overlaid with GIS referenced global databases of spatial distribution of deforestation. Results show that at very low opportunity cost[22] (~US$5.5/t), a mechanism could reduce 90% of global deforestation (Strassburg et al. 2008).

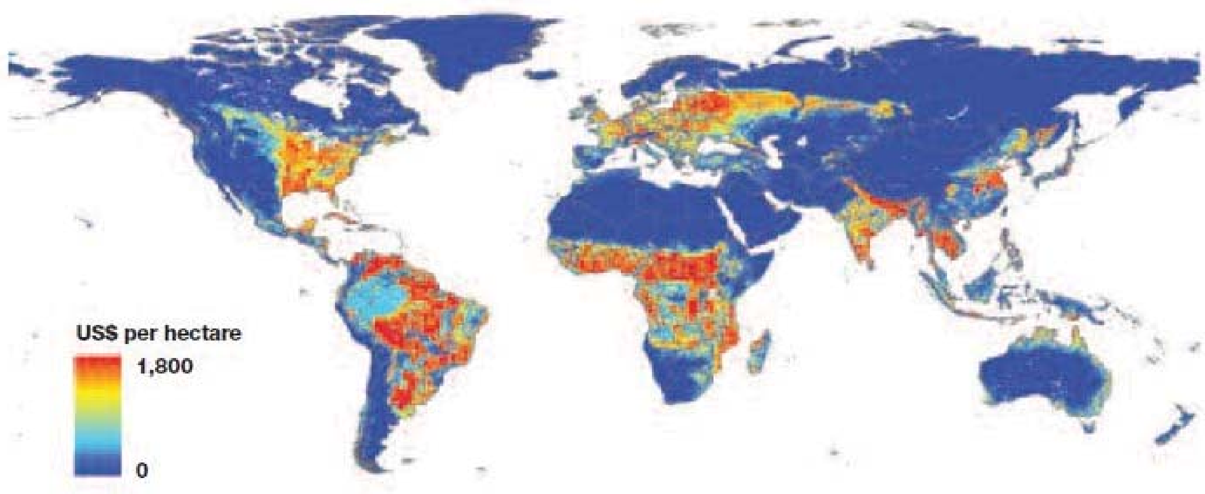


Figure 1.8. Agricultural returns per ha

Source: Sukhdev (2008) from Strassburg, et al. (2008) based on data from Naidoo & Iwamura (2007).

Three approaches compared

85. Figure 1.9 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_2e$, 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_2e. 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 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).

[22] Since other costs of REDD+ were not considered, the original phrasing of *$C0_2e$ prices* is more like an opportunity cost.

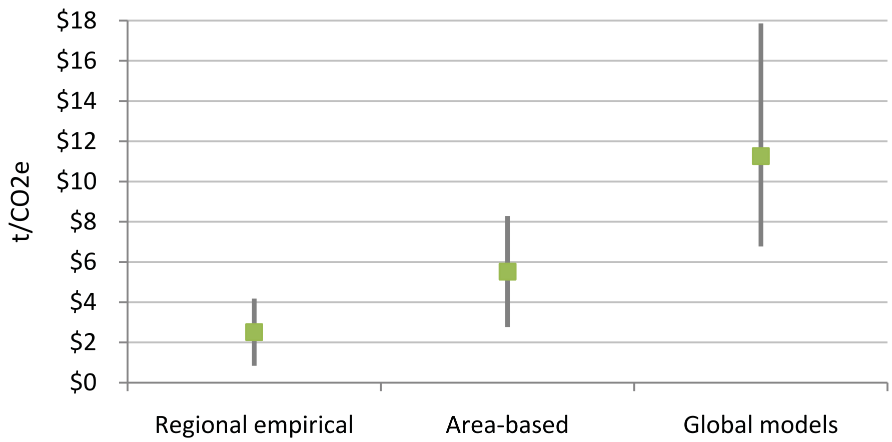


Figure 1.9. Mean estimates of opportunity cost approaches (and high-low range)

Source: Boucher, 2008b.

86. 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_2e. In Brazil, Nepstad et al. (2007) estimated that eliminating 94% of emissions from deforestation and forest degradation would cost $0.76 per t$CO_2$e. Costs to eliminate 100% would be nearly double ($1.49 per t$CO_2$e).

87. 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).

88. The next chapter provides an overview of the training manual contents and the process of estimating REDD+ opportunity costs.

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Estimating the opportunity costs of REDD+
A training manual

Version 1.3

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

Contents

Overview & preparations

ASB Partnership for the Tropical Forest Margins
CGIAR
Forest Carbon Partnership Facility
World Bank Institute
Carbon Finance Assist

Structure of the training manual

1. If estimating REDD+ opportunity costs were simple, a training manual would not be needed. Here we explain a process to estimate REDD+ opportunity costs. The approach used is based on detailed sub-national data. A strong foundation of empirical information helps to substantiate analysis results and support policy decisions. Sampling and extrapolation procedures are also shown to generate cost-effective and accurate national-level estimates of REDD+ opportunity costs.

2. The manual presents a series of distinct - but related- activities in estimating opportunity costs. An initial step 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). Although these policies are evolving within the UNFCCC framework, knowledge of them helps to link opportunity cost estimates within a larger decision framework.

3. Chapter 4, opportunity cost analysis begins with identifying and classifying land uses. An associated task includes 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 of land use change scenarios and establishing reference emission levels. Histories of land use are helpful in identifying future land use trajectories. Scenario analysis of trajectories (e.g. business as usual and alternatives) is essential in estimating and negotiating reference emission levels of countries within the UNFCCC framework. As indicated above, these activities are closely linked to countries' strategic objectives, as defined in national REDD readiness preparation proposals under the Forest Carbon Partnership Facility (FCPF) of the World Bank or national joint programs under UN-REDD.[23]

4. For the entire range of land uses, Chapter 5 shows how to estimate their carbon stocks, while Chapter 6 illustrates how to estimate their associated profits. 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. It important to note that other REDD+ preparation activities may provide data for opportunity cost analysis. For example, countries are developing reference scenarios and operational forest monitoring and carbon accounting systems at the national level.

5. 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

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[23] That is, land use classification, identification of drivers, and development of historical (and potentially future) reference scenarios are part of a country's REDD+ policy process.

advance in two ways – for estimating the vertical (cost) and horizontal (quantity) components of the curve.

6. The vertical axis is based on an **opportunity cost (oppcost) matrix**, which summarizes the opportunity costs for all land use changes in $/$tCO_2e$. 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 tCO_2e.

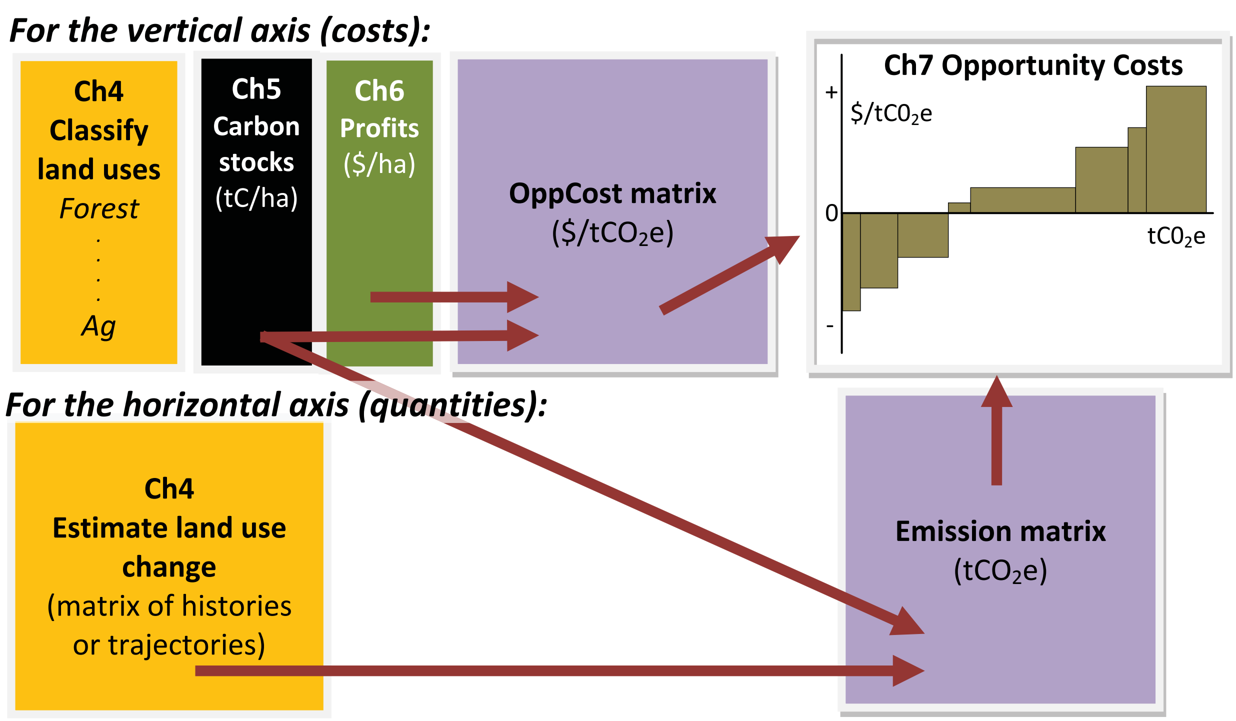

Figure 2.1. Analytical steps for developing an opportunity cost curve

8. In addition, the manual includes discussion of how to improve 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 four of the more important basic components to estimating opportunity costs: (1) analyzing land use, (2) measuring carbon, (3) estimating profits, and (3) calculating an opportunity cost curve. Throughout the estimation , with discussion and critique process, participation of a range of professional expertises and scientific disciplines make the analytic approach and results not only more precise and accurate, but also more understandable to a wider audience – including those who may be affected by REDD+ policy.

Analyzing land use

10. A framework of land use systems is required to estimate opportunity costs of REDD+. The word *systems* is used because land uses often have multiple activities that my change over time. 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 uses, and (2) distinguishing between different land use systems from remote-sensing imagery.

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),
    - Profit-relevant (homogeneous in profits),[24]
    - Policy-relevant (supports the mandates of different national agencies),
- Valid for different versions of RED(D++),
- Consistent for reporting at multiple scales: global, national, local.

12. Easily observable characteristics of rural areas, both bio-physical (e.g., vegetation, elevation, soil quality) and socio-economic (e.g., 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 on-site confirmation.

13. Nevertheless, estimating land use system *changes* is the basis 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 reference emission levels.

Estimating carbon and profits

14. 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

[24] 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.

(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.

15. In contrast, socioeconomic data do not have protocols for collection and analysis. 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 includes taking account of how revenues and costs differ over multiple years within a land use system.

16. Accurate biophysical and socioeconomic information is not sufficient for opportunity cost analysis. Equally important the ability to ***integrate*** socioeconomic and biophysical information of land use systems identified within the analytical framework. In other words, the information must be based on the same units of analysis – per hectare with annual data transformable into a multi-year analytical framework. To facilitate a better understanding and transparency of the process, the recording of contexts, processes and assumptions are highly recommended.

Estimating opportunity costs and other analyses

17. Opportunity cost analysis of REDD+ generates a money-based representation (e.g., \$/ha, \$/tC or \$/CO_2e) 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.

18. Opportunity costs estimates are a basis for further analysis and discussion. Such topics include:

- sensitivity analysis of opportunity cost estimates to changes in methods, assumptions and data,
- biodiversity and water co-benefits,
- scenario analysis of
  - different future land use trajectories,
  - distributional impacts of REDD+ policies and compensation upon
    - land users (e.g., smallholders, plantation owners), and
    - associated economic sectors (timber, agriculture, etc.)

19. Such analyses related to opportunity cost estimation can help national policymakers understand the implication of REDD+ policies.

Sensitivity

20. 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

21. 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, and thereby have 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

22. Scenario analysis can reveal how assumptions of future conditions can potentially affect estimates of land use, reference emission levels and associated economic-social-environmental 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 can assist policy development and decision processes. Discussion and exercises are found in Chapter 9.

Conclusions and next steps

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

Who should do the work?

24. Estimating the REDD+ opportunity costs requires a wide variety of expertises. 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 valid opportunity cost estimates, critique the methods used to reach the findings, and prepare the best national strategy for participating in REDD+ funds and marketplaces.

25. 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 the skill from different scientific disciplines and professional backgrounds to work together, such as forestry, economics, agriculture, geography, and policy.

26. Since many are likely to be affected by REDD+, others may want to be aware and participate, such as ecologists, hydrologists, community activists, and private sector.

Therefore, country teams will need to decide how best to balance the benefits of obtaining additional perspectives and insights with the costs of coordinating numerous contributors.

A national REDD+ analytic and policy team

27. 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
6. ***national REDD+ administrators*** to identify policy responses.

28. Participation of personnel within government agencies fosters discussion REDD+ concepts and helps to 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.

Ways to use this manual

29. 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).

Box 2.2. Do I know enough already?

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*

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 of expertise.

Likely topic priorities per expertise

30. ***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**

31. ***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

32. 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.

33. 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 2.3). Nevertheless, per agreements reached in Cancun, the Subsidiary Body for Scientific and Technological Advice (SBSTA of the UNFCCC) will define C-accounting rules and MRV etc. for national REDD+ systems. The rules may supersede or complement the IPCC Good Practice Guide.

Box 2.3. 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.

34. 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

35. Despite opportunity cost analysis not being required explicitly with REDD+ readiness processes, opportunity cost estimates inform the formulation of national REDD+ strategy. The inquiry process, analytical results, and critical review from stakeholders helps to identify optimal national strategies within Readiness Preparation Proposals (RPPs), presented to the FCPF of the World Bank (see FCPF, 2009; FCPF and UN-REDD, 2010). In addition, some investment and operating costs can be shared across other REDD+ preparations, such as collecting data and associated analytical frameworks for reference emission levels (RELs) and carbon measurement, reporting, and verification (MRV).

36. While speedy availability of results is valuable for informing decisions, accurately estimating opportunity costs requires substantial data inputs and rigorous analytical methods. If the needed data is not readily available, significant investments of time and cost can be made as Tier 1 or 2 type analyses are be advanced.

37. REDD+ preparation is a process, and countries can be at different stages. Figure 2.2 summarizes three phases for implementing a comprehensive REDD+ program and associated levels of opportunity cost analysis. The phased 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, strategy development and negotiation processes (REDD+ Phase 1). Improved opportunity cost results will also help with policy design and implementation within national development strategies (REDD+ Phase 2).

38. During these phases, some of the technical information (e.g., profitabilities, carbon stocks) may indeed 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.

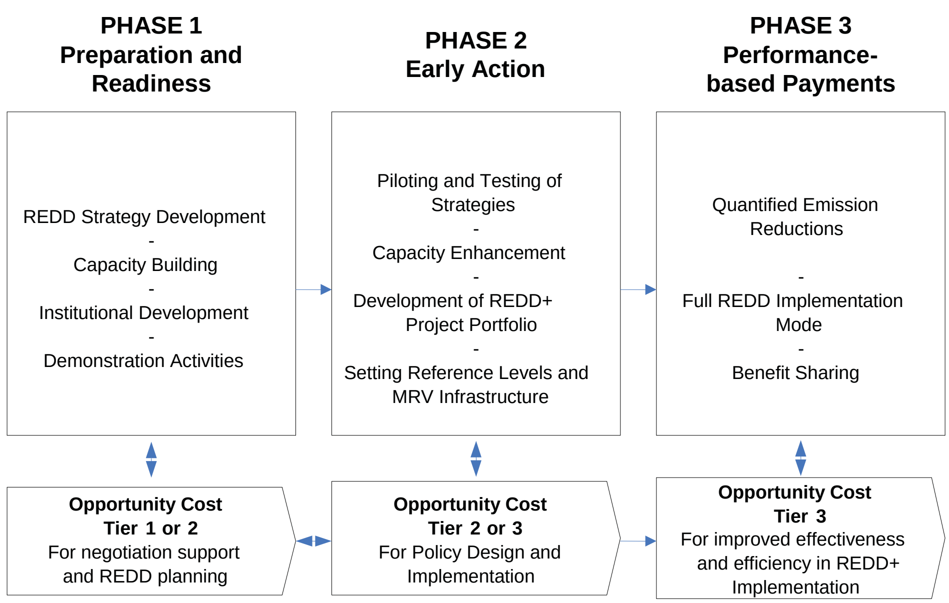

Figure 2.2. Stages of opportunity cost analysis within REDD+ program development

Source: Authors.

39. 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.

40. 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.

What information is needed upfront?

41. 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.

42. 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

43. 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).

Table 2.1. Process planner and checklist

Topic	Task	Required expertise/skills								Process
		Geography /remote sensing	*Forestry*	*Carbon measure*	*Economics (Ag,For)*	*Field (Ag,For)*	*Hydrology*	*Ecology*	*Policy*	
Team preparation	Participant identification									
	Workshop training									Regional workshop
	Invitation and TOR of presentation									
	Identify deforestation drivers									National workshop 1
Land use	Diagnose and review data and analysis									
	Develop a national land use framework									National workshop 1
	Create land use maps									
	Validate land uses and classifications									Meetings
	Estimate land use change									
	Identify land use trajectories									National workshop 1
Carbon	Coordinate with national accounting system									Meetings
	Diagnose and review data and analysis									
	Establish sampling procedure									
	Measure C in different land uses									Sub-team activity
Profits	Diagnose and review data and analysis									
	Clarify accounting stance and other assumptions									Meeting
	Develop enterprise budgets									Sub-team activity
	Estimate profits from land uses									
	Estimate NPV of land use trajectories									
Water & BioD Co-benefit	Diagnose and review data and analysis									
	Identify co-benefit areas									Meeting
	Prioritze co-benefit areas									National workshop 2
Analysis & discussion	Estimate opportunity costs									
	Map the REDD opportunity costs									
	Analyze scenarios and sensitivity of results									National workshop 2
	Discuss policy implications									National workshop 2
	Develop national REDD strategy									National workshop 3

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Estimating the opportunity costs of REDD+

A training manual

Version 1.3

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

RED(D++) policy context

1. Terms and phrases that are commonly used when discussing REDD+ policy are in Box 3.1. For definitions, see Glossary in **Appendix A**.

REDD+ policy words

Deforestation	Baseline	Business as usual
Degradation	Removal	Reference emission level
AFOLU/REALU	LULUCF	Additionality

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.

An evolving REDD+ eligibility policy

3. 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[25]) and expanded to

[25] Changing carbon-rich forest land into another land use with lower carbon stocks.

REDD taking into consideration forest degradation (which does not involve a land use change from forest land to non-forest land).

4. The discussion next broadened to also consider forest conservation, sustainable forest management, and enhancement of forest carbon stocks (REDD+). In Bali December 2007, the parties to the UNFCCC confirmed their commitment to addressing global climate change, yet an agreement on REDD+ was not reached. Advances were made towards an agreement including reference to REDD, [26] calling for:

> *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+).*

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.[27] During the COP16/CMP6 in Cancun, the Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA) of the UNFCCC adopted a mechanism that encourages developing countries to contribute to mitigation actions in the forest sector by the full scope of REDD+ activities (reducing emissions from deforestation, from forest degradation, conservation of forest carbon stocks, sustainable management of forest, enhancement of forest carbon stocks).

6. Although not discussed at the UNFCCC level, 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++.[28] The definition of forest also may have implications on REDD+ (see Box 3.2 for details on what is considered forest).

Box 3.1. 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^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 *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.

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[26] UNFCCC Decision 1/CP.13, UNFCCC Decisions 2-4/CP.13, Decision 2/CP.13 dedicated to REDD.

[27] The option will require policies and efforts to avoid double counting with eligible clean development mechanism (CDM) afforestation/reforestation projects.

[28] The second + can have different meanings, depending on a person or context. It used to imply afforestation/reforestation, social safeguards, and REALU (Frey, 2010; personal communication).

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,
- 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. To estimate REDD+ opportunity costs, associated levels of carbon and net earnings of degraded and improved forests can be calculated.

[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.*

7. 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

8. Identifying who pays the costs, and receives benefits, of REDD+ is essential to understanding how a policy will function. For national REDD+ program, three types of perspectives are important to recognize: (1) *individual groups or actors*, (2) *national or country,* and (3) *government agency*. The mixing of these perspectives can lead to estimation errors that potentially misinform policy decisions. The perspective from which impacts are estimated is termed an accounting stance.[29]

9. The accounting stances of REDD+ policy can be identified by other names. 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 estimating the opportunity costs of REDD+, the terminology has been adjusted to avoid confusion. (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 3.1. Contrasting names for accounting stances

Country/National	=	Social	=	Economic
Individual groups	=	Private	=	Financial
Pagiola & Bosquet, 2009		*Monke & Pearson, 1989*		*Gittinger, 1982*

10. Three important differences exist between the accounting stances. One refers to **what costs and benefits to include** within calculations. 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

[29] This presentation is adapted from Pagiola and Bosquet, 2009.

country.[30] 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.)

11. 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, subsidies, trade restrictions, etc.) or because of market imperfections (e.g., monopoly power, externalities,[31] 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.

12. 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.

13. 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. For example, although a government payment to forest owners is a cost to government, it is also a benefit to the landowner. The administrative cost, however, remain a cost to the country.

14. 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.[32]

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[30] Examples of benefits realized primarily outside the country include the climate change mitigation benefits of carbon sequestration and biodiversity conservation.

[31] 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.

[32] 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. Type of REDD+ cost to be included per accounting stance

Cost category	Individual	Government agencies	Country
Opportunity	✓		✓
Implementation	*	✓	✓
Transaction		✓	✓

* denotes a cost that may be partially assumed by individuals.

15. *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 *not* be considered an economic cost to the country. (*For more on this subject, see Pagiola and Bosquet, 2009, and Chapter 6 on Estimating the profits from land uses*.)

Reference emission levels

16. How much emission reduction can be achieved at a specific carbon price? The answer to this question enables a country to identify and negotiate 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+.

17. 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*mn. 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 tsm). 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 nmwv).

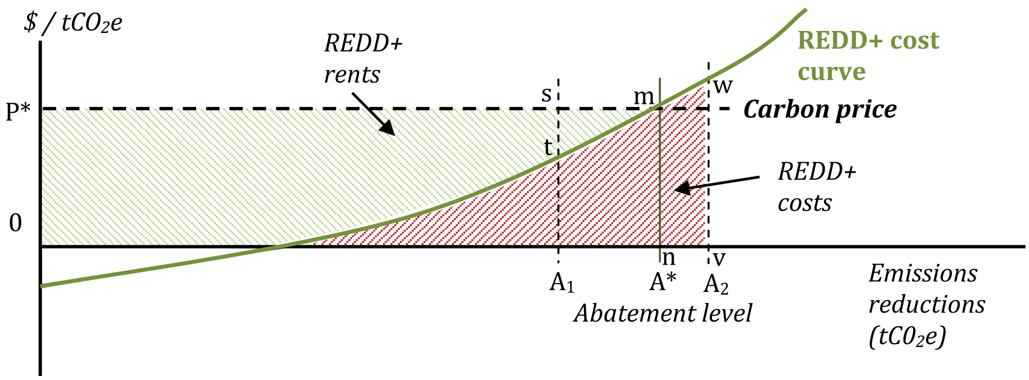

Figure 3.1. REDD+ rents and costs

Source: Authors.

18. 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)

19. 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.

20. 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.

21. 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). In Cancun, agreement was reached to officially recognize NAMAs under the multilateral process. An international registry will be developed with the purpose of recording and matching developing country mitigation actions with finance and technology support.

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.

SESAs and safeguard policies of the World Bank

24. A number of World Bank safeguard policies may affect national REDD+ strategies and implementation. These policies are also reflected within a Strategic Environment and Social Assessment (SESA) of an RPP (Forest Carbon Partnership Facility, 2010). World Bank safeguards and SESAs are two mechanisms that enable a REDD Country Participant to identify likely impacts and risks, as well as opportunities, and consequently make more informed and appropriate choices between strategic options.[33]

25. 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. The following are some of the more relevant safeguard policies to REDD+.[34]

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[33] FCPF. 2010. RPP template. Version 4

[34] For a complete list and explanation, see: http://web.worldbank.org/WBSITE/EXTERNAL/PROJECTS/EXTPOLICIES/EXTSAFEPOL/0,,menuPK:584441~pagePK:64168427~piPK:64168435~theSitePK:584435,00.html

Involuntary resettlement

26. Involuntary Resettlement[35] is triggered in situations involving involuntary taking of land and involuntary restrictions of access to legally designated parks and protected areas. 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[36] 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[37] 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

[35] Operational Policy 4.12
[36] Operational Policy (OP)/Bank Procedure (BP) 4.10
[37] Operational Policy 4.04

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.

Projects in Disputed Areas

32. Projects in Disputed Areas[38] 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.

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Estimating the opportunity costs of REDD+

A training manual

Version 1.3

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.

Contents

ASB Partnership for the Tropical Forest Margins
CGIAR
Forest Carbon Partnership Facility
World Bank Institute
Carbon Finance Assist

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. A series of steps are presented 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. For predicting land use change, important to develop scenarios, different modeling approaches are briefly presented.

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
    6. Predicting land use change

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

Spatial analysis and remote sensing words

Land cover	Resolution
Land use	Spectral
Land use system	Spatial
Classification system	Ground truth
Land use legend	Minimum mapping unit
Land use trajectory	Mixed mapping unit
Attribute table	Vector GIS
	Raster GIS

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 actual land uses 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.

Land cover ≠ Land use

7. To enable correct and consistent use of land use information (e.g., carbon, profits) for opportunity cost analysis at a national level, a **hierarchal land use framework can be** employed (Figure 4.1).

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 him will he 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.

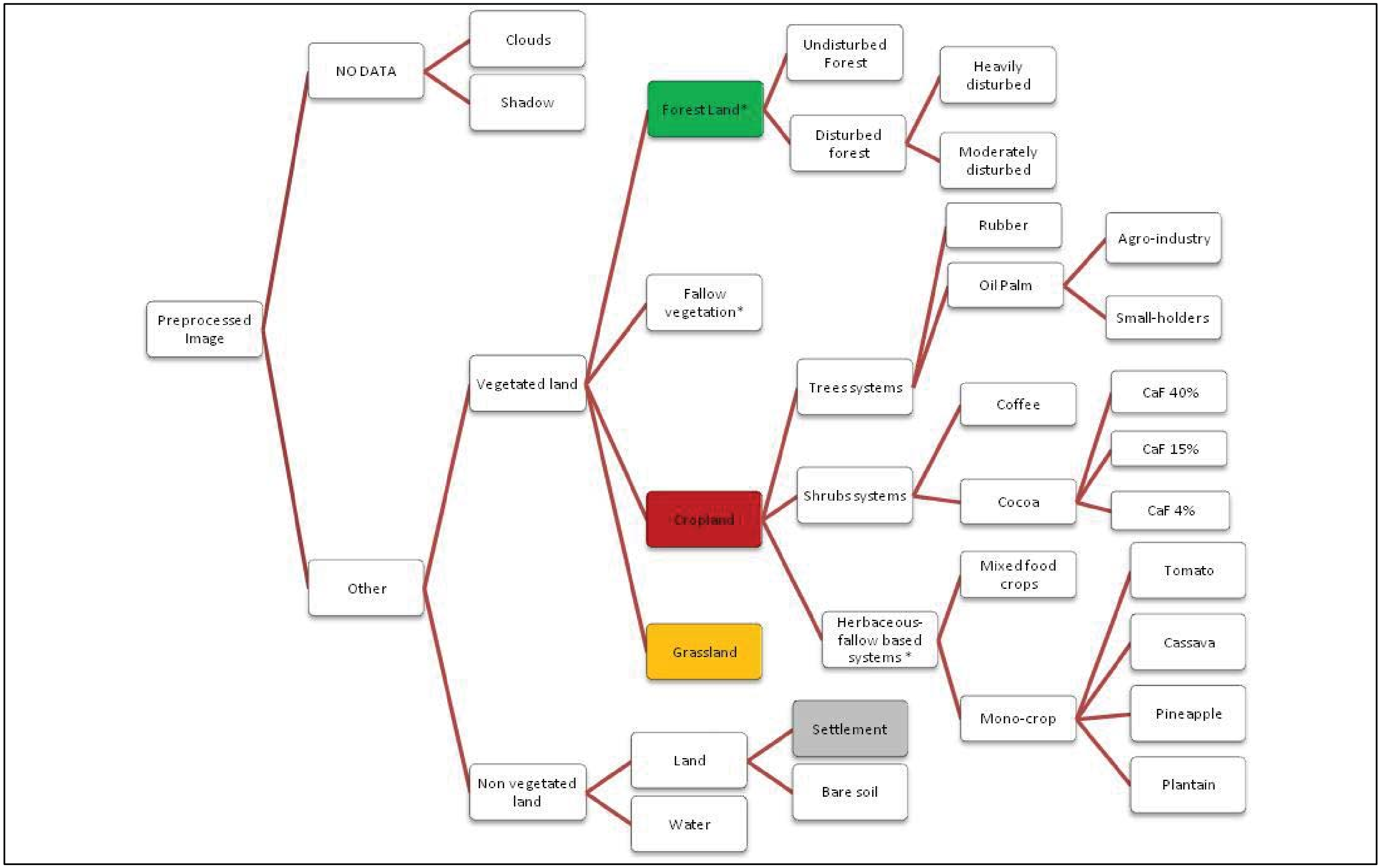

Figure 4.1. A hierarchical land use framework in Cameroon humid forest zone.[39]

Source: Robiglio, 2010.

[39] 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.

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 REDD+ programs.

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. A lower number of classes requires less data management and analysis. In addition, a false sense of precision may arise by creating numerous sub-classes from inadequate resolution of images, 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.

Table 4.1 shows a land cover and land use classification with three 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. A fourth level (not depicted) only refers to forest, using percent canopy cover as distinguishing criteria. In this example, - 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.

Table 4.1. A legend from a hierarchical land cover classification system

Level 1		Level 2		Level 3			
1	**Forest**	*> 10% canopy Cover and > 40 % forest cover **					
Forest		1	Evergreen & Semi-evergreen Forest	0 1 2 3	Unknown Evergreen – lowland forest Evergreen – mountain forest Semi-evergreen forest	4 5 9	Heath forest / Caatingas Coniferous 6. Bamboo forest Other
		2	Deciduous Forest	0 1 2	Unknown 'Dense dry' forest (Africa) Miombo' (Africa)	3 4 9	(Dry-) Mixed deciduous (Asia) Dry Dipterocarp' (Asia) Other
		3	Inundated Forest	0 1 2	Unknown Periodically inundated –Varzea Swamp forest (perm. Inundated)	3 4 9	Swamp forest with palms Aguaj. Peat swamp forest Other
		4	Gallery-forest	0			
		5	Plantation	0 1 2	Unknown Teak Pine	3 9	Eucalyptus Other
		6	Forest Regrowth	0			
		7	Mangrove	0			
		9	Other	0			
2	**Mosaic**	*>10% - 40 % forest cover (and > 10% canopy cover)*					
Mosaic		1	Shifting Cultivation	0 1 2	Undefined ≤ 1/3 cropping > 1/3 cropping		
		2	Cropland & Forest				
		3	Other Vegetation & Forest				
		9	Other				
3	**Non-Forest Natural Vegetation**	*≤ 10% forest cover or < 10% canopy cover*					
Non-Forest Natural Vegetation		1	Wood & shrubland	0 1 2 3 4	Unknown Woodland savanna – Cerrado] Tree savanna Shrub savanna Bamboo (pure stands)	5 6 7 9	Swamp savanna Humid (evergreen) type (Asia) Dry (savanna) type (Asia) Other
		2	Grassland	0 1 2 9	Unknown Dry grassland Swamp grassland –varzea Other		
		3	Regrowth of vegetation				
		9	Other				
4	**Agriculture**	*≤ 10% forest cover or ≤ 10% canopy cover*					
Agri-culture		1	Arable	0 Unknown, 1 Irrigated, 2 Rain-fed			
		2	Plantations	0 1 2	Unknown Rubber Oil Palm	3 9	Coffee, Cacao, Coca Other
		3	Ranching				
		4	Small holdings				
		9	Other				
5	**Non-vegetated**						
Non-vege-tated		1	Urban				
		2	Roads				
		3	Infrastructure	1 Mining, 2 Hydro-electric, 9 other			
		4	Bare soil				
		9	Other				
6	**Water**						
Water		1	River				
		2	Lake	1 Natural, 2 Artificial			
7	**Sea**						
8	**Not visible**						
Not visible		1	Clouds				
		2	Shadow				
9	**No data**						

Source: Puig et al., 2000

14. 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.

15. 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 System[40] (LCCS; Di Gregorio, 2005). The LCCS includes a thorough description of classification concepts and guidelines for matching land cover types to global standards.

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 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 with 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.

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[40] The LCCS manual and software can be acquired from the Global Land Cover Network website (http://www.glcn.org/).

Box 4.1. 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

16. 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 Guidance and the GOFC-GOLD REDD Sourcebook (IPCC, 2006; GOFC-GOLD, 2009).

Remote sensing data

17. 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.umiacs.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

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

Source: Adapted from GOFC-GOLD, 2010.

18. 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.

19. 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).

Figure 4.2. A spatially heterogeneous farm landscape in Cameroon.
Source: Robiglio, 2009.

20. 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.

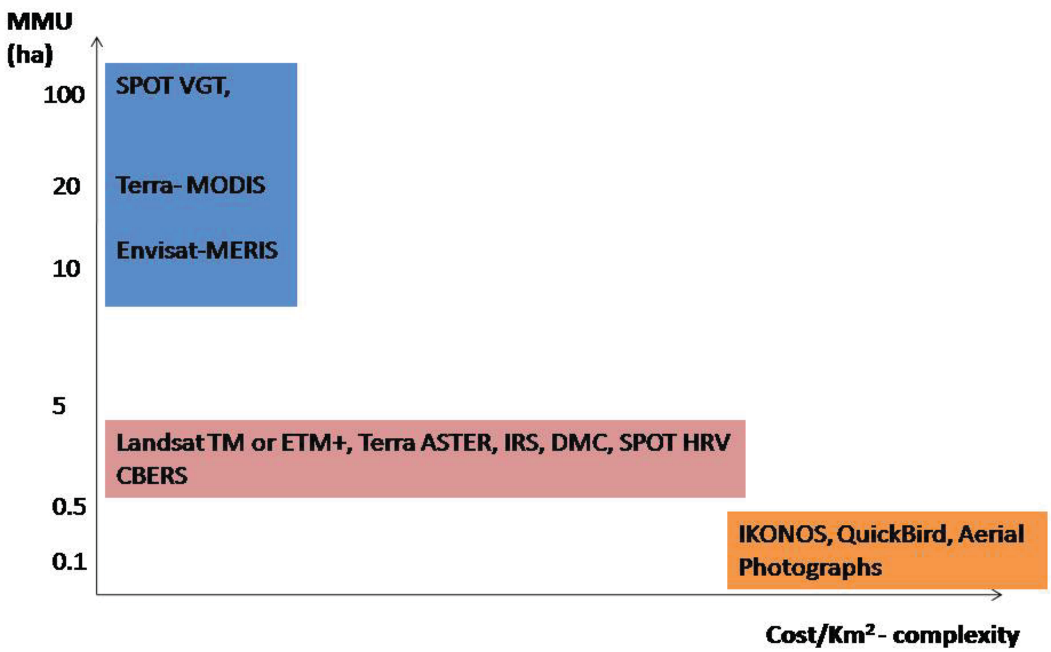


Figure 4.3 Remote sensing data: cost and complexity versus resolution (MMU)

Source: Authors

21. 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 4.4 below). As they become available and accepted, analysts can consider these new approaches.

Box 4.2. 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

22. 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).

23. 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.

24. 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 4.3. The challenge of identifying forest degradation

Forest degradation is a reduction of tree density, measured by 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 of 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. Forest inventory plots can produce accurate biomass and carbon estimates yet results are site specific (see Harris, et al. 2010) In the land use legend presented earlier in this chapter, forest degradation is accounted for by identifying the different levels of canopy cover. Associated spatial data may be used to identify areas where degradation may be occurring (e.g. in logging concessions). Forest density and tree coverage can be estimated using expert judgment, LIDAR (Light Detection and Ranging) or multispectral 3-dimensional aerial digital imaging.

Identification of forest degradation is a hot topic in remote-sensing research. Asner (2009) has developed a method to combine traditional satellite mapping approaches with an active airborne, laser technology approach called. LIDAR produces information on the height of trees, crown diameter 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).

M3DADI uses (1) GPS-based techniques to identify tree crown mosaics, and (2) off-the-shelf camera equipment mounted on Cessna aircraft to generate accurate raster-based photomaps. From the aerial videography, a 3D reconstruction is developed that identifies terrain features and vegetation types and measures the height and mass of individual trees. The measurements are then calibrated with the carbon inventory data and regression equations to estimate carbon remotely (Stanley, et al. 2006).

The time costs for the field sampling approach were about 2.5 to 3.5 times longer than for the M3DADI approach to achieve the same precision level. Although M3DADI has high fixed costs, the costs for additional plots are low (Brown and Pearson, 2006). Another advantage of remote-sensing approaches is that the data provide a permanent record of what was found in a given location at any given time. The images can be re-visited and verified, or new assessment techniques applied to historical data to improve historical estimates (Stanley, et al. 2006).These new method and others promise to improve our capacity to cost-effectively identify forest degradation.

Checking accuracy

25. 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

26. 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.

27. 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.

28. 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.

29. 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.

30. 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

31. 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.

32. 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 ve*rification protocol* document includes a sample survey form for recording information.[41] 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. 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 4.4. Optimizing activities in the field

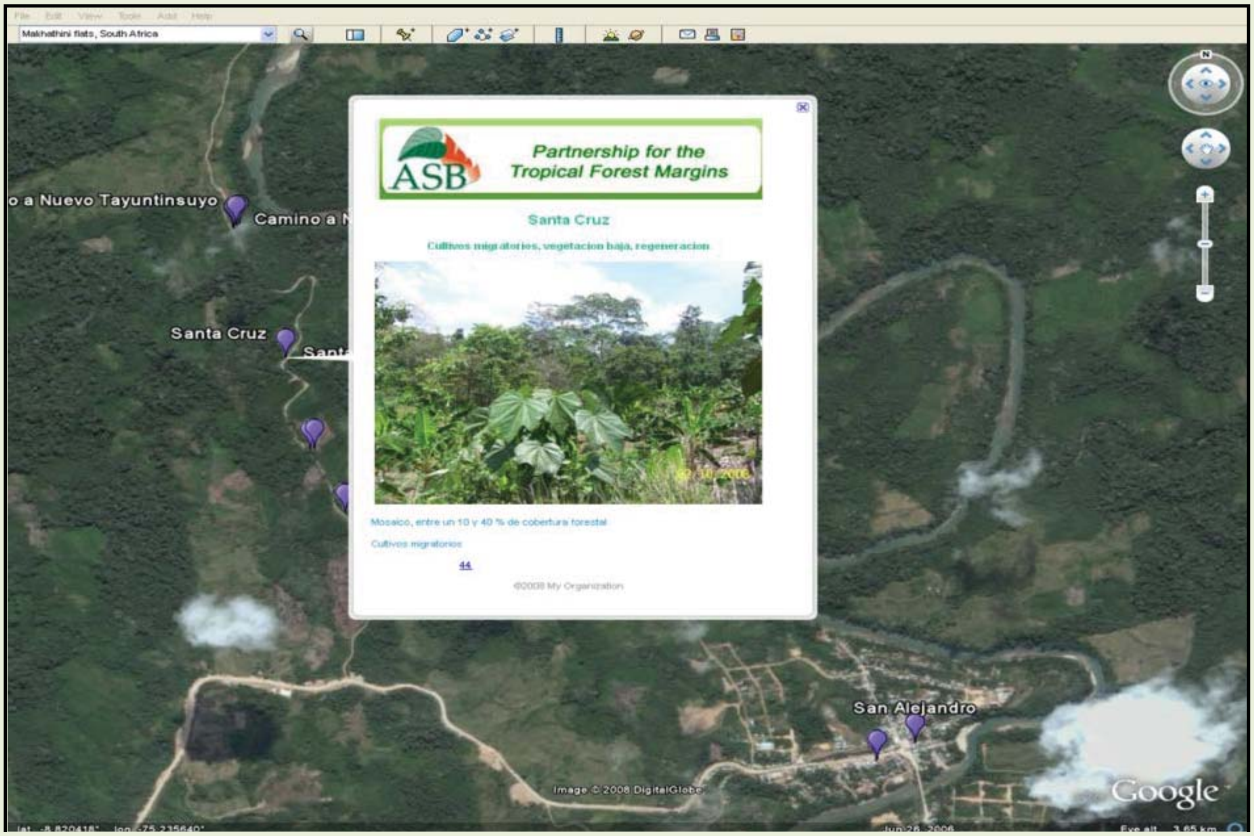
Fieldwork in the study area can accomplish multiple objectives at the same time. For example, while researchers are taking plot level measurements of biomass, digital photographs and global positioning system (GPS) points can be collected with notes on the land conditions.

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

[41] The CIFOR-ICRAF-Biodiversity Platform has produced a document titled "Ground-truthing Protocol," available from http://gisweb.ciat.cgiar.org/GoogleDocs/FPP_Mapper/groundtruth_protocol.pdf.

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 photograph of a ground-truth point within a landscape

33. 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

Land Cover Classes	1	2	3	4	5	6	7	8	9	Google	Users
1	40					3				43	93.0
2		31				2				33	93.9
3			29		1	3				33	87.9
4				28		4	1		1	34	82.4
5					24	2				26	92.3
6	1	4	1	4	1	36	3	3	3	56	64.3
7				3			30			41	73.2
8	1						4	26		31	83.9
9			1	2			3		21	27	77.8
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.

Source: White and Hyman, 2009.

34. 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.

35. 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.

36. 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.

37. 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

38. 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.[42] 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.[43]
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.

39. 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).

40. 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).

41. 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

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

[43] 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.

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.

		Change to **Land cover 2006**							
Change from **Land cover 2003**		FL	CL	GL	WL	SL	OL	ND	**Total**
	FL	89.11	1.22	1.64	0.47	0.02	0.45	0.69	**93.6**
	CL	0.87	45.28	1.09	0.30	0.35	0.39	0.18	**48.45**
	GL	1.79	1.27	14.73	0.49	0.03	0.21	0.15	**18.66**
	WL	1.22	0.65	0.58	7.78	0.03	0.30	0.01	**10.57**
	SL	0.03	0.17	0.04	0.01	2.61	0.02	0.01	**2.91**
	OL	0.20	0.28	0.32	0.11	0.02	2.09	0.01	**3.02**
	ND	5.25	1.50	1.03	0.20	0.04	0.17	2.51	**10.7**
	Total	**98.46**	**50.37**	**19.42**	**9.36**	**3.09**	**3.63**	**3.57**	**187.91**

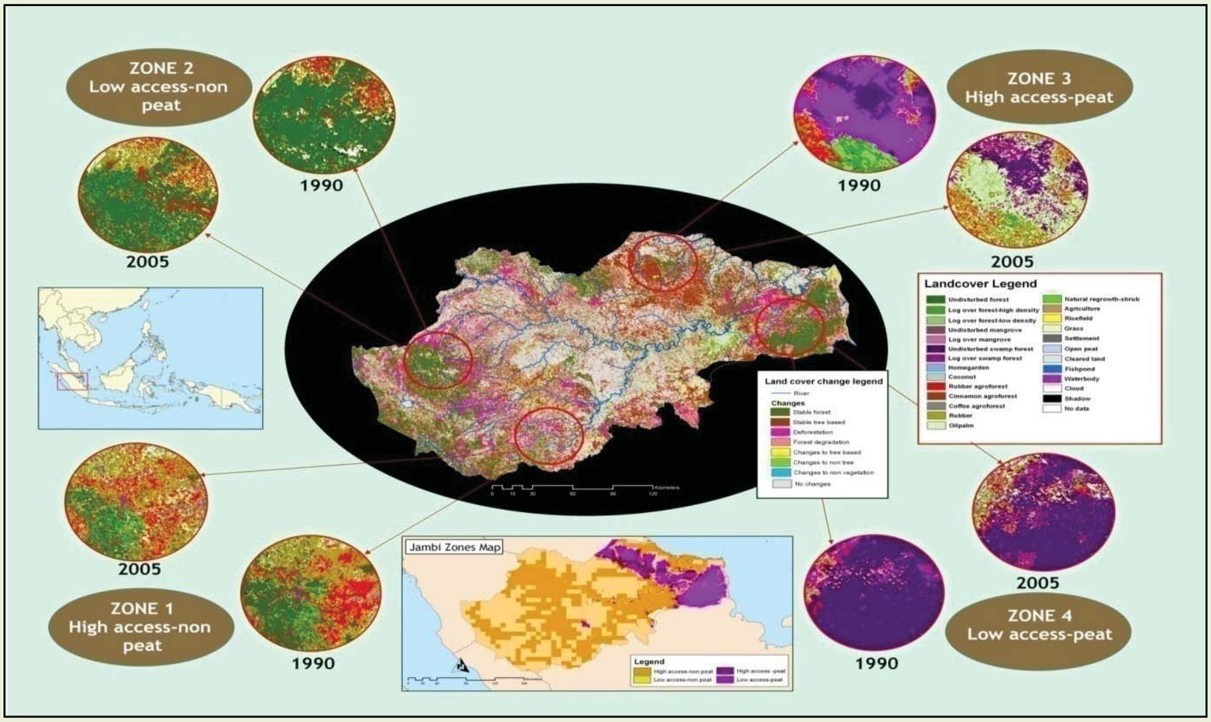
Land covers: FL= forest land, GL= grassland, WL= wetland, SL= settlement, OL= other land, ND= no data.
Source: Authors

42. 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.

43. 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 4.5. 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

44. 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.

45. Here we discuss three related topics, the *forest transitions, drivers of deforestation* and *land use trajectories*. Inquiry into forest transitions helps to identify the conditions of national forests: ranging from natural/pristine to logged and degraded. Forest condition has implications on carbon content, future profits and opportunity cost estimates. Analysis of the drivers of deforestation attempts to answer the question of why deforestation occurs. The topic of land use trajectories is based on analysis of past land use change. Understanding of forest condition, drivers of change and types of change are essential to identifying plausible future land use trajectories, from which REDD+ opportunity costs are estimated.

Forest transitions

46. The world's forests have experienced different levels of use. Given the condition of forests, specific components of REDD+ policy (with respect to deforestation, degradation, afforestation/reforestation) can be more relevant in some countries than others. To compare the status forests can be a transition curve can be used (Figure 4.4) that reflects the dynamics of agriculture, forests and other land uses over time (Angelsen, 2007). Consequently, the location of a country (or sub-national region) on the forest transition curve can affect the priorities for participating in REDD+ programs and associated opportunity costs. The forest transition framework uses four basic categories:

1) Countries with **low deforestation and high forest cover** such as the Congo Basin and Guyana. In these countries, forests are relatively undisturbed, however deforestation and degradation may increase in the future. Degradation is important since these countries are less likely to benefit from 'avoiding deforestation'.
2) Countries with **high deforestation** such as (areas of) Brazil, Indonesia and Ghana. These countries have strong incentives to engage in deforestation accounting. Nevertheless, they are less likely to have a significant interest in accounting for degradation unless little additional accounting effort is required.[44]

[44] The exclusion of forest degradation from national REDD+ programs, especially where selective logging is common, could lead to considerable leakage.

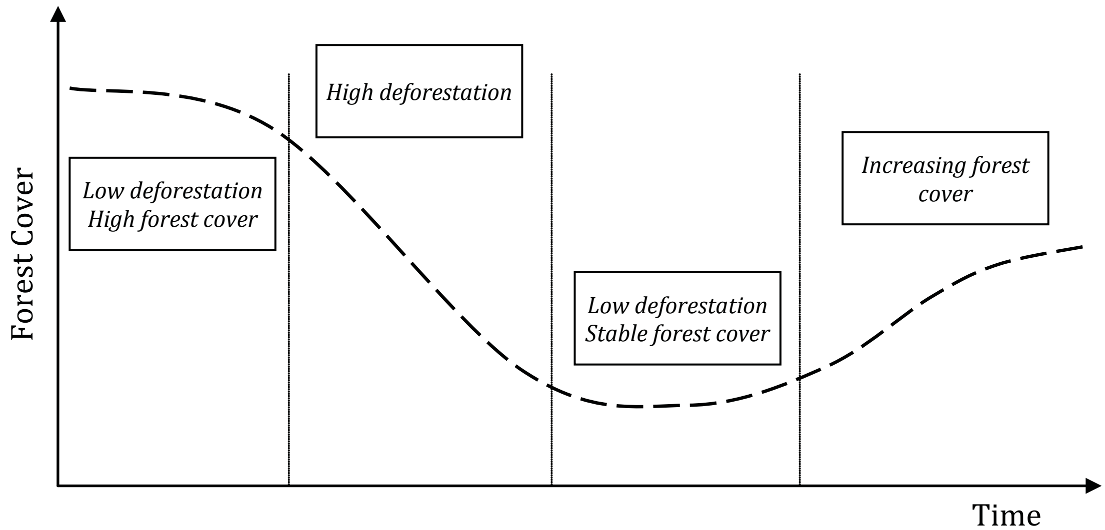


Figure 4.4. Categories of forest transition

Sources: Adapted from Angelsen (2007) and Murdiyarso (2008).

3) Countries with **low deforestation and stable forest cover** are characterized by forest mosaics and stabilized forests. Either because the forest has already been largely cleared or because of effective forest protection policies, deforestation rates have leveled off. India and parts of Central America may pertain to this category. These countries may be interested in reducing degradation, probably in combination with forest conservation, afforestation and reforestation, and other schemes aimed at enhancing forest carbon stocks.
4) Countries with **increasing forest cover** such as China and Vietnam. These countries have interest in degradation accounting and enhancing their carbon stocks. Although national forest area may be increasing through plantations, existing forests may be simultaneously experiencing degradation, which could be reverted through protection or enrichment plantings.

Driving forces of deforestation

47. Knowledge of the broader factors driving deforestation helps analysts understand the potentially complex causes of land use change, estimate both business-as-usual and reference emission levels, and identify appropriate policies required for achieving REDD+.

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

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

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 4.5). 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.

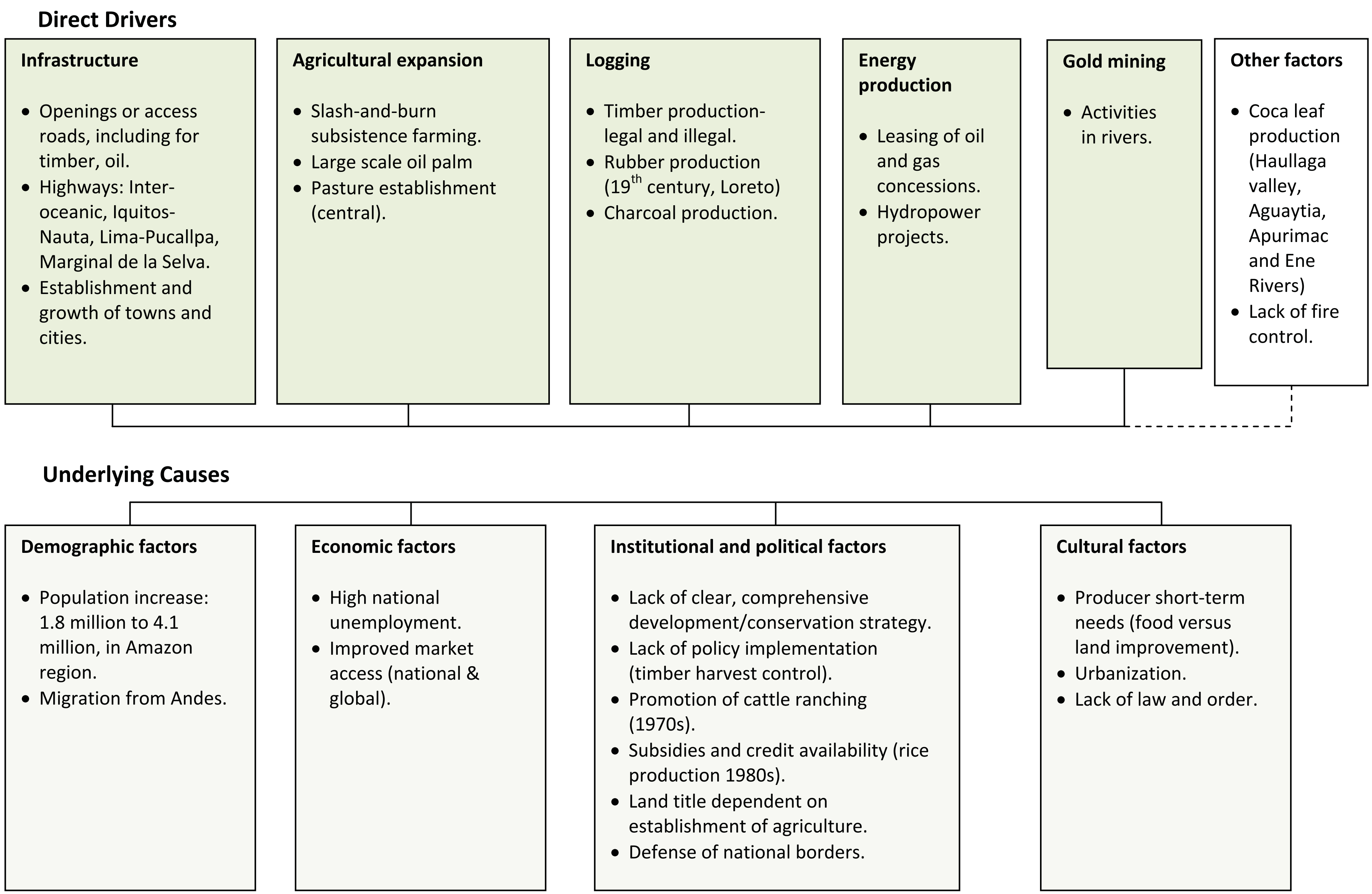


Figure 4.5. Direct and underlying causes of deforestation in the Peruvian Amazon
Source: Adapted from White, et al. (2005), Geist & Lambin (2002), Reducing Emissions from All Land Uses *project (REALU; Velarde, et al., 2010).*

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 4.6. Context of the analysis is provided by the forest and non-forest land uses before the analysis horizon.

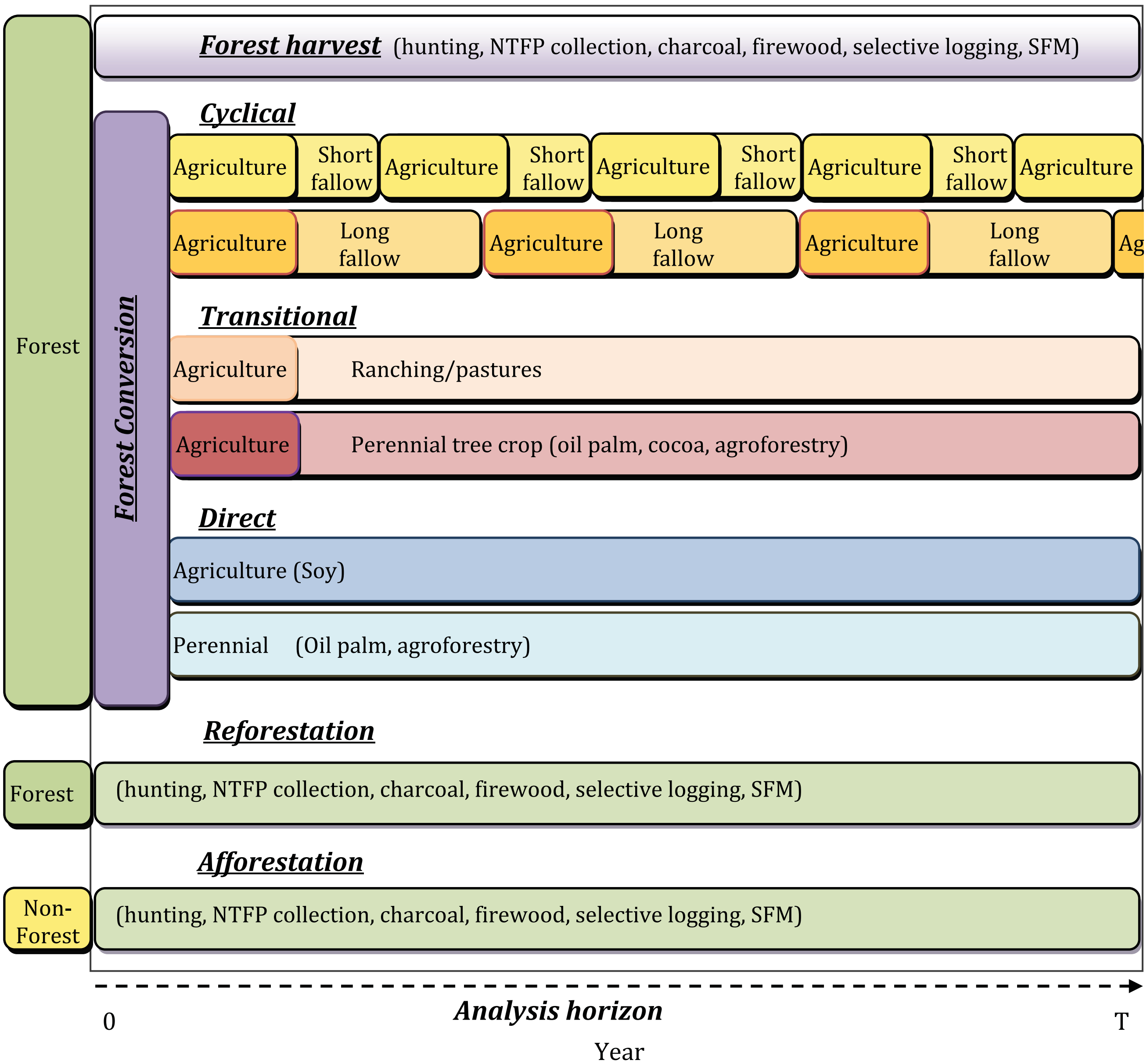


Figure 4.6. Land use change trajectories: types and examples

Source: Authors.

Forest harvests

56. 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.

57. 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 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, agroforestry systems or oil palm plantations are examples of direct changes.

The following land 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). Numerous types of livelihood activities can occur with established forests.

Afforestation

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

Predicting land use change

66. Future projections of land use change are an important component in estimating baseline and reference emission levels. Figure 4.7 shows how analysis of historical trends link with future projections.

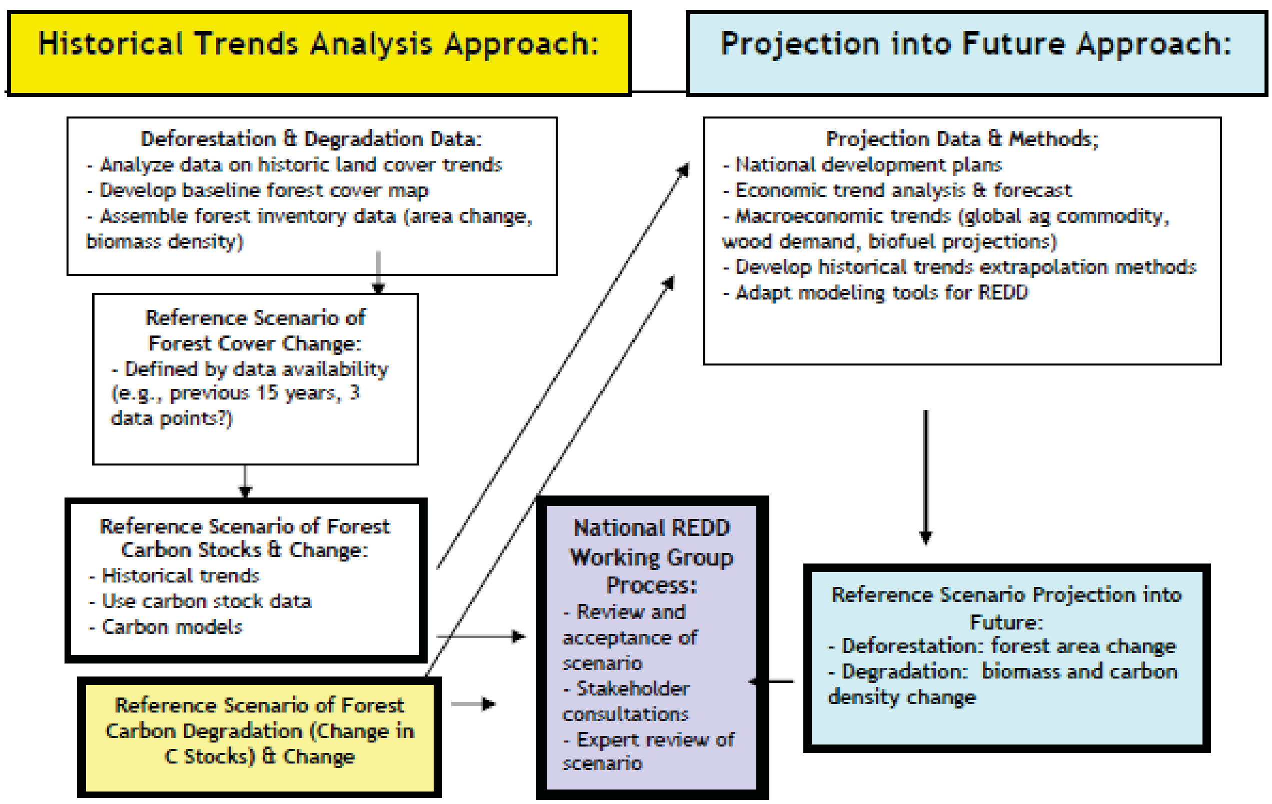


Figure 4.7. Land use change: links between historical and future analyses
Source: FCPF, 2010.

67. Analyses of future land use change range from simple to sophisticated. Simple approaches include extrapolating past land use change into the future. Adjustments can be made to account for both bio-physical (e.g., soil fertility, road access, etc.) and socio-economic factors (e.g., population growth, government development policy, food prices, etc. Sophisticated approaches include spatial probabilistic analyses with different explanatory variables and feedback effects. See Agarwal, et al. (2002) for an extensive review of land use change models. Despite the wide range of complex analytical methods, scenario analyses are important to compare the effect of different data, contextual and method assumptions.

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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 framework,
3. Introduce carbon measurement protocols and reference materials, using a bottom-up approach for carbon measurements from plot to land use, to landscape/sub-national level, and to national scale,
4. Identify data sources, gaps and measurement priorities,
5. Estimate ”typical carbon stock values” (time-averages) of land uses for use in an opportunity cost analysis.
6. Assess costs for capacity building based on available national capacities.

Contents

1. Numerous terms are used in the measurement of carbon. For definitions, please refer to the Glossary in **Appendix A**.

> ***Forester and carbon specialist words***
>
> Allometric equation
> Biomass
> Carbon dioxide flux
> Diameter at Breast Height (DBH)
> Humification
> Litterfall
> Landscape
> Necromass

Know your carbon

2. How much carbon would be emitted if a given hectare of forest were converted to another use? The answer to this question is a critical part of analyzing REDD+ opportunity costs. 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. Important carbon measurement protocols and reference materials are presented along with how to identify data sources and carbon measurement priorities. Cost estimates for applying these methods are also provided.

Terrestrial carbon cycle

3. Carbon dioxide (CO_2) is exchanged between terrestrial vegetation and the atmosphere. Net balances change between sequestration (also known as storage or fixing) and release according to 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 (or fluxes) can be expected to cancel out, thereby enabling a focus on net carbon changes.

> Link this carbon analysis with on-going carbon MRV efforts

4. Carbon can take different paths. In most years, the annual net effect of photosynthesis, respiration and decomposition is a relatively small increment in stored carbon. Nevertheless, accumulated gains sometimes are lost in drought years where fire consumes organic matter. Carbon can also move off-site. 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

5. 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.' Since tropical forests in their natural condition contain more aboveground carbon per unit area than any other land cover type (Gibbs, et al., 2007), they are important to consider within effort to mitigate climate change.

6. Consistent accounting for all carbon inflows and outflows is more complex than a simple check of the bottom-line change in total global 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 particularly small source areas with high emission estimates (IPCC, 2006). For the purposes of estimating REDD+ opportunity costs, carbon measures of different land uses are required in order to estimate the carbon effects from numerous types of land use change.

Carbon is not just carbon

7. Carbon is found in different pools. Terrestrial carbon stocks of all carbon stored in ecosystems 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 micro-organism biomass)

8. In the IPCC guidelines, these pools are described as *above-ground biomass*, *below-ground biomass*, *dead wood and litter*, and *soil carbon*. These are summarized in Figure 5.1 described in more detail below.

Table 5.1. Four IPCC carbon pools

	Alive	*Dead*
Above ground	Biomass (, stems, branches leaves of woody and non-woody vegetation)	Wood and litter
Below ground	Biomass (roots, fauna)	Soil carbon (including peat)

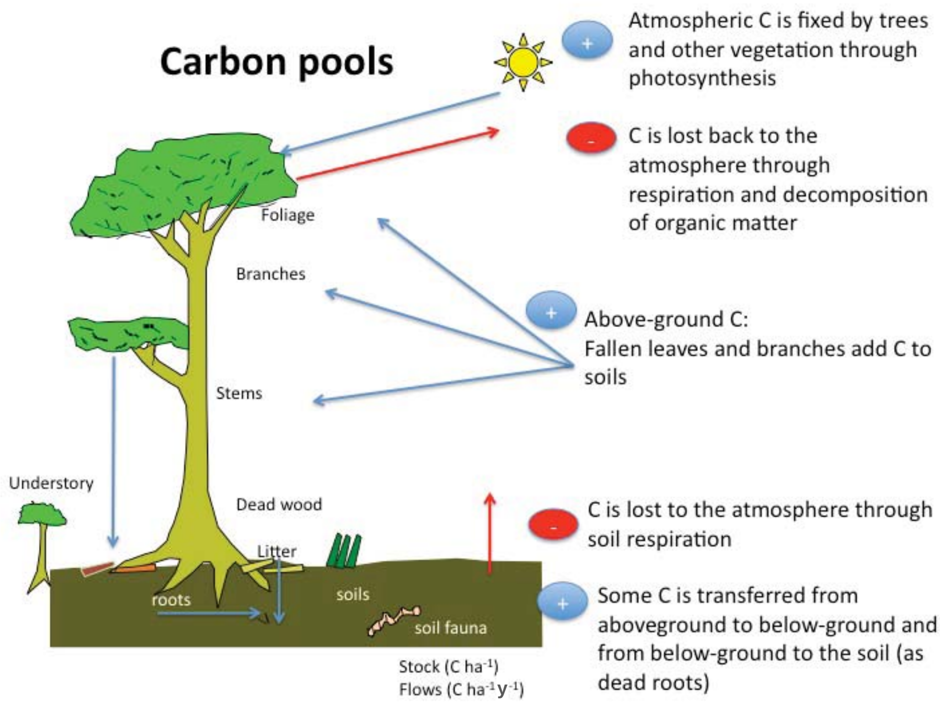


Figure 5.1. Terrestrial carbon pools

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

Living plant biomass carbon

9. *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.

10. *Below-ground biomass* comprises roots, soil fauna, and the microbial community.

Dead plant biomass carbon

11. The dead organic matter (i.e., 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/yr, 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. Since logging tends to focus on harvesting the more valuable trees and damage many others, necromass may be 30-40% of the aboveground carbon stock after logging. If fire is used in land clearing, the resulting carbon will be emitted directly or reside for approximately 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.

14. The change in soil carbon content due to land use change is rarely larger than 20 Mg carbon per ha (IPCC, 1997; Murty, et al., 2002), unless in wetland conditions. Under specific climatic conditions (e.g., with an annual rainfall surplus but a prolonged dry season in flat terrain with deep groundwater storage) trees with deep root systems are able to prolong the growing season. in addition, the turnover of fine roots at depth adds soil carbon stocks at depths that can lead to soil carbon changes after conversion in excess of 20 Mg carbon per ha. 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 from the initial stock of 40.8 ± 20.4 Mg /ha can be expected (Agus, et al., 2009).

Box 5.1. Most of the biomass is in the few really big trees

The carbon stock in an individual tree depends on its size. Trees of 10-19 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. With approximately 900 trees per ha, the corresponding associated biomass is 121.5 t/ha. Yet, most of the biomass is in the few large trees. With a DBH of 50-70 cm, the mass per tree could be approximately 20,000kg (20 t). With 10 trees/ha, the corresponding biomass would be about 200 t/ha. The below table summarizes this example.

Thus, the implications of large trees on biomass (and carbon) per ha is very significant. Although selective logging may only remove a few trees per ha (and damage surrounding ones), timber harvests can cause substantial decreases in total biomass and carbon stock.

Example of tree biomass composition in a hectare of tropical forest

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

Priority carbon pools for national accounting

15. The decision of which carbon pools should be measured as part of a 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. In IPCC terminology, the prioritization of carbon pools process is regarded as "key category analysis." Major sources and sinks of CO_2 are identified at specific reporting levels: 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)

17. Since carbon 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, the inclusion 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.)

18. 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 more vulnerable forest areas to change tend to be those with higher opportunity costs, such as forests next to roads.

19. Table 5.1 summarizes 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.[45]

[45] Nevertheless, it is not clear whether or how peatlands will be included in REDD+.

Table 5.2. Priorities and costs of measuring carbon by land use

C pool	*Method*	Land use					
		Forest		Perennial		Annual Crop	
		Cost	*Priority*	*Cost*	*Priority*	*Cost*	*Priority*
Tree biomass	*DBH and allometric equations*	2	4	2	4		
Understorey biomass	*Destructive samples*	4	2	4	1		
Crop	*Literature, secondary data*					2	3
Dead biomass	*Non destructive*	2	2	2	1		
Litter	*Destructive*	3	2	2	1		
Soil C	*Destructive: density and C content*	4	3	4	3	4	3

Note: Higher values indicate greater priority (shaded green) or higher cost (shaded red). Example from Indonesia.
Source: Authors.

Establish a carbon analysis framework

20. Clear and simple approaches to carbon stock measurement contribute to transparent national accounting. The simplified approach proposed here is for establishing a carbon basis for opportunity cost analysis. Although more straightforward, the approach is not always consistent with the detailed carbon calculation methods stipulated in the *Good Practice Guidance* (GPG) of the IPCC.[46] The GPG provides procedural information to classify, sample and collect data for national accounting of carbon stocks and greenhouse gas emissions and removals associated with Agriculture, Forestry and Other Land Use (AFOLU) activities. 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

[46] Examples include: (1) the use of a 4:1 default value for the shoot/root ratio, (2) a carbon conversion factor of 0.46 for living biomass, necromass and soil organic matter.

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

- ***Transparent***: Data sources, definitions, methodologies and assumptions should be clearly described.

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 (2003b). 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 uses 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.

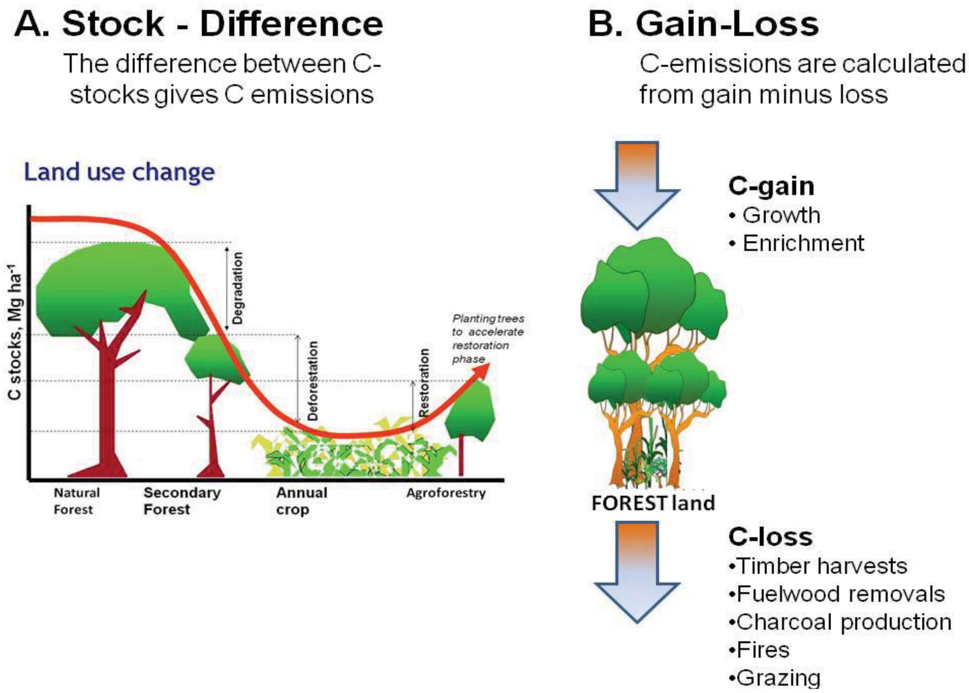


Figure 5.2. Comparison of stock-difference and gain-loss methods

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 profitability estimate of net present value (NPV). A typical carbon stock value integrates the gains and losses over a life-cycle of a land use. Below, we discuss (1) steps to establish a national carbon accounting system, (2) approaches for measuring carbon, and (3) assessment of carbon data quality, sampling procedures and field measurements of carbon stocks.

27. Determining the typical carbon stock starts by recognizing the life-cycle of the land use (see Figure 5.3). A 'time-averaged' carbon stock recognizes the dynamics of land uses

(Palm et al., 2005). This 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.

28. For land uses that are in equilibrium 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 an estimate equals the sum of gains and losses of carbon. For land use 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 (ASB, 1996). Specific steps to calculate time-averaged carbon stock for a monoculture and mixed systems are in **Appendix D**.

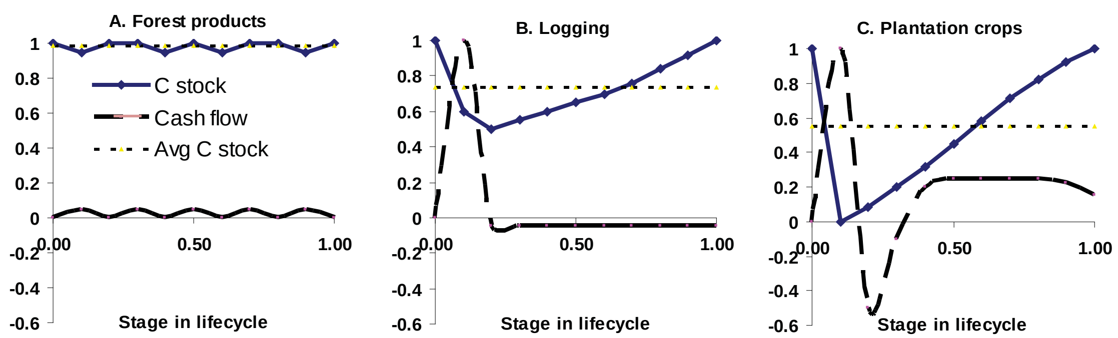


Figure 5.3. Aboveground carbon stock and cash flows of three land uses

´Time-averaged carbon stock´ in agroforestry systems

29. In agroforestry systems, where farmers incorporate various trees 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. To estimate carbon stocks, it is useful to develop annual time courses of the carbon stocks. In Figure 5.4, solid (darker) lines represent the annual carbon stocks, while dotted (lighter) lines depict corresponding time-averaged carbon stocks of: 230 tC/ha for forest, 80 tC/ha for agroforestry, and 29 tC/ha for annual crops or *imperata* grasslands of degrading productivity.

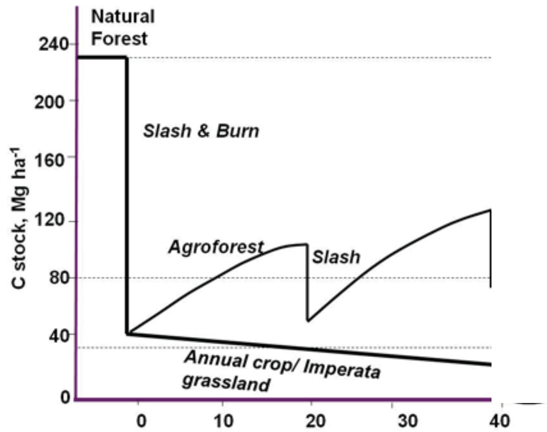


Figure 5.4. Example carbon stock changes of different land uses

Source: IPCC/LULUCF-section 4 (2000)

Accounting for forest degradation

30. Even without converting forests to other uses, carbon emissions can be produced from forest degradation. Forest degradation can be defined as *direct human-induced long-term loss (persisting for X years or more) of at least Y per cent of forest carbon stocks (and forest values) since time (T) and not qualifying as deforestation* (IPCC, 2003a). Despite this definition, agreement has not yet been reached on an operational procedure for monitoring, reporting and verification (MRV) of degradation. The measures of X, Y and minimum area are difficult to specify since the values depend on types of degradation activities and forest composition (Murdiyarso et al., 2008).

31. Common activities that degrade forests in the tropics include (GOFC-GOLD, 2009):

- Selective logging
- Large-scale and open forest fires
- Collection of fuelwood and non-timber forest products
- Production of charcoal, grazing, sub-canopy fires, shifting cultivation.

32. Apart from selective logging, few analyses has been made of the impacts of these processes on the loss of forest biomass and the time needed for regrowth. Estimating the carbon stocks of forests in contexts of deforestation and degradation requires monitoring of: (1) changes in forest area by forest type and (2) average carbon stocks per unit area and forest type (IPCC, 2003b). A Tier 1 analysis keeps track of area changes within forest categories and uses global default values for carbon densities of those forest categories. At Tier 2, precision and accuracy are increased by estimating carbon densities using country-specific data instead of global default values. A Tier 3 analysis uses models and inventory systems to adjust estimates to national circumstances repeatedly over time, thereby measuring changes in carbon densities within the accounting period.

Table 5.3. Measuring forest degradation: stock-difference and gain-loss methods

Activity	*Stock-difference method*	*Gain-loss method*
Selective logging	• Legal harvesting usually requires measurement of biomass after harvesting, thus necessary data should be available. • Illegal harvesting would require additional data collection. • Data on undisturbed forest can be used as a proxy if pre-harvesting data for particular sites is not available.	• Uses estimates of mean annual increment (MAI)and centralized records on timber extraction activities. • Reliability depends on honesty of timber companies in reporting rates of extraction.
Large-scale forest fires	• Reference data from undisturbed forest can be used for the pre-fire situation, but forest inventory would be needed to measure post-fire biomass.	• Losses due to fire can be estimated from the area burned and emission factors used to estimate the emissions based on the biomass lost.
Harvesting of fuelwood and non-timber forest products	• Pre-harvesting biomass levels could be estimated from typical levels in undisturbed forest, but in practice much of the forest subject to these uses will already be partially degraded at the start of the accounting period. • In areas already under individual or community management, pre- and post period forest inventories can be carried out by forest users.	• Data on losses (e.g., registers of commercial wood-based products, estimates of fuel wood use) may be available. • Fuel wood off-take could also be calculated using population and data on average household fuel wood consumption. • Data on gain available from standard MAI statistics.
Cattle grazing, shifting cultivation, sub-canopy fire	• Pre-harvesting biomass levels could be estimated from typical levels in undisturbed forest, but most forests subject to these changes will already be partially degraded at the start of the accounting period. • Community measurements can be made and can help establish local 'ownership' of the process.	• Data on gain are available from standard MAI statistics. • Data of losses are rarely available in national statistics.

Source: Murdiyarso, et al. 2008.

Diagnosing existing carbon data

33. When compiling or reviewing estimates for the typical carbon stocks of land uses, a variety of data may already be available. Such information can be categorized according to IPCC tier:

- *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

- o 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),
- o ecological data on long-term plots that include all biomass and necromass pools.

34. As mentioned earlier, the prioritization of carbon pools or "key category analysis" takes into account the major sources and sinks of carbon 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.

35. 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.

36. Questions regarding any of these issues can make data suspect for use, 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

37. A basic premise of the IPCC *Good Practice Guidance* (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.[47]

38. This IPCC GPG assumption of non-ambiguous land categories may agree with existing institutional traditions in some countries, but the premise can 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

[47] For REDD+ opportunity cost analysis, sub-categories are also needed for land use systems generating different levels of profit.

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

39. 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

40. This category includes agricultural land, including rice fields, and agroforestry systems where the vegetation structure (current or potentially) falls below the thresholds used for the *Forestland* category.

(iii) Grassland

41. 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

42. 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.

(v) Settlements

43. 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

44. 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 5.2. 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

45. 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).

46. Guidelines for obtaining the number of samples units needed can be found in Box 5.4. It is important to note that increasing the desired level of accuracy and precision will have cost implications.

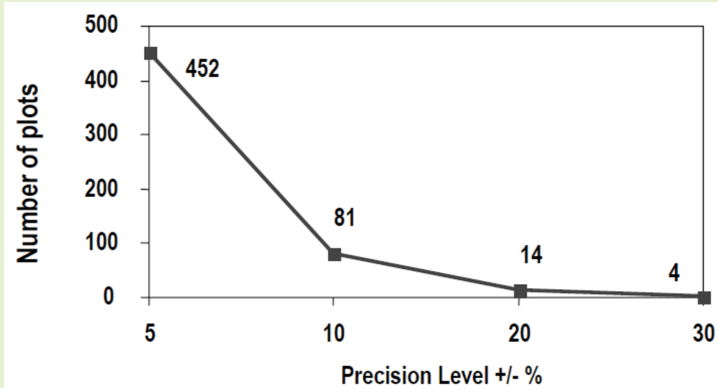
Box 5.3. Steps to determine the number of sampling plots

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.



Source: IPCC 2003b, 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 of 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.

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad S^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1} \qquad S = \sqrt{S^2}$$

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:

$$n = \frac{\left(\sum_{h=1}^{L} N_h * s_h\right)^2}{\frac{N^2 * E^2}{t^2} + \left(\sum_{h=1}^{L} N_h * s_h{}^2\right)}$$

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

47. Once the number of sampling units is calculated, a design of the sample is needed. Figure 5.6 summarizes the recommended sizes of plot and sub-plots under each sampling unit.

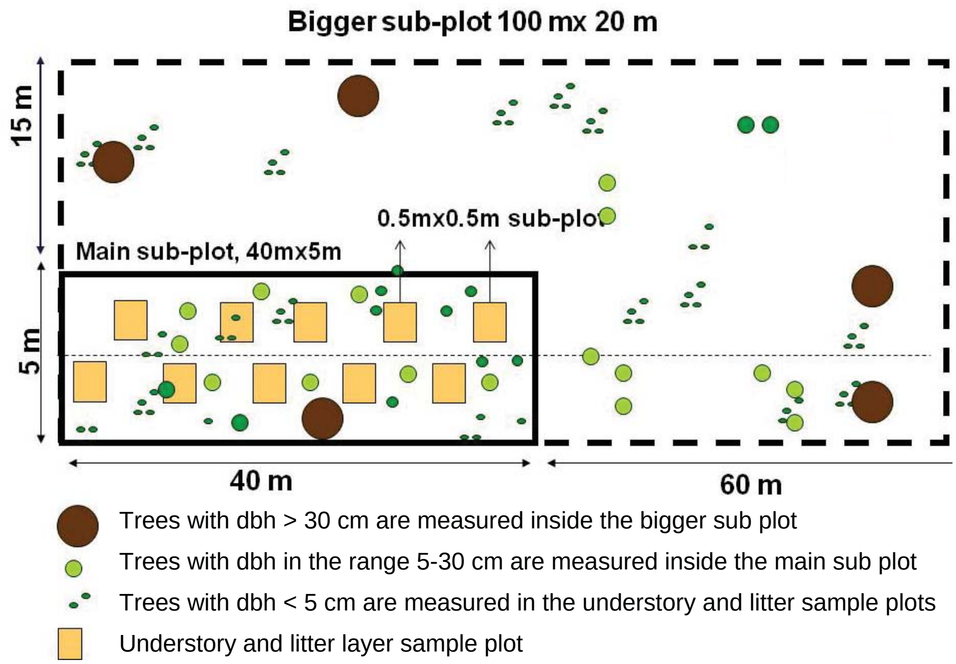


Figure 5.5. Recommended plot and sub-plots sizes for carbon stocks sampling

Source: Hairiah, et al. 2010.

Plot level sampling

Measuring carbon stock at the plot level requires assessing:

- Biomass
  - o destructive sampling of small plots of understory vegetation, annual crops, or grasses, and
  - o non-destructive tree biomass estimates using allometric biomass equations.
  - o default values for below-ground biomass (roots).
- Necromass
  - o destructive (for litter remains on soil surface) or
  - o non-destructive (for dead wood).
- Soil organic matter.

48. 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).

49. 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,
- two parameters that relate biomass to stem diameter ('allometrics').

50. 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 (Chave, et al. 2005; see Table 5.3 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 R^2 (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 **Appendix C**.

Table 5.4. Criteria for choosing an allometric equation

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

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

Box 5.4. 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

51. 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. The spreadsheet **OppCost** in the file **SpreadsheetexercisesREDDplusOppCosts.xlsm** links the carbon stocks for land use change according to land use category. A couple of examples to calculate time-average carbon stock for monoculture and diverse systems are

shown in **Appendix D**. Estimated values of time-averaged carbon stock of selected land-use systems from various countries are shown in Table 5.4 below.

Table 5.5. Time-averaged carbon stock (mean and range) of selected land uses

Land use	Time averaged carbon stock, Mg /ha	Reference, remarks
Primary forest (Indonesia)	300 (207-405)	Palm et al., 1999
Selectively logged forest (Central Kalimantan, Indonesia)	132	Brearly et al., 2004
Shrub/crop rotation	15	Prasetyo et al. (2000)
Imperata grassland	2	Palm et al. (2004)
Oil palm (Indonesia)	60	Recalculated from Rogi (2002)
Oil palm (Indonesia)	40	Recent data ICRAF-Indonesia
Rubber agroforest, 25 year old (Sumatra, Indonesia)	68	Averaged from Palm et al. (2004)
Rubber agroforest, 40 year old (East Kalimantan, Indonesia)	100	Rahayu et al., 2004
Coconut plantation	60	Adjusted from 98 Mg ha^{-1} according to IPCC (2006) based on Rogi (2002)
Jatropha plantation	10	June (2008) based on Niklas (1994)
Tea plantation	28	Adapted from Kamau et al. (2008)
Sugar cane	9	Soejono 2004, modified
Coffee-based agroforestry system	51	Hairiah (2007, for shaded coffee)
Cacao	58	Lasco et al. (2002)

From land use to sub-national region

52. Once the time-averaged carbon stock per land use system is obtained, we need to calculate/estimate the time-averaged carbon by land cover in order to extrapolate to landscape level. For example, in Figure 5.6, 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), an average for the land cover is estimated.

53. 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.

Land cover	LUS	Plant density per ha	Total C stock, Mg ha^{-1}	Max. Age, year	Time Avg. C Stock, Mg ha^{-1}	
1.Forest	Degraded Forest	2248	161	50	161	161
2. Agroforestry	AF_Multistrata	3970	123	30	111	111
	AF_Simple	4018	99	30		
3. Plantation	Pinus	795	183	30	144	
	Agathis		190	40	146	
	Mahogany	963	198	50	212	139
	Clove		142	35	70	
	Bamboo	3188	159	15	121	
4. Grassland	Napier grass, 4 months	-	100	0.25	11	11
	Napier grass, 1 month	-	78			
5. Annual crop	Vegetables	-	79	0.25	1.5	1.5

Pennisetum purpureum (Rumput Gajah=napier grass)

Figure 5.6. Extrapolating carbon from land uses to land covers at the landscape level

Source: Hairiah, et al, 2010.

From sub-national region to nation

54. Scaling-up landscape carbon estimates to sub-national and national levels requires a combined effort of different government agencies, NGOs, and other institutions. 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.

55. Within countries, different areas with similar conditions have often been identified already with respect to climatic, elevation or vegetation. These different classes should be used as the basis for the stratification process within sampling scheme (Box 5.4) 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.

56. Inaccuracy and uncertainty of forest inventory data can range up to a multibillion-ton difference in the global stock of carbon in trees. Sources of error include area of forest, timber volume per area, biomass per timber volume, and carbon concentration. Since the factors are multiplied together to estimate carbon stock, a more precise measurement of the most certain variable improves accuracy little. In contrast, a 10% error in biomass per

hectare, for example, can cause a discrepancy equivalent to a mistake of measuring forest area by millions of hectares. Thus, unbiased sampling of regional forests is of important to accurately monitoring of global forests (Waggoner, 2009).

57. 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 land use categories.

Building a national monitoring system

58. 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.

59. 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.

60. **Appendix B** provides a summary table of required capacities for a national monitoring system of emissions.

61. 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 for whoever collects the primary data. Unexpected results may indicate an opportunity to learn, if they are confirmed via cross-checking. Nevertheless, inaccurate "participatory" results may skew overall results if retained in the dataset.

A forest carbon database

62. Carbon data is becoming more available. A Forest Carbon Database and exchange system is being developed within the public domain (CIFOR, 2010; Kurnianto and Murdiyarso, 2010). The database helps national and sub-national monitoring, reporting and verification of REDD+ activities. The open access database is designed to allow participation of researchers and practitioners, who conduct regular forest inventory, manage sample plots, and conduct research on forest carbon stocks and related topics.

63. The system allows the accounting of the five carbon pools. Supporting information can also be added (e.g., site details, land cover, climate and soil) to share the context of the carbon stock data. If the entire inventory of data is uploaded, the carbon stock will be automatically calculated, per factor that recognize ecosystem factor (e.g., rainfall, temperature). The system:

- reduces duplicate data collection by making data available, which have already been collected. This reduces costs.
- provides easy access to data that cannot be readily replicated, such as large surveys that are too expensive to replicate.
- enables comparison carbon stocks across land use types based on data provided by other contributors.

Cost estimates of measuring carbon and capacity building

64. 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 is developing professional capacity.

65. Given the high and changing carbon content of forests and possibility for inaccurate measures, many efforts are advancing to improve cost effectiveness of ground-based inventories and surveys. Stratification of forests by carbon stock (e.g. affected by timber harvest), not necessarily by forest type, can reduce uncertainty and costs (Brown, 2008)

66. In the short term, capacity building is desirable at the national/sub-national level. 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. In some cases, foresters, biologists, ecologists, etc., can transfer some of the basic skills for carbon measurement to communities living in the forest and forests margins. Such an approach encourages local community participation and reduces the costs in the long term.

67. Table 5.5 summarizes relative costs of using data of different resolution, capacities to be used and required capacities. Although the involvement of international organizations also results in higher costs, skills can be transferred to national and local levels through partnerships and alliances to achieve cost savings. Start-up costs are usually higher than maintaining and upgrading the capacities.

68. 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 5.6) and a national forest inventory in India (Table 5.7). The average cost of assessing forest cover and changes on a per unit area basis in India is US$ 0.60 per km^2. The cost per unit is derived from the total forest cover of the country, which is estimated at 677,088 km^2.

Table 5.6. Relative costs of building a national carbon accounting inventory

Issue	Scale		
Data resolution	**Tier 1: Global estimates**	**Tier 2: National available data**	**Tier 3: Plot/watershed data**
	Freely available online but need expert knowledge to interpret data	Not freely available and scattered in most cases. Costs are mostly related to the bureaucracy to obtain the data	Normally only available at small scale or very specific and not freely available or need to collect own data. Sources are local or regional institutions or government
Relative cost	$	$$	$$$
Capacities used	**International expertise**	**National expertise**	**Local expertise**
	Personnel from international organizations (WB, UN, NGOs, etc) with direct access to governments and normally involved in the start-up of the process	Personnel from national government agencies and local NGOs, education institutions, usually based in the cities and setting national standards/policies	Local experts (e.g., universities and communities based in tropical forests). Some have built alliances with international experts or other national experts
Relative costs	$$$$	$$	$-$$
Capacities required for MRV	**Start-up**	**Maintain**	**Upgrade**
	Initial set up, varies according to current in country capacity	Keeping up to date and implement quality assurance and quality control schemes	Specialized training, participation in international conferences or access to international standards
Relative costs	$$$	$$	$$-$$$

Source: Authors.

Table 5.7. Equipment and personnel for above ground biomass sampling in Colombia

Activity	Equipment	Personnel	Time (*per plot, **per tree)
Sampling non-tree vegetation	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	3 people	40 - 60 minutes*
Forest inventory	1 GPS 1 50 meter tape 1 hypsometer 3 machetes 1 2m long wood pole (can be obtained in the field) 30 m nylon cord Markers, pencil, forms	3 people	120-150 minutes*
Trees and palms	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	4 people	1-5 hours**

* 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.
Source: Carbono y Bosques, 2005, cited in Rugnitz, et al. 2009.

Table 5.8. Cost of measuring forest cover and change using satellite imagery in India

Components	Cost per 100 km^2 (US$)	%
Human resources (cost of data interpretation by technicians, supervision and checking by professionals and ground truthing)	38.5	64
Cost of satellite data (IRS.P6- LISS III of 23.5 x 23.5 m)*	6.5	11
Equipment (cost of hardware/software with assumed life of 5 years plus day-to-day maintenance, air conditioning plant, network, etc.)	15.0	25
Total	*60.0*	*100*

*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 km^2.
Source: UNFCCC, 2009.

Measurement priorities arising from forest condition

69. The cost of measuring and monitoring degradation depends on national circumstances, which include factors such as the:

- area of forest cover
- forest stratification (e.g., Democratic Republic of Congo has one major forest type, whereas Indonesia and Mexico have four or more)
- Tier level of carbon accounting

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Estimating the opportunity costs of REDD+
A training manual

Version 1.3

Chapter 6. Profits and net benefits 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.

Contents

1. Economic analysis has many terms and phrases that are commonly used (Box 6.1). For definitions, see Glossary in **Appendix A** .

Economist words

Discount rate	*Rent*	*Capital*
Net present value	*Net returns*	*Accounting stance*
Profit	*Enterprise budget*	

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

- *What profits and jobs are generated by forests?*
- *When forests are cut, what do other land uses generate in terms of profit and employment levels?*
- *When forests are re-established what profits and jobs do they produce?*
- *What profits and jobs are associated with non-forested lands before af(re)forestation?*

3. This chapter shows how to estimate two important economic components of opportunity costs: profits and employment. Both profits and labor earnings from forests and other land uses are needed 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 wide range of land use activities.[48]

Box 6.1. 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 is 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 8.) Thus *profit* is used in this manual to represent the general concept of net benefits that land users receive from a given land use.

[48] Other less-precise REDD+ opportunity cost approaches are described in the introduction, Chapter 1.

Why such detail?

4. The bottom-up approach provides a rigorous and transparent record of the data collected and its 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 will enable policymakers to estimate REDD+ opportunity costs.

5. This chapter helps develop capacities to:

   1) systematically estimate and compare profits generated from different land uses,

   2) identify data required for analyses, and

   3) estimate profits according to a three-level hierarchy of activities within land uses:

      a) *enterprise (or activity) budget*, the basic building block of information per activity,
      b) *land use system budgets* account for the multiple enterprises found within land uses,
      c) *budgets of land use trajectories* represent how a land parcel may undergo numerous land use changes.

Upfront issues – clarifying assumptions

6. 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)

7. REDD+ programs involve different types of landowners. Such owners can be a country or from an individual group (e.g., farmer, rancher, logging company, community). The way costs and revenues are calculated – called an accounting stance – represents the viewpoint of individual groups[49] or the country.[50] Although an accounting stance does not affect productivity data (e.g., yield/harvest quantities), the difference in perspective determines the data collected, prices and discount rates within budget accounts, and thus 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).

8. For the accounting stance of a country, costs and benefits should be valued at the social value of resources (i.e., their value in their next-best alternative use) rather than

[49] Often termed *private* or *financial* profitability.
[50] Often called *social* or *economic* profitability.

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.), or market imperfections[51] (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).

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

Which actual price to use?

10. Actual prices can differ, often substantially, according to location: farmgate, local market, national market and international market. Because of transportation and intermediary costs (e.g., 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.

11. The recommendation is to use farmgate prices to represent the actual costs on a particular land use. Adjustments are needed when farmgate prices are expected to differ from prices from where data are collected (e.g., local markets). 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?

12. Prices can also differ due to government market interventions. Inputs subsidies (of e.g., agrochemicals, gasoline, fertilizers) can increase profitability; whereas input taxes can reduce profits. Similarly, profitability of farm and forest land use is decreased by export taxes which typically affect farmgate prices. Output subsidies or import taxes and quotas increase prices and profitability.[52]

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[51] 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).

[52] In some countries, cattle production and oil palm are land uses, for example, that have received subsidies.

13. 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 typically limit the use of such mechanisms. In addition, governments often have less financial capability to subsidize economic sectors as budget overspending and debt is being controlled by lending organizations (e.g., banks, International Monetary Fund, etc.).

14. If such price distortions are apparent and important, the recommendation is to have separate estimates for (1) costs to land users and budgetary costs to the government (using unadjusted prices), and (2) costs to the country (using prices that correct for distortions). A Policy Analysis Matrix (PAM) can used to compare of the results different accounting approaches (or methodological assumptions) of economic analysis. For example, differences in agricultural and natural resource policies and factor market imperfections can contrasted with budgets calculated at private and social prices (Monke and Pearson 1989 is the basic reference).

Why use a discount rate?

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

16. The discount rate to assess costs to the country should be the social discount rate normally used by the government. In contrast, the discount rate to estimate 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. In other words, the costs to the government and the individual groups determines the overall costs to the country.

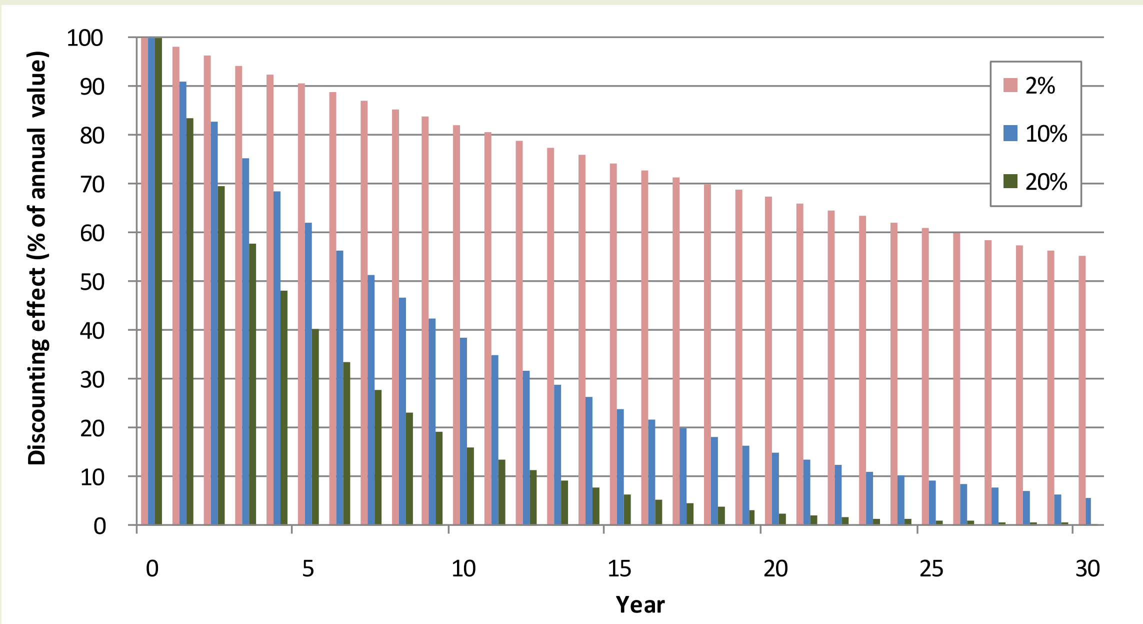
17. From a national perspective, the discount rate can be equated to the cost of borrowing money. The interest rate on loans (often between 5 and 10% annually) is a useful proxy. From an individual perspective, the costs of borrowing money are typically much higher. Interest rates in countries often range between 10 and 30% per year, or higher, if loans are available. For the purposes of opportunity cost analysis, the real interest rate should be used. How to deal with inflation is discussed below.

Box 6.2. 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%).



Effect of discounting on future values (2, 10, 20%)

Source: Authors.

How to estimate unstable and non-existent prices?

How to value inputs provided and outputs consumed by the household?

18. Especially with smallholder farms, labor inputs or inputs retained from previous harvests (e.g., seeds, manure, etc.) are often used within a farm and are not purchased. Therefore, the prices of such inputs may not be readily available. 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.

19. In addition, some farm inputs may have multiple possible prices (e.g., seeds retained from harvest could be valued at the forgone income at time of harvest, or the cost at time of planting). 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.

20. 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 an assumption upon results of the analysis. With such an analysis and review, the difference may turn out to be rather either insignificant or worthy of discussion amongst peers to decide the best, most relevant, option.

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

21. 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 over a span of many years. 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), 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).

22. 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. Meanwhile, yields can decrease resulting from soil degradation.

23. Prices may also 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 within the planning horizon. A gradual adoption of pest resistant corn varieties, for example, can be introduced in the analysis by

slowly increasing yields and reducing pesticide expenses in the corn enterprise budget according to the expected trends in these parameters. Uncertainty and associated risk of parameter estimates can by analyzed using stochastic analysis (Box 6.4).

Box 6.3. Risk and uncertainty analysis

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

24. 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[53]), and information from field surveys may be subject to recall biases. In addition, survey respondents tend to generalize based on recent year experiences. 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?

25. Profits can be measured in terms of time (e.g., workday or salary) or in terms of returns to land (i.e. $/ha). Within REDD+ opportunity analysis, returns to land typically makes most sense. Moreover, it is a common measure understood by many.

Should the cost of land be included in calculations?

26. 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 the profitability of activity A to activity B is being compared, it makes little sense to include costs of land in profitability estimates, since the costs cancel out. For example, investments to improve profitability, and the value of land, are accounted for within a multi-year analysis.

And labor?

27. 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

[53] 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.

more sense to express results both in terms of return to land and family labor. Especially in forest frontier regions, labor and capital are limiting factors of production. Since land is relatively abundant, smallholder farmers most carefully allocate their scarce labor resources (along with their land and capital resources).

28. Opportunity costs of REDD are nevertheless calculated in terms land. Fortunately, it is possible to impute the value of family labor in the farm activity costs, thus giving 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 can be a relevant measure of the opportunity cost of land use change.

29. From the perspective of an individual, household income from a given land use is a relevant measure. This includes 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 forgone with REDD+.

Which profits from a land use should be analyzed?

30. A profitability analysis starts with developing detailed budgets of simple activities (also called enterprises) within land uses. These budgets are a summary of cost and revenue information. Enterprise budgets typically describe the activities that occur within a planting and harvest season. Examples of enterprises include NTFP collection, timber harvesting, and annual crops. Enterprise budgets of multi-year crops (e.g., cassava), animal production, perennial tree crops (e.g., cocoa, oilpalm, coffee, etc.) require accounting of multiple years that represent all phases of an enterprise: preparation/investment, maintenance, harvest and post-harvest activities on-farm. Enterprise budgets are an important building block to represent land uses and land use trajectories.

31. Budgets of land use systems can account for a combination of activities, such as agricultural and tree crops. These budgets are also multiple year summaries representing all phases of an activity: preparation, maintenance, harvest and, perhaps, fallow periods.

32. 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

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

Source: Authors

33. 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. Although these changes make no difference to an analysis from the country's perspective, it can be very important when the analysis is from the perspective of an individual group. Adequate and proper compensation for REDD+ depends on such knowledge of land use changes.

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

34. 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.

35. Wide differences exist between the harvest yields of cocoa producers (Figure 6.1). In Ghana, the distribution of yields from nearly 5,000 producers show that the mean is more than 100 kg/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.

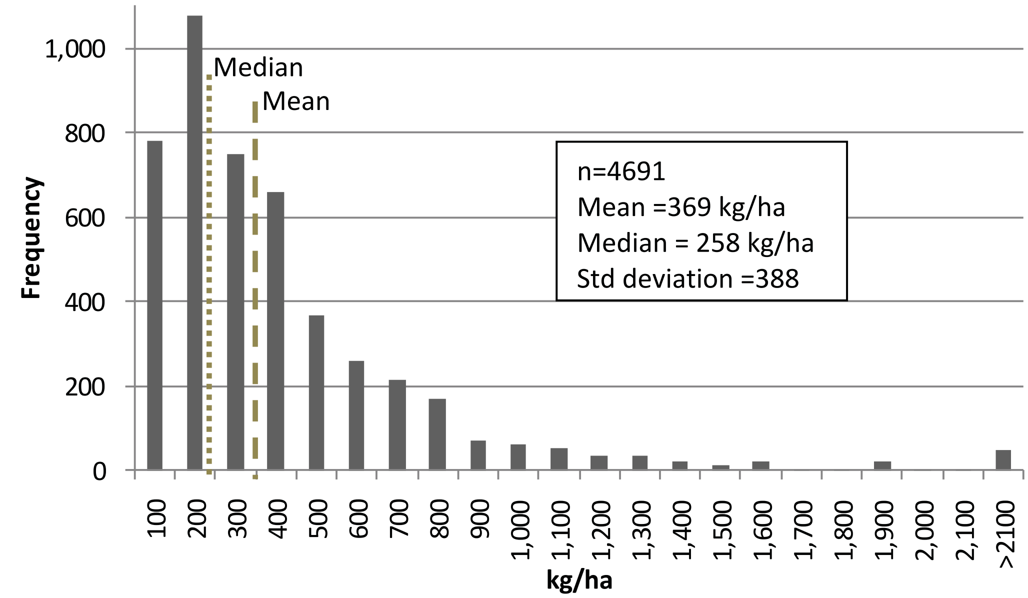


Figure 6.1. Cocoa: harvest yields per ha, Ghana

Source: 2001/2 Sustainable Tree Crops Program, baseline survey (IITA, unpublished data).

36. Within the forest sector, timber prices and previous harvests often affect forest profit levels (and opportunity costs). In Brazil, for example, large amounts of timber have been harvested. Figure 6.1 is a provincial scale map of a forest logging history.

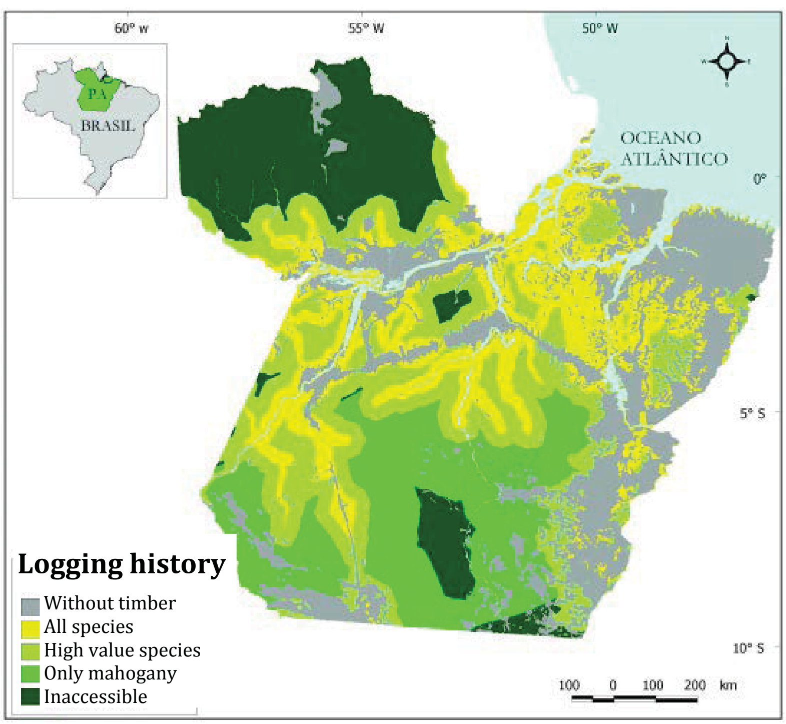


Figure 6.2. A geographic assessment of logging history (Para, Brazil)

Source: Souza Jr, et al. 2000.

37. Although a forest inventory provides an assessment of available timber and timber already harvested, analysis of current and future logging activities can be conducted per geographic region, thereby revealing profit potentials. Within Para, four areas of logging activity have been identified: Central, Estuarine, East and West (Figure 6.2).

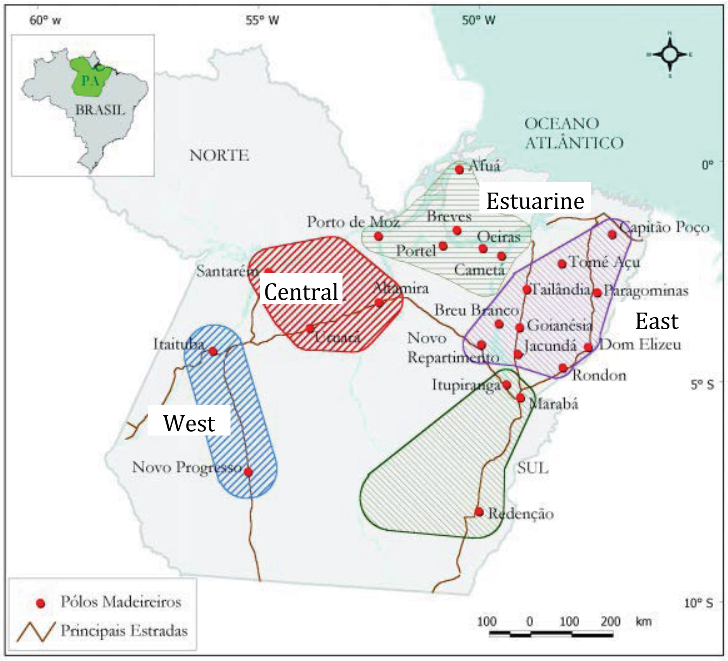


Figure 6.3 Logging regions within Para, Brazil.

Source: Verissimo, et al. 2002.

38. 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.

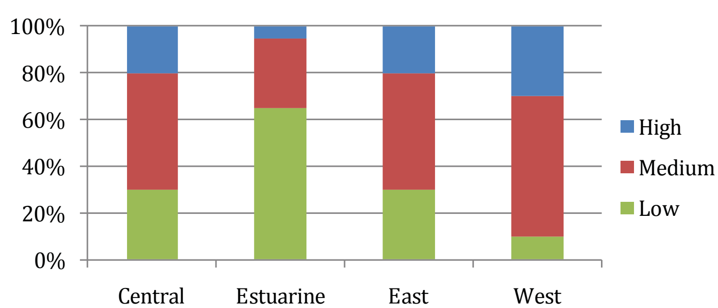


Figure 6.4 Regional estimates of timber quality (% timber; Brazil, 1998)

Source: Verissimo, et al. 2002.

39. Prices received for timber differ per quality category and, to a lesser extent, logging region. The price differential between high and medium quality is significantly greater than the difference between medium and low quality timber. The price of high value timber is approximately 2½ times more than prices of medium and low quality timber.

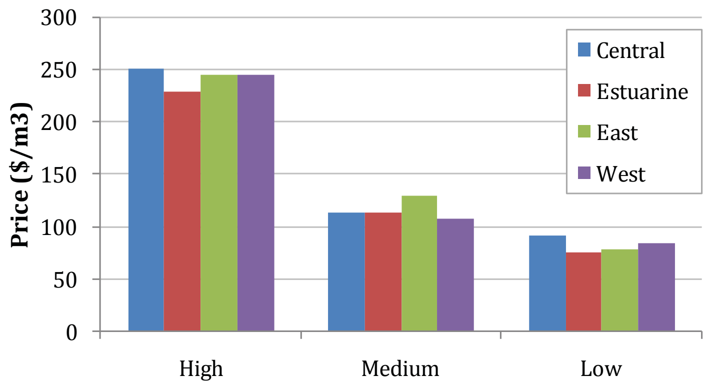


Figure 6.5 Price of sawn timber per region and quality grade (US$/m^3; Brazil, 2001)
Source: Verissimo, et al. 2002.

40. Therefore, at a national level, different budgets should be developed to adequately represent the differences within land use systems.

Enterprise budgets

Components and construction

Enterprise budgets estimate profit (Π) in local currency per hectare ($/ha):

$$\Pi = pq - c$$

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

41. Revenues (*pq*) come from the output (e.g., crop, animals, timber) of a land use activity. Costs (*c*) arise from the use of two types of inputs: physical (or capital) and labor. These measures serve as adjustable parameters for subsequent scenario, sensitivity and tradeoff analyses.[54] A sample enterprise budget is presented in Table 6.2. For more detail on enterprise budgets, see Gittinger (1982).

[54] A parameter is a specific value of variable estimated or selected (e.g., mean, median) within an analysis.

42. *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.

43. *Labor* inputs can be estimated using wage rates. Two types of rate, however, are typical: legal minimum wage and actual wage. Nationally-established minimum wages may include social benefits: health and pension. In contrast, actual wages are often significantly lower, especially 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.

44. A monthly labor calendar is helpful to identify, discuss and quantify workday activities in order to estimate total labor input. Labor activity may be valued at a single wage or 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. The labor calendar can be differentiated between hired and family labor, and also by gender. This enables analysts to examine the potential social effects of REDD+ policies.

Table 6.2. A sample enterprise budget

Rice *(per hectare)*	
Profit	
Total Input Costs	

Total Revenues	
Harvest	*Price*

Product	*Quantity*	*Price*	***Cost***	*Units*
Seed				
Fertilizer				
Machinery				
Tools				

Labor Activity	*Workdays*	*Wage*	
Preparation			
Planting			
Weeding			
Harvest			
Threshing			
Transport			

Calendar: Workdays

Activity	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***	***Total***
Preparation													
Planting													
Weeding													
Harvest													
Post-harv. process													
Transport													
Total													

45. Careful consideration of the units of analysis within budgets is essential. Units of measure, such as kg, liters, tons, should be noted. 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.

46. While yields can be converted to required per hectare units, cost information may come in different units, e.g., workdays per ton of product harvested and thus require conversion to a land-based measure. 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.

47. 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. Consequently, notes regarding contexts and assumptions are helpful to understand the accuracy and assure the relevance of budget information.

Data collection

48. The 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.

49. Detailed secondary information on inputs (e.g., workdays, prices) is rarely readily available. Essential to estimating costs, accurate data on enterprise inputs is best obtained via farmer and key informant interviews. Given budgetary or time restrictions, precise measures for some items within an enterprise budget may not possible. 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.

50. Budgets should be developed in local domestic currency. As estimates in domestic currency are typically less vulnerable to exchange rate fluctuations,[55] any database should be expressed and maintained in domestic currency. Conversion to foreign currency can be accomplished for specific purposes when needed. For example, at some later point

[55] Prices of internationally-traded commodities such as cocoa or palm oil, may be less volatile.

countries will need to know how their REDD+ opportunity costs compare to possible REDD+ payments, which will be stated in US$/t$CO_{2e}$ or other such terms. For this particular purpose, countries will need to convert results to US$ or €.

51. Budgets collected through field surveys can avoid most of these problems but are much more expensive to collect. The accuracy and reliability of budgets also depends on appropriate sample design and enumerators being well-trained. Pre-testing of questionnaires with focus groups along with a review and critique of responses can help assure the collection of all needed information. Where areas are relatively homogeneous, focus group interactions instead of wide-scale surveys can provide better information. Focus groups permit the acquistion of in-depth information and beneficial dialogue in comparison with surveys, which typically extract rather repeative basic information.

52. It is important to note that budgets developed through interviews can only obtain reliable data for the current and recent years. Data obtained while attempting to remember earlier years can be very inaccurate. In addition, when yields and prices are very variable, official budgets can also be very unreliable. Therefore, comparison and discussion of official government information, farmer responses and expert opinion are helpful to identify the most appropriate budgetary information.

53. Interviews are difficult when the activities concerned are illegal (e.g., logging, bushmeat trade, coca production). By enhancing trust and assuring anonymity of responses, required information can often be obtained. Working through social networks of families, friends and co-worker can also facilitate the data collection process.

54. 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

Method	Advantages	Disadvantages
Survey (in-person)	-Expert-based -Timely -Comprehensive, large sample size can increase statistical significance of results.	-Follow-up questions require second communication -Expensive for large sample -Proper training of interviewers/ enumerators essential.
Case Study	-Close discussion with land user -Broader questions -In-depth questions and answers possible.	-Dependence on secondary information and knowledge by personnel -Limited representativity.
Experiment station	-Control over data quality -Allows for the testing of alternate scenarios and ideas.	-Higher yields than field conditions - Limited validity of extrapolation -Specific individual results
Existing sources	-Cheap to collect -Data already processed.	-Results may not contain information needed -Results may reflect "average" conditions that do not represent any actual farmer -Information may be out-of-date -Results may be of "best case" yields, especially for crops of interest to the ministry/project, and rarely achieved in practice, -Results show input use that reflects recommended rather than actual practice, -Methods use official rather than observed prices, -Methods may be based on hidden assumptions.

Adapted from: Pokorny and Steinbrenner (2005);Pagiola (personal communication, 2010).

55. Given the challenges mentioned above, many estimates within enterprise budgets will likely be imperfect. A systematic approach to data collection with notes on context and assumptions enables the process to be transparent, reviewed, revised and improved. For example, price data may be affected by market distortions, as a result of government subsidies, sales taxes or minimum price policies. 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).

56. 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

57. Farmers can usually recall yields 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.

58. 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.

59. On smallholder farms, many separate activities often occur in within a small patch of land. 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).

60. Since 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.

61. Smallholder practitioners of slash-and-burn farming rarely 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.

62. 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 of 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.

63. 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.

Forests

Timber

64. 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

65. Data collection methods for non-timber forest products (NTFPs) appear in numerous studies. Sheil and Wunder (2002) provide a useful critique of methods applied. For charcoal products, few studies exist; examples include: Hofstad (1997), Coomes and Burt (2001) and Labarta, et al. (2008).

Land use budgets

66. Information from enterprise budgets is essential to estimating the profitability of land uses and land use trajectories. For land uses with more than one product, land use budgets require managing revenue and cost information of separate enterprise budgets. Thus the representation of profit is:

$$\Pi = \underbrace{\left(\sum_{h=1}^{H} p_h q_h + \sum_{i=1}^{I} p_i q_i \right)}_{\text{Revenues}} - \underbrace{\left(\sum_{j=1}^{J} c_j y_j + \sum_{k=1}^{K} c_k y_k \right)}_{\text{Costs}}$$

67. The above equation makes explicit not only the prices and multiple market goods and services of a land use, (p_h 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 (of c_k). The use of shadow prices for non-marketed goods is common.

68. 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:

$$\Pi_{land\ use} = \sum_{t=1}^{T} \Pi_t$$

69. The file **SpreadsheetExercisesREDDplusOppCosts.xlsm** (available on the manual website) contains examples of land use budgets with different phases and products. Such 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 and site context.

70. For some land uses, complementary activities should be noted, if not included in estimates. For example, fodder production for feeding animals that provide transport or other farm activities, such as plowing, should be attributed a proportional use basis. Details of such assumptions are discussed at the end of the chapter.

Agriculture

71. Land use budgets can be developed to represent both land use change cycles and transitions (see Chapter 3 for definitions). Distinct versions of land use budgets can different locations and context, such as within a forest frontier. For example in Peru, swidden agricultural production typically has a three year production phase, but different fallow periods according to age of settlement. Farmers in established settlements with higher population pressure commonly practice shorter "bush" fallows of 2-6 years. In contrast, pioneer farmers typically leave their lands fallow for longer periods, 6-15 years. Since both input (e.g., labor) and output (e.g., harvest) levels are different between such systems, separate budgets are justified.

72. Land use budgets of perennial systems, such as tree crops (cocoa, oil palm) and cattle, include costs of establishment and production. These multi-year budgets could typically have high investment costs and require numerous years before revenues exceed costs.

73. The workbook of land uses contains example spreadsheets of cocoa, oil palm, cattle, rice-plantain systems. Cells, highlighted in yellow, represent parameters that can be adjusted to better represent local conditions. Different contexts and land management practices should be examined within scenario analyses of land use trajectories. Adjustments of parameters such as yields could include harvest increases that represent new seed and fertilizers or harvest decreases resulting from land degradation. In addition, ash flow constraints (especially with cattle and perennial systems) may require land uses to be phased in as funds become available.

Forests

Timber

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

75. Timber cost analyses are typically divided according process stage: timber harvest, transportation and milling. Harvesting comprises a set of activities undertaken to fell and extract trees to a landing or a roadside where they are processed into logs and consolidated. Logs are then transported over unpaved and paved roads to a processing facility or other final destination. Milling refers to log sawing activities into a variety of different shapes and dimensions. The spreadsheet named **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).

76. 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***.

77. ***Forest quality*** refers to the status of the forest with respect to previous use by people. Many relatively dense 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.[56]

78. 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, for example, will not generate the same profits as a pristine forest. 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 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.

79. Past activities will affect future potential uses of the forest. Thus, in contrast to forest quality, ***forest use*** refers to upcoming activities within a forest. For example, pristine or

[56] 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.

natural forests have had few human activities but a wide range of potential uses. Respective select- and partially- cut forests have increasing levels of previous use, yet fewer potential uses. Fewer potential uses implies lower profitability. Per forest quality category, Table 6.4 summarizes both previous and potential forest uses.

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

Forest quality status	Past uses	Potential future uses
Pristine or natural	NTFPs Tourism	NTFPs Tourism Highest-value trees extracted High-mid value tree harvests Forest conversion (timber, charcoal) Other land uses (agriculture, ranching)
Selectively cut	Highest-value trees extracted NTFPs Tourism	NTFPs Tourism High-mid value tree harvests Forest conversion (timber, charcoal, pulpwood) Other land uses (agriculture, ranching)
Partially cut	Highest-value trees extracted High-mid value trees harvested NTFPs*	NTFPs Forest conversion (timber, charcoal, pulpwood) Other land uses (agriculture, ranching)

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

80. Forest quality also determines possible timber harvests. Select cut- or partial- timber harvests, for example, decrease carbon content and potential near-term future profits, albeit less than clear cutting. While selective forest harvest practices may not cause a land parcel to lose its distinction as a forest, their effects on carbon and potential future profitability need to be assessed.[57] For example, after thinning (e.g., selective harvest) remaining trees grow faster.

81. 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.

[57] 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.

82. 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).

83. When trees are not sold, forest conversion costs are not offset by income, thereby causing sometime substantial profit losses in the initial year. 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).[58]

84. Experiences from Brazil, the largest timber producing country in the tropics, and Peru are used to illustrate costs and revenues from the timber industry. 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, maintenance), labor, material, administration, and stumpage fees.[59] Most studies took into account transportation costs from the forest site to the sawmill along public roads, whereas 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.

85. Studies of logging operations provide numerous cost and revenue estimates. Profit estimates show significant variation – ranging from US$24/ha to US$1435/ha (Olsen & Bishop, 2009). In reviews of forest operation studies, Pokorny and Steinbrenner (2005) and Bauch, et al. (2007) 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, organization, wage rates),
- harvesting strategy
  - conventional logging (CL) and reduced impact logging (RIL) practices. (See Box 6.5) for a description of the logging techniques and cost
  - distance from the forest to the processing location
- cost calculation methods (overall costs versus specific sub-activity), and

[58] Although trees can used for many local uses, their estimated value is relatively small and therefore not included in an analysis of profits.
[59] Stumpage fees are the cost of purchasing the rights to log a parcel of land. Payment is typically made on a m^3 basis. Such fees are a component of opportunity cost of logging - the value of the trees to the landowner.

- approaches used for data collection.

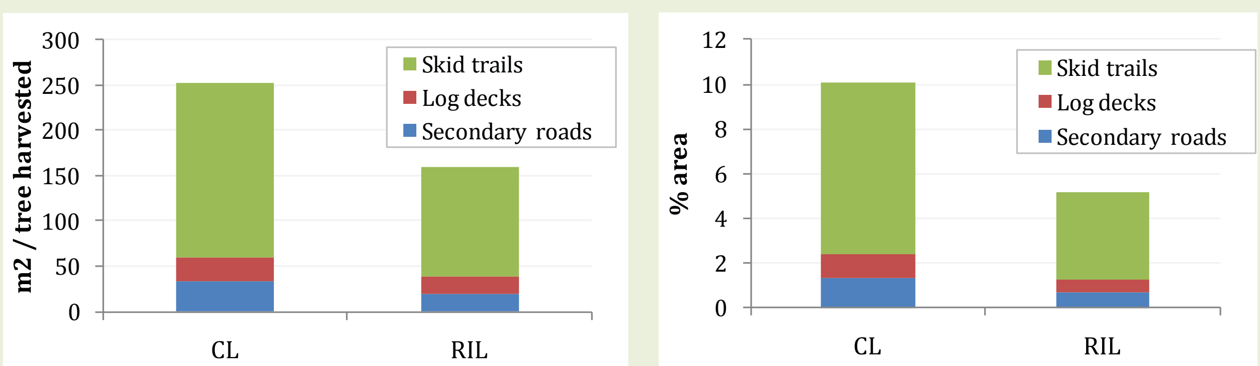
86. The conversion rate from logs to sawn timber is a useful factor to contrast efficiency (and profitability) of timber harvest operations. Stone (1990) considers a conversion rate of 47% while Stone (1995) considered a conversion rate of 34%.[60]

Box 6.4. Reduced impact logging

Reduced impact logging (RIL) can be more profitable than conventional logging (CL) practices. Despite requiring investments, RIL can accrue benefits in the both short and longer term. At an initial harvest, forest worker training generates efficiency gains to skidding, recovery of potential marketable timber and log deck[61] productivity. Longer term economic and ecological benefits of RIL include less damage to residual trees and disturbed soils (Holmes, et al. 1999).

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 wood wasted and increased wood volume can reduce costs by 12% per cubic meter versus a typical CL operation (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: 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 (Dykstra and Heinrich 1996).



Ground area disturbed by CL and RIL (m^2 per tree harvested and % area)

Source: Holmes, et al. 1999.

Although RIL is not a fixed prescription, the techniques and guidelines attempt to adapt best harvesting practices to existing biophysical and economic conditions. Pre-harvest,

[60] 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).
[61] Location to where logs are skidded stacked for subsequent loading onto trucks.

harvest planning and infrastructure costs of CL operations were \$0.71 per m^3 and \$1.93 per m^3 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. Nevertheless, the REDD+ opportunity costs of different forest management strategies can be examined through sensitivity and scenario analyses.

87. Timber waste is a concept related to conversion rate. Timber waste arises from felled logs not being skidded and young trees of commercial value being needlessly destroyed. In mills, waste is produced when logs degrade during storage and inaccurately sawn lumber (i.e. excessive thickness) (Gerwing, et al. 1996). According to Pokorny and Steinbrenner (2005), the multiple components of timber waste from field to mill, resulted in greater differences in the costs than single estimates of field productivity.

88. Profit estimates of logging operations can also differ because of 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 potential forest uses establishes a starting point of analysis for estimating future profits.

89. The profits generated from high value forests can be substantial. A case of mahogany harvests in Brazil is an example of high profits with potentially low carbon impact (Box 6.6).

Box 6.5. 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 their 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 typically included in deforestation maps (Nepstad, et al., 1999). In addition, since only a portion of the tree is being harvested, a substantial amount of the biomass is not of commercial quality. The unused portion of the tree should to be considered within carbon accounts of forests.

To assess selective logging, budgets should be estimated for the forest land with logging (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.

Other forest products

90. 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 value of three types 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. Although likely to be minor, corresponding levels of carbon in forest and the effect of gathering on carbon stocks were not examined.

Reforestation

91. Since the 2010 UNFCCC meetings in Cancun, the enhancement of forest C stocks has been included with REDD (thereby becoming REDD+). This implies, for example, REDD+ eligibility would include changes from: (1) a particular non-forest land use returning to forest, or (2) a degraded low-carbon forest to a forest with higher carbon content.

Profitabilities of land use trajectories

92. With land use budgets, we now have an analytical framework and sufficient information to analyze the profitability of land uses over many years. Where needed, the enterprise budgets have been combined into multiple year budgets representing a land use. Yet, since land uses can change over time and credits represent carbon contained in land uses for multiple years (specifics not decided yet within REDD+ policy), a profit analysis of land use trajectories is called for when estimating REDD+ opportunity costs. Although the length of the time horizon for analysis can be an arbitrary decision, it should be guided by REDD+ policy. Common analysis horizons range from 20 - 50 years, and perhaps more.[62] For the purposes of this manual, a 30-year horizon is used.

93. Sample results of a profit analysis from Peru are summarized in Figure 6.6 and associated Table 6.5. For each land use change 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.[63]

94. Profits also differ each year for most of the land uses. While not producing greater profits, agriculture and pasture systems generate profits earlier than tree-based systems.

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[62] The longest horizon of CDM project activities, other than Afforestation/Reforestation (A/R), is 21 years. For A/R activities, the time horizon is 20 to 60 years (UNFCCC, 2010).

[63] When timber can be sold, for example, first year profits are typically 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).

In the Peru example, the agricultural systems are based on either short- and long- fallow systems, which produce positive profits in years two and three. During the fallow periods of 4 and 8 years, respectively, no costs or earnings result in zero profit.[64]

95. 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.

96. 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. The tree-based systems generate negative profits (losses) for one or two years, given that weeding and other investments are typically required before production.

97. These sample results are highly sensitive to yield, price and input assumptions. 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 9.

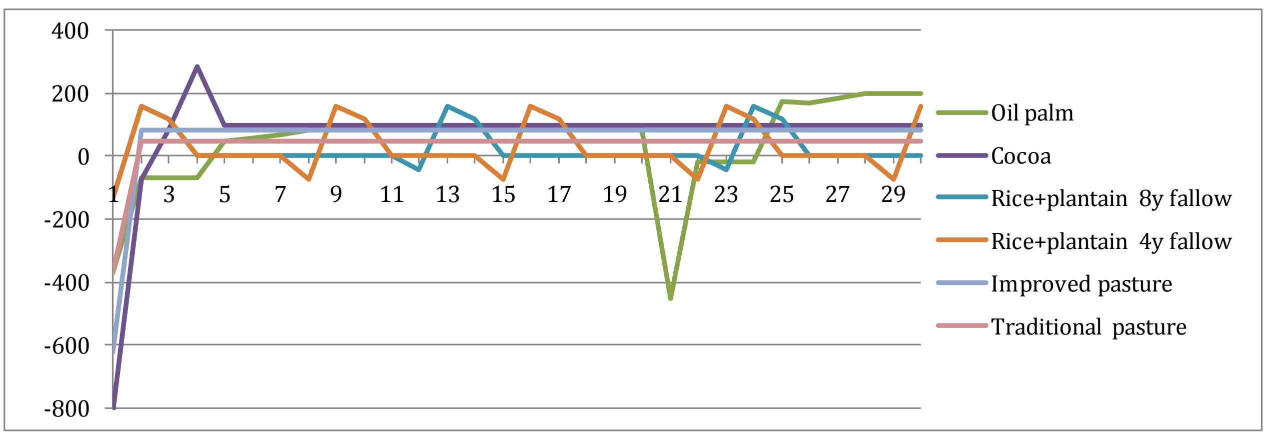

Figure 6.6. Sample multi-year profit analysis (undiscounted values, $/ha)

[64] The rental rate of land is considered to be zero. Discussion on this assumption below.

Table 6.5. A multi-year profit analysis results, Peru (undiscounted; years 1-15, 30)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	30
Oil palm	-264	-70	-70	-70	46	57	69	81	81	81	81	81	81	81	81	200
Cocoa	(815)	(75)	84	284	97	97	97	97	97	97	97	97	97	97	97	97
Rice+plantain 8y fallow	-133	158	115	0	0	0	0	0	0	0	0	-45	158	115	0	0
Rice+plantain 4y fallow	-133	158	115	0	0	0	0	-73	158	115	0	0	0	0	-73	158
Improved pasture	-633	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74
Traditional pasture	-384	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Charcoal	378															
Charcoal+oil palm	114	-70	-70	-70	46	57	69	81	81	81	81	81	81	81	81	200
Charcoal+rice+plantain 8y fallow	245	158	115	0	0	0	0	0	0	0	0	-45	158	115	0	0
Timber	450															
Timber+improved pasture	-183	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
NTFP collection	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Net present value

98. The above multi-year profit analyses illustrate how profit levels change annually during a time horizon. Despite all the results, 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 occur at the end of a time horizon.

99. 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%.

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

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

Where t = year, T = length of time horizon, Π = 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?

101. 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.[65] The interest rate reflects the opportunity cost of obtaining profits - not now - but in the future.

102. 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.

103. 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

[65] 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.

104. In sum, it is important to select a discount rate the 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 analysis** 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 0.

Results of profitability analysis

105. 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 $1047 for a timber and improved pasture land use trajectory. The next lowest performing trajectory was traditional pasture. Low productivity and initial investment costs decrease the NPV estimates. In contrast, the inclusion of profits from either timber or charcoal sales significantly increases 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.[66]

106. 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.

107. Figure 6.7 show the discounted profit horizon of 30-year trajectory. In comparison to the undiscounted horizon, the discounted values during the latter years are closer to zero. This holds true for both positive and negative (investments) profits that occur in the distant future.

[66] 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)

Oil palm	**245**
Cocoa	604
Rice+plantain 8y fallow	**302**
Rice+plantain 4y fallow	**409**
Improved pasture	618
Traditional pasture	**336**
w/Charcoal	360
Charcoal+oil palm	605
Charcoal+rice+plantain 8y	662
w/Timber	429
Timber+improved pasture	1047
NTFP collection	15

Source: Authors.

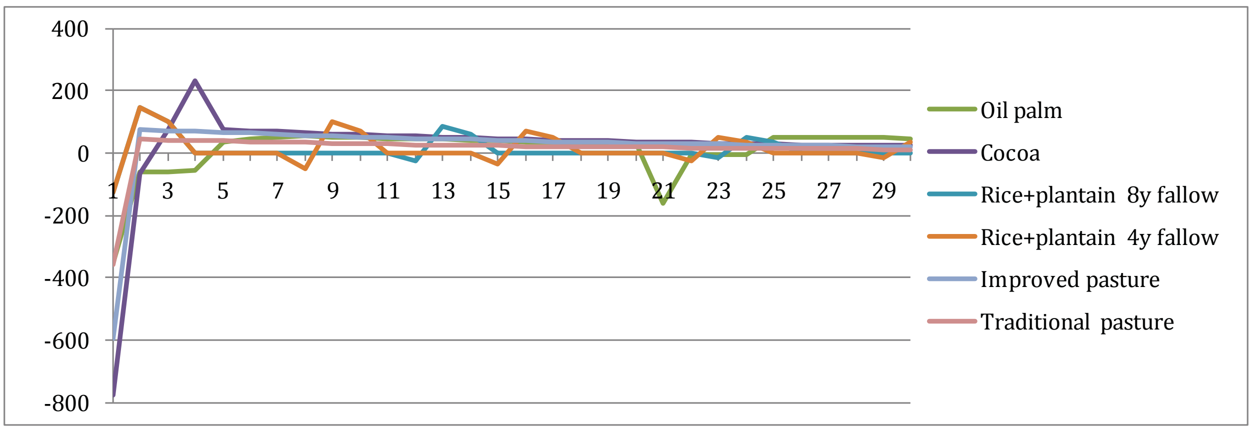

Figure 6.7. Sample multi-year profit analysis (5% discounted values, $/ha)

Source: Authors.

Backend issues – more methods and assumptions

108. Since the results of profitability analyses always depend on a series of assumptions (e.g., data sources or discount rate), results can and should be questioned. It is therefore crucial to review profit estimates and the step taken to generate them. In this section, we revisit important elements of profitability analysis and discuss the implications of assumptions.

How to handle shared and long-lasting inputs

109. 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 activities become more profitable.

110. 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

111. Countries may want to estimate hypothetical land use practices within a profitability analysis. Some practices are not currently observed but may have higher carbon benefits than current practices (e.g., RIL). Also, other potentially new land uses might come about (e.g., biofuel production).

112. When estimating hypothetical cases, extra caution should be taken. Often prospective budgets make unrealistic assumptions in order to obtain funds for research and implementation. Careful review of the literature about projected yields and associated costs savings are recommended. In addition, both the socio-economic and bio-physical conditions of case studies should be comparable to the proposed locations.

How to account for inflation

113. Estimates should be calculated in real terms. In other words, inflation is accounted for in the analyses, whereby 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 show the actual increase in value, and how much of a return was just the effect of inflation.

Time horizon of a net present value analysis

114. 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.

115. The use of a higher discount rate and longer time horizon can help to improve the methodological consistency when estimating the land use profits. Since harvest cycles of different land uses are likely to have differing period lengths, discrepancies can result within a time horizon. For example, some land uses may end in the end or middle of a productive phase while other may be in a fallow stage. (Note that in Figure 4.6, 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.

116. If a short time horizon is used, then substantial residual values may arise for many land uses. Using a long time horizon can be easier (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.

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Estimating the opportunity costs of REDD+
A training manual

Version 1.3

Chapter 7. Opportunity cost analysis

Objectives

Show how to:
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

Opportunity cost analysis

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 measure 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 CO_2e.

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), which in fact is an opportunity cost curve (see Figure 1.6 and related text discussion), the highlighted options are related to land use. In this example, some opportunity costs 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, timber extraction and 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.

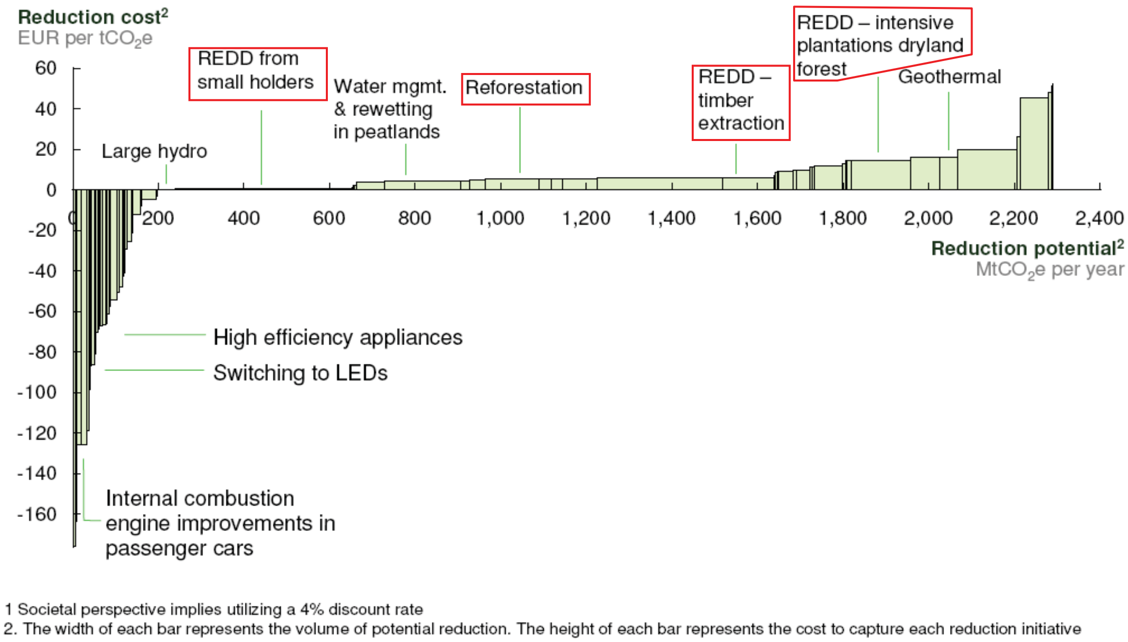

Figure 7.1. A national opportunity cost curve

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

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 file entitled **OppCost** is a simplified example of an opportunity cost analysis. (See **Appendix F** for sections of the described spreasheets and manual website to download the file **SpreadsheetExercisesREDDplusOppCosts.xlsm** (with macro).

8. 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.

9. 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 $0.44/$tCO_2e$. A land use change from logged forest to agroforestry has an opportunity cost of $1.14/$tCO_2e$; and a change from natural to logged forest has the highest opportunity cost of $1.36/$tCO_2e$. A land use change from agriculture to agroforestry would imply a negative opportunity cost (in other

words – a potential benefit) of \$0.84/tCO_2e. This type of land use change reflects how the higher profits can also store more carbon.

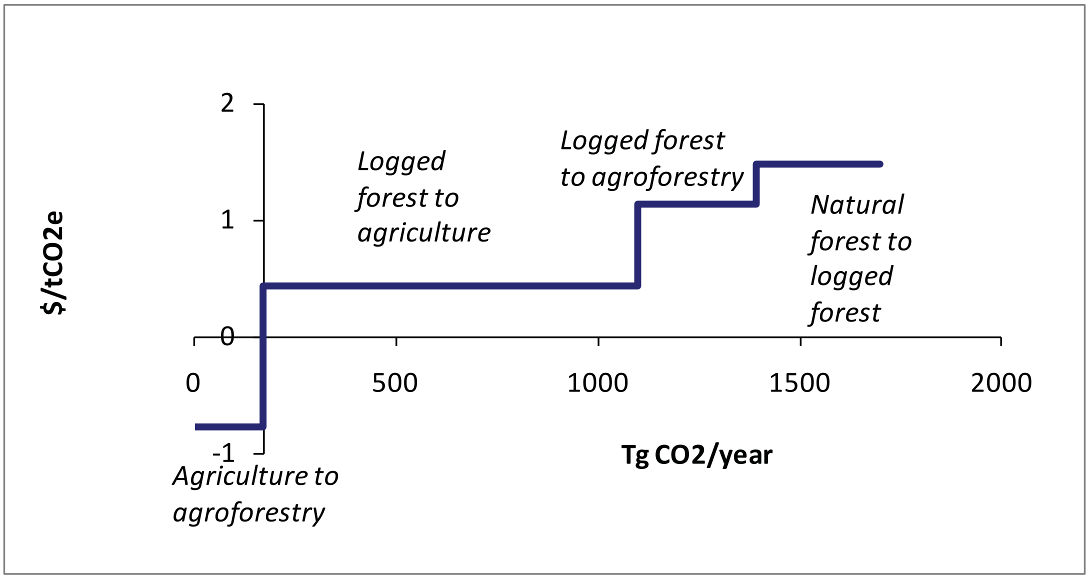

Figure 7.2. Example opportunity cost results from spreadsheet

10. 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 lower the value of a parameter by a certain percentage, is useful means to assess the potential implications of uncertain parameters.

Sensitivity analyses

11. 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 parameters that account for more effect 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 impact that such changes would have on the results. Key steps thus include:

- Identifying the key input parameters and assumptions that are likely to affect the results,
- Prioritizing parameters for sensitivity analysis (e.g. inputs, yields, prices),
- Determining the realistic range of variation of the parameter or assumption,
- Examining the results of low and high estimates of each parameter,
- 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).

12. In the case of opportunity cost analysis, key parameters for consideration are profits and carbon content of the land uses. Profits can change as a result of price or yield changes. Estimates of carbon content for different land use may be different with a country or as new research results become available.

13. Here we examine two parameter changes to see their effect on opportunity costs.

Sensitivity analysis A. Logged forest generates $400NPV instead of $300NPV.

In the spreadsheet page **OppCost**, a change in profitability of the logged land use affects three of the four opportunity costs (Figure 7.3).

1. *From logged forest to agriculture.* The opportunity cost estimate decreases from $0.44 to $0.29. In other words, a $100 increase in NPV reduces the opportunity cost of the land use change by 34%.
2. *From logged forest to agroforestry.* The opportunity cost estimate decreases from $1.14 to $0.91. Here, a $100 NPV increase reduces the opportunity cost of the land use change by 23%.
3. *From natural forest to logged forest .* The opportunity cost estimate increases from $1.47 to $2.02. In this case, a $100 NPV increase increases the opportunity cost of the land use change by 37%.
4. *From agriculture to agroforestry.* No effect.

Note that the quantity of emission does not change for any of the above.

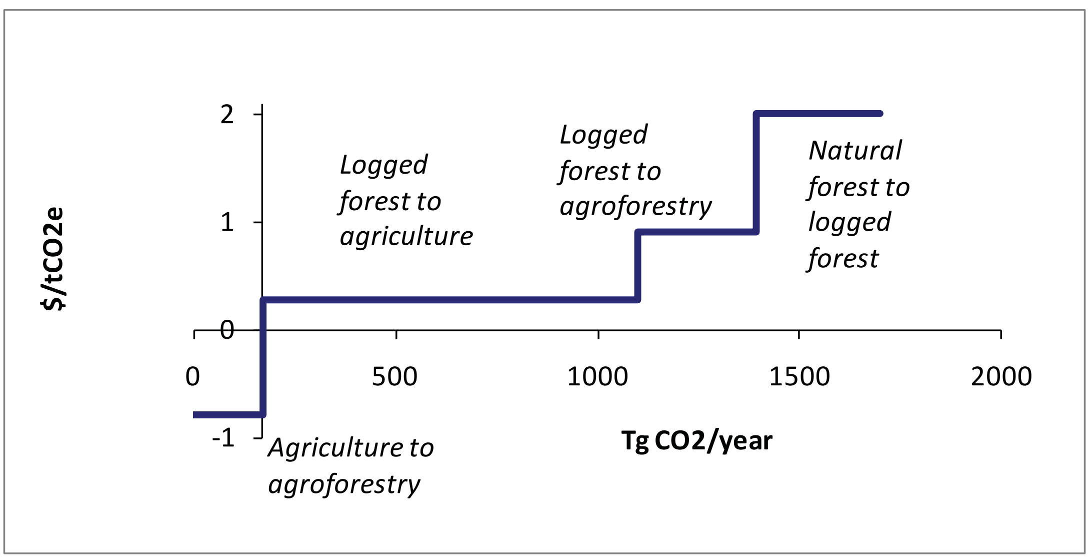

Figure 7.3. Sensitivity analysis A (with logged forest of $400NPV)

Sensitivity analysis B. Logged forest contains 150 tC/ha instead of 200tC/ha.

In the spreadsheet example **OppCost**, a change in carbon content of the logged land use also affects three of the four opportunity costs and corresponding emissions (Figure 7.4).

1. *From logged forest to agriculture.* The opportunity cost estimate increases from \$0.44/tCO_2e to \$0.58. In other words, a 50tC/ha decrease increases the opportunity cost of the land use change by 32%. The associated emissions change from 928 to 855 TgCO2e.
2. *From logged forest to agroforestry.* The opportunity cost estimate decreases from \$1.14/tCO_2e to \$0.74. Here, a 50tC/ha decrease reduces the opportunity cost of the land use change by 35%. The associated emissions decrease from 293 to 171 TgCO2e.
3. *From natural forest to logged forest .* The opportunity cost estimate increases from \$1.47/tCO_2e to \$1.95. In this case, a 50tC/ha decrease increases the opportunity cost of the land use change by 33%. The associated emissions increase from 305 to 611 TgCO2e.
4. *From agriculture to agroforestry.* No effect.

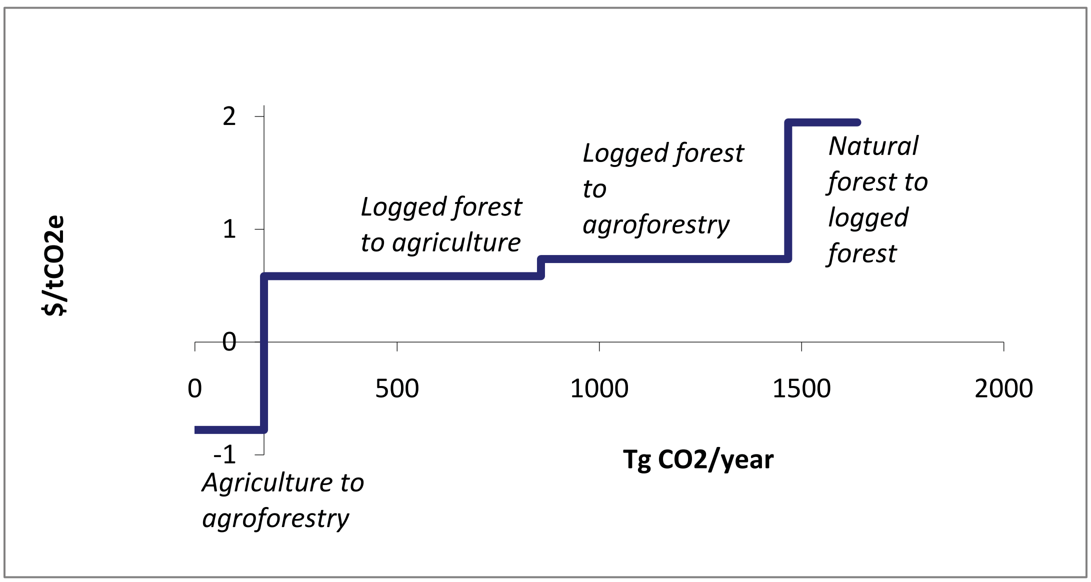

Figure 7.4. Sensitivity analysis B (with logged forest of 150tC/ha)

14. In addition, an appraisal of trends, locations, and behavioral dynamics relating to change in a given country can also help identify priority parameters to examine. In this manner, sensitivity analyses thereby become related to analysis of different scenarios of future conditions and pathways (Chapter 9).

15. 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.

REDD-Abacus

16. Opportunity cost curves of only a few land uses can be easily estimated with Microsoft XL spreadsheets. Two limitations hinder larger analyses:

1) Emission reduction options must be ordered according to costs, with lower costs to the left of the figure and increasing along the horizontal axis. A macro sub-program is needed to create opportunity cost curves.
2) Identifying and labeling each segment of the curve with a figure requires separate manual tasks, which cannot yet be automated.

17. REDD-Abacus is a computer program that facilitates the creation of cost curves (World Agroforesty Center, et al., 2010). Carbon and profit data of numerous land uses and sub-national regions can be examined entered within the program for analysis (Figure 7.5). By dividing a country into distinct sub-national zones, different characteristics that affect carbon content (e.g., rainfall or elevation) and profit levels (e.g., yields, farmgate prices) of land uses can be recognized in order generate a more accurate analysis of opportunity costs. Consequently, the resulting opportunity cost curves represent not only each possible land use change but also correspond to each sub-national region (Figure 7.6). The ease of data management and calculations helps to speed the process of sensitivity and scenario analyses. **Appendix G** contains an example analysis with results interpretation.

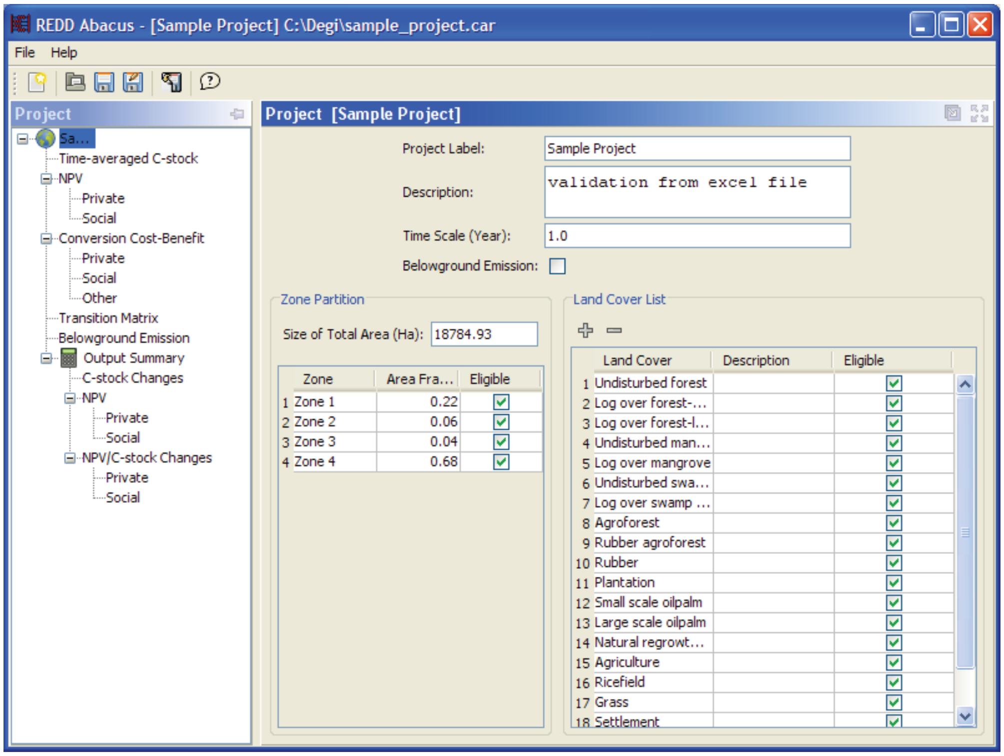

Figure 7.5. Land uses and regions of a sample analysis within REDD-Abacus

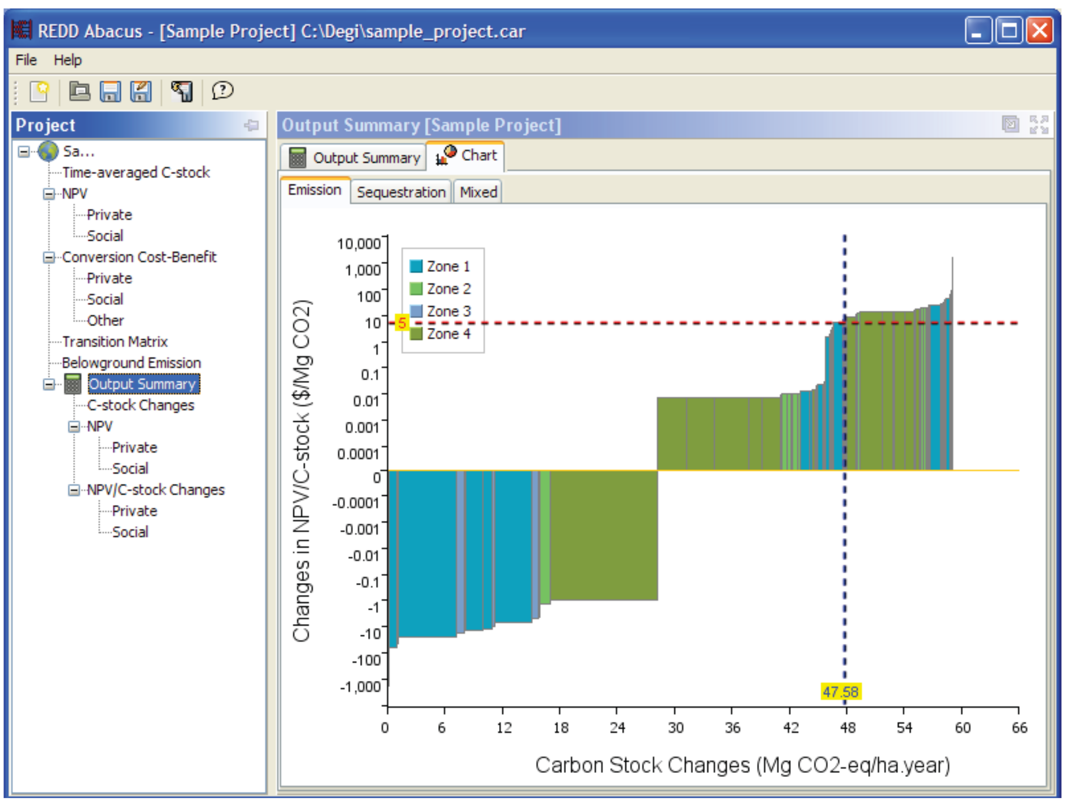

Figure 7.6. An opportunity cost curve per land use change and sub-national region

Opportunity costs maps

18. 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.

19. Figure 7.7 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 into a GIS, where they are linked to the land use transition maps described above.

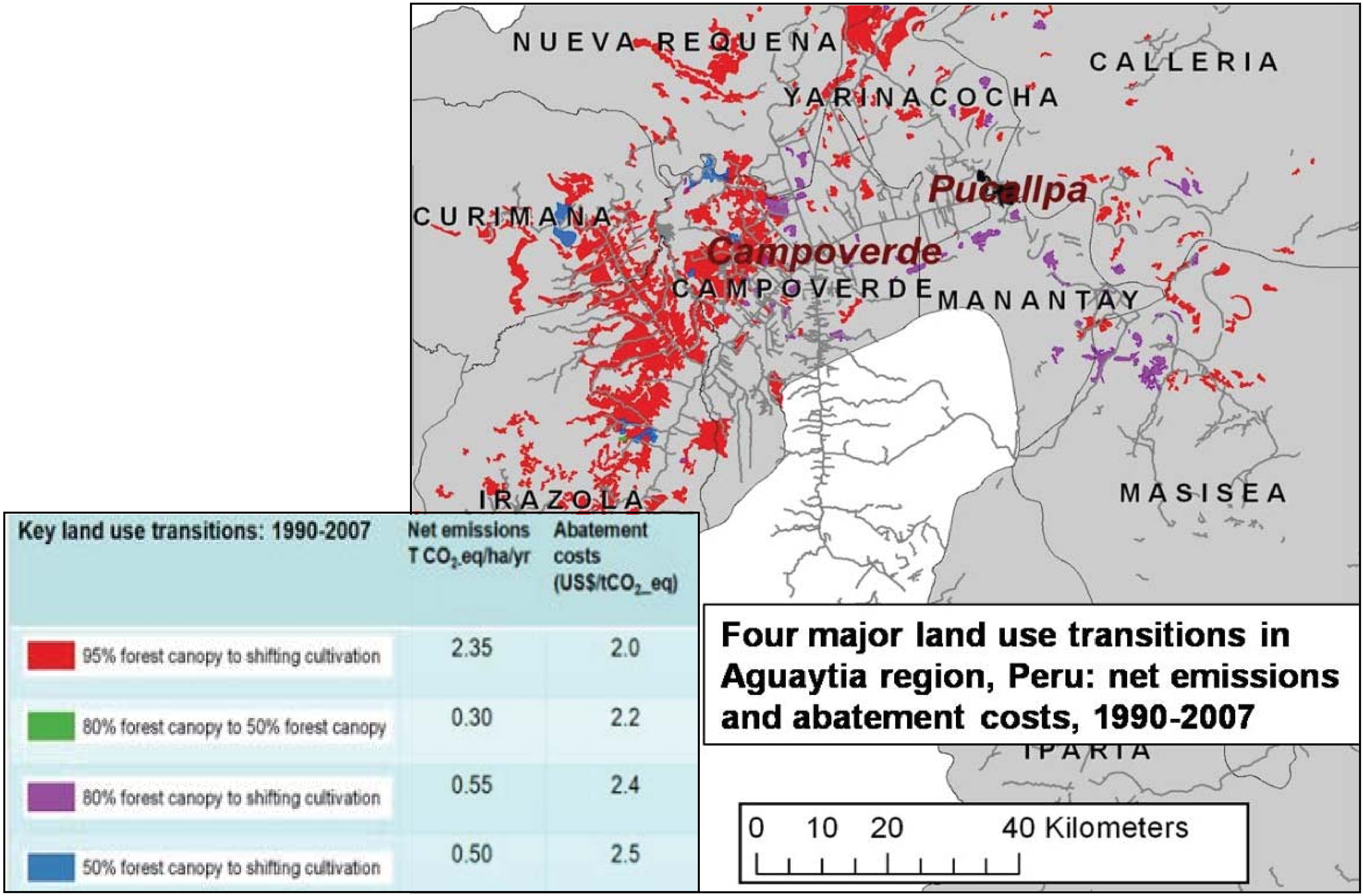

Figure 7.7 An opportunity cost map, central Peruvian Amazon 1990 – 2007.

Source: White and Hyman, 2009.

20. 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.

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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?

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 forgoing 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+.[67] 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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[67] 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/

- *co-benefit analysis:* water provisioning and other regulating, cultural, supporting services

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

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

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.[68]

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.

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[68] The CBD Program of Work on Protected Areas (PoWPA) Gap Analysis: a tool to identify potential sites for action under REDD+ http://cdn.www.cbd.int/doc/programmes/cro-cut/pa/pa-redd-2008-12-01-en.pdf

Table 8.2. Water benefits and services

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

Source: White, et al. 2008, adapted from Sadoff and Grey (2005) and MEA (2003).

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.[69]

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 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.

[69] This section largely based on Porras, et al. (2008) and Pagiola, personal communication, (2010).

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.[70] 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.

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.

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[70] This second role is un-mentioned in Porras, et al. (2008) review, but can be a very important one (Pagiola, personal communication).

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 (Jeanes, 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.[71] 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).[72] 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 micro-organisms 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

[71] In such cases, the opportunity costs of REDD+ could theoretically be negative.
[72] And sometimes by other countries, as with transboundary rivers.

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.[73] 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,[74] at times the definition of a particular species or boundary between

[73] 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.

[74] 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).

42. 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)

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

* 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[75] 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 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. Box 8.2 presents analyses of species richness for three ASB sites. 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.

[75] higher plants that have lignified tissues (e.g., ferns, bushes, trees).

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 Table 8.3.

Table 8.3. Plant species richness of land uses in three ASB sites

Land use	***Number of plant species within a 200 m² plot***		
	Brazil	Cameroon	Indonesia
Natural forests	63	103	111
Managed forests	-	-	100
Logged forests	66	93	108
Extensive agroforests	47	71	112
Intensive agroforests	-	63	66
Simple tree systems	25	40	30
Long fallow agriculture	36	54	43
Short fallow agriculture	26	14	39
Continuous annual crops	33	51	15
Pasture/grasslands	23	25	11
Intensive pasture	12	-	-

47. Forests typically have significantly higher levels of plant species richness. Nevertheless, disturbances to forests can increase diversity. After logging, newcomers 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 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 they 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 interations). 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, understory 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, across the continents, the first trees (pioneers), which grow in an open patch of land and have very large leaves, belong to different plant families. Yet, the functional types of plants are comparable across continents in different parts of the lowland tropics.

A composite approach to estimate biodiversity

52. 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 (m^2 / ha),
- 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)

53. 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).

54. 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).

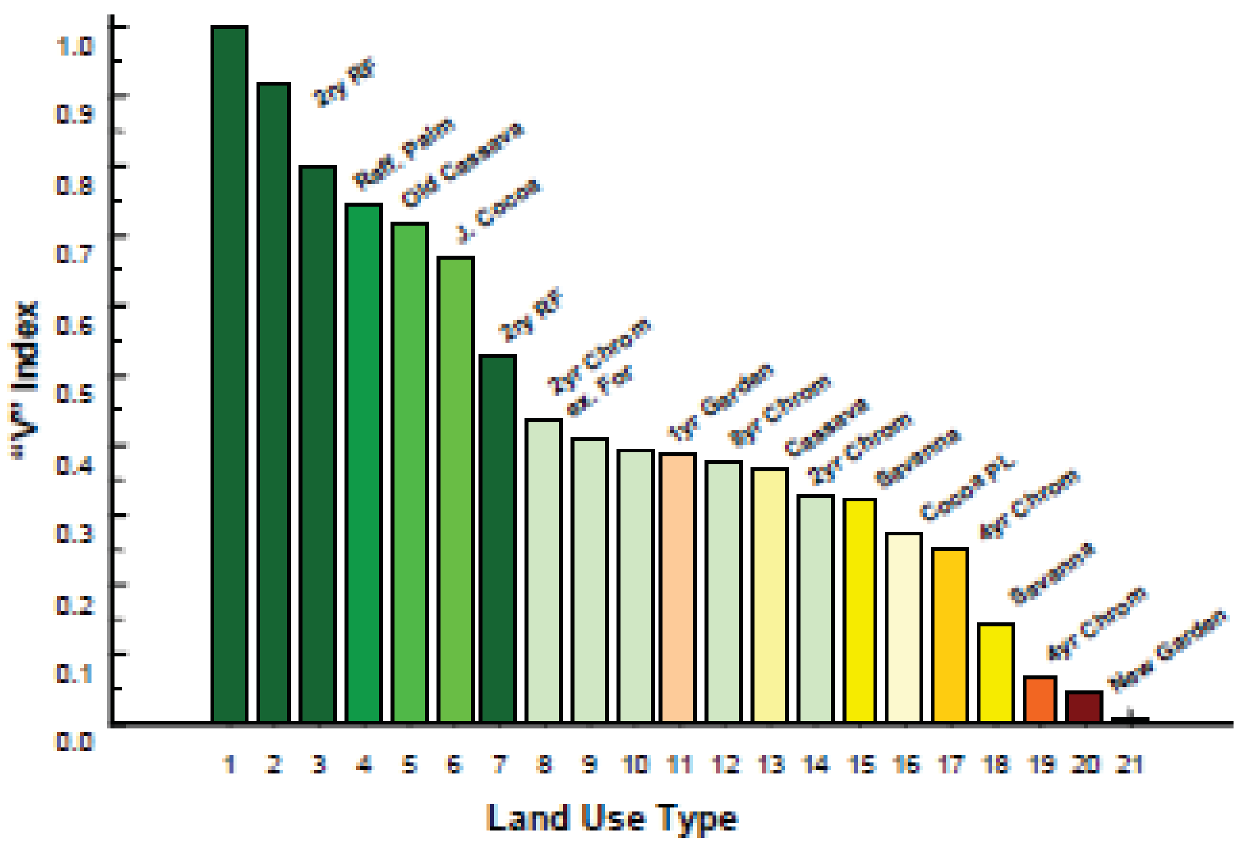

Figure 8.1. V-index values of land uses in Cameroon.

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

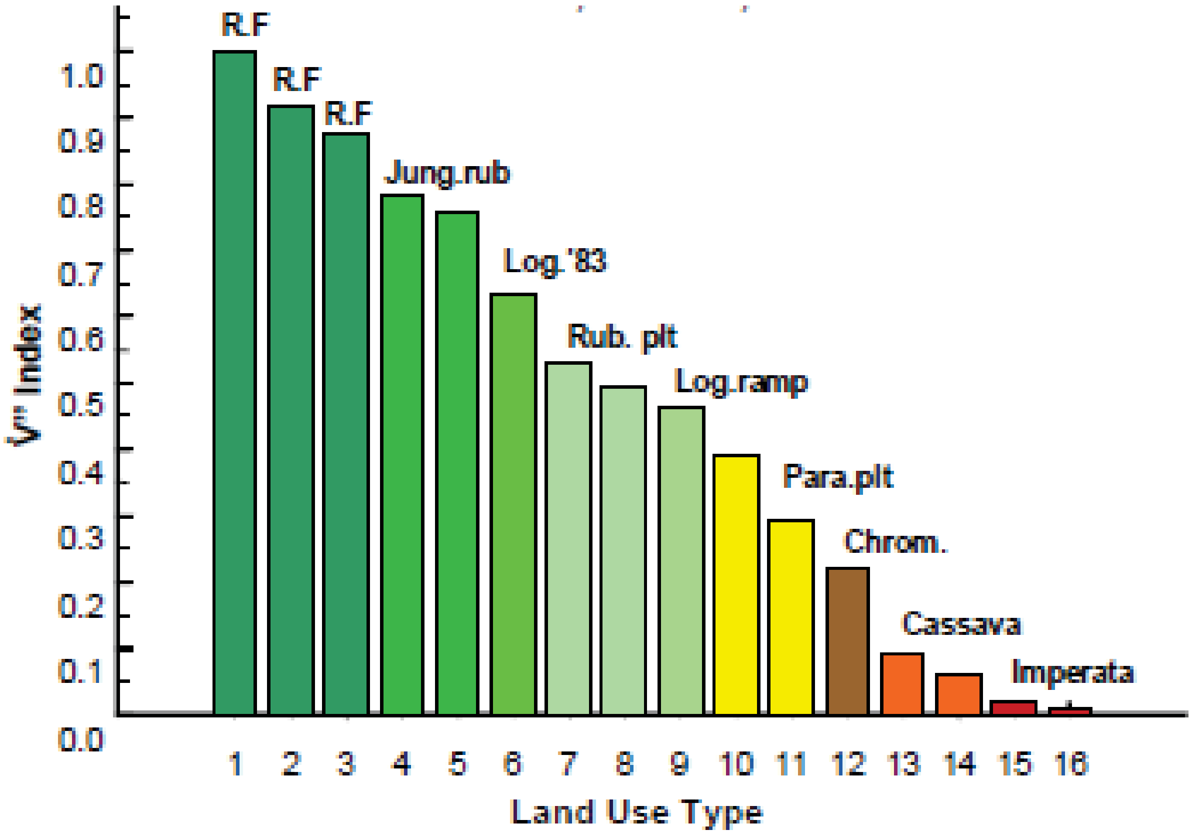

Figure 8.2. V-index values of land uses in Indonesia.

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.*

55. 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

56. 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.

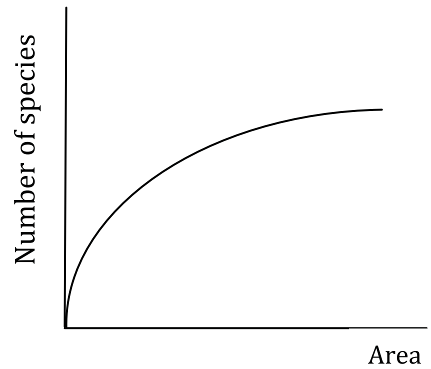

Figure 8.3. A species-area curve

Box 8.3. A cautionary note with species-area curves

Scaling relations (the shape of the species-area curve) may differ between types of vegetation (Figure 8.4), 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.

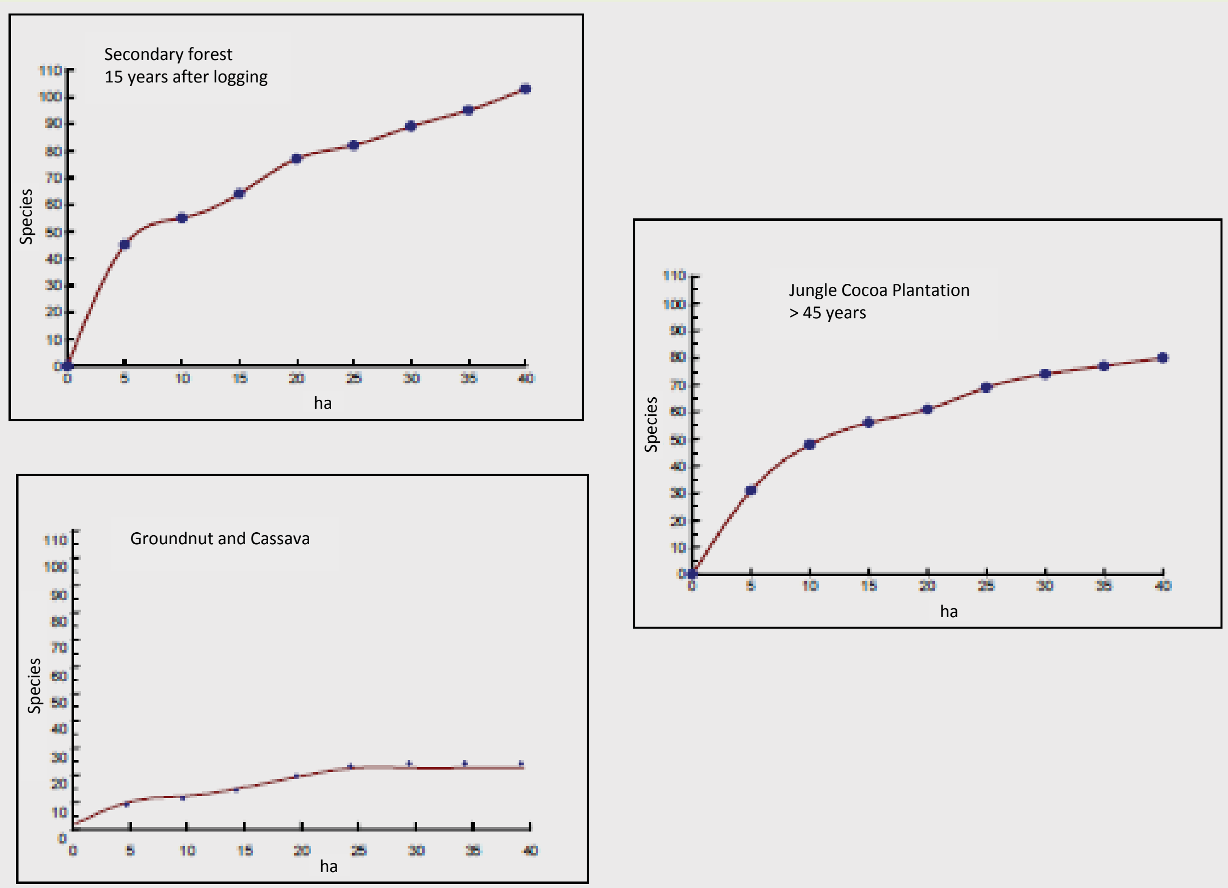

Figure 8.4. Species area curves for three land uses in Cameroon

Source: Gillison (2000a)

57. Another way to examine scalar relationships of biodiversity is to associate three types of diversity (Figure 8.5).

- 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.

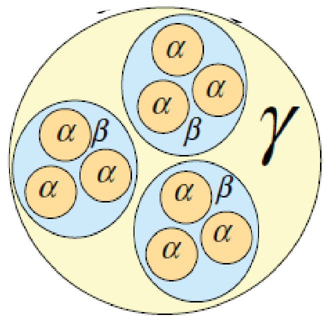

Figure 8.5. Biodiversity at different scales

58. 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).

Biological resources and conservation priorities

59. 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.

60. Gap analysis is another 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.

61. 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

62. Despite the importance of biodiversity, economic valuations are often complex, expensive and likely imprecise. To address these shortcomings, non-economic methods exist that help to examine public concern for biodiversity. Insights gained from public participation can complement benefit-cost approaches for policy decisions. **Appendix E** includes details on estimating the value of bio-diversity also the references below contain numerous sources.

Co-benefits and opportunity costs

63. 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).

64. Within REDD+ discussions, off-site within-country benefits are typically termed: co-benefits of conserving, improving or establishing forests.

65. Here we present two sample "Tier 2" studies. Pagiola, et al. (2006) 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 8.4). The second example of co-benefits maps comes from Tanzania (Box 8.5).

Box 8.4. 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.

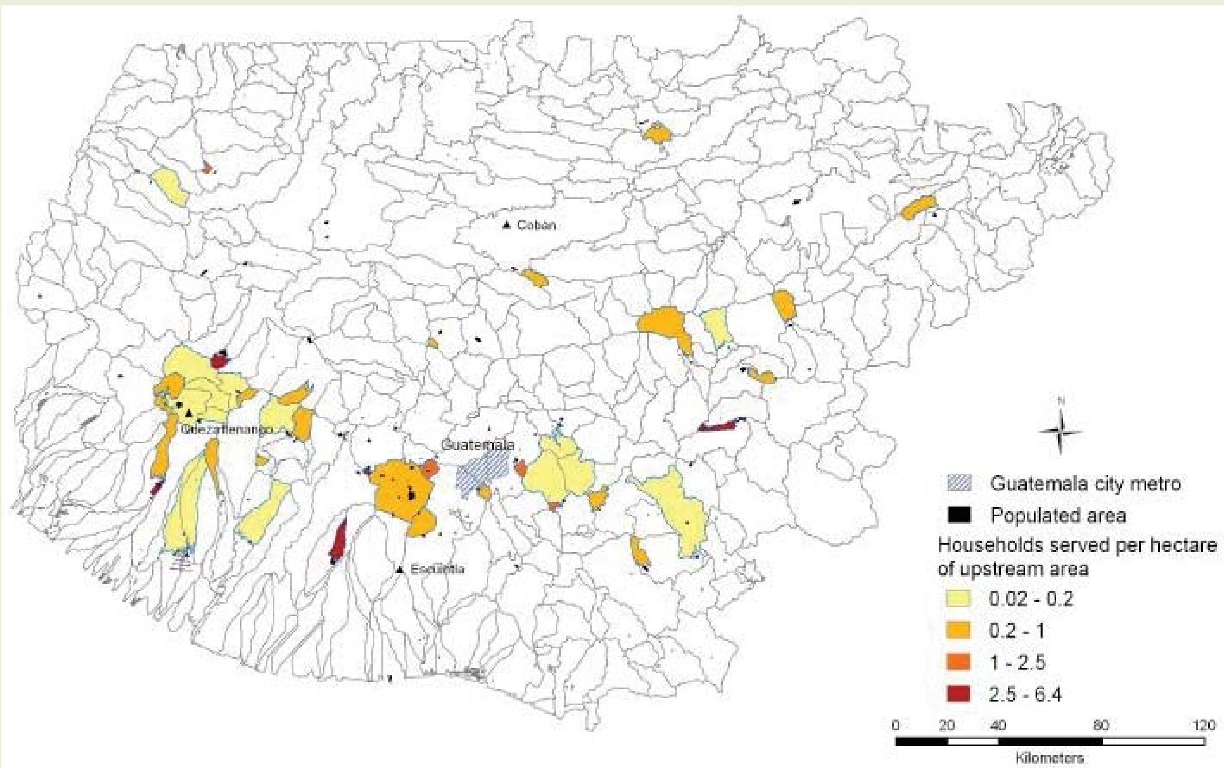

Figure 8.6. Municipal water systems and supply areas, Guatemala.

Source: Pagiola, et al. 2007.

Box 8.5. 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).

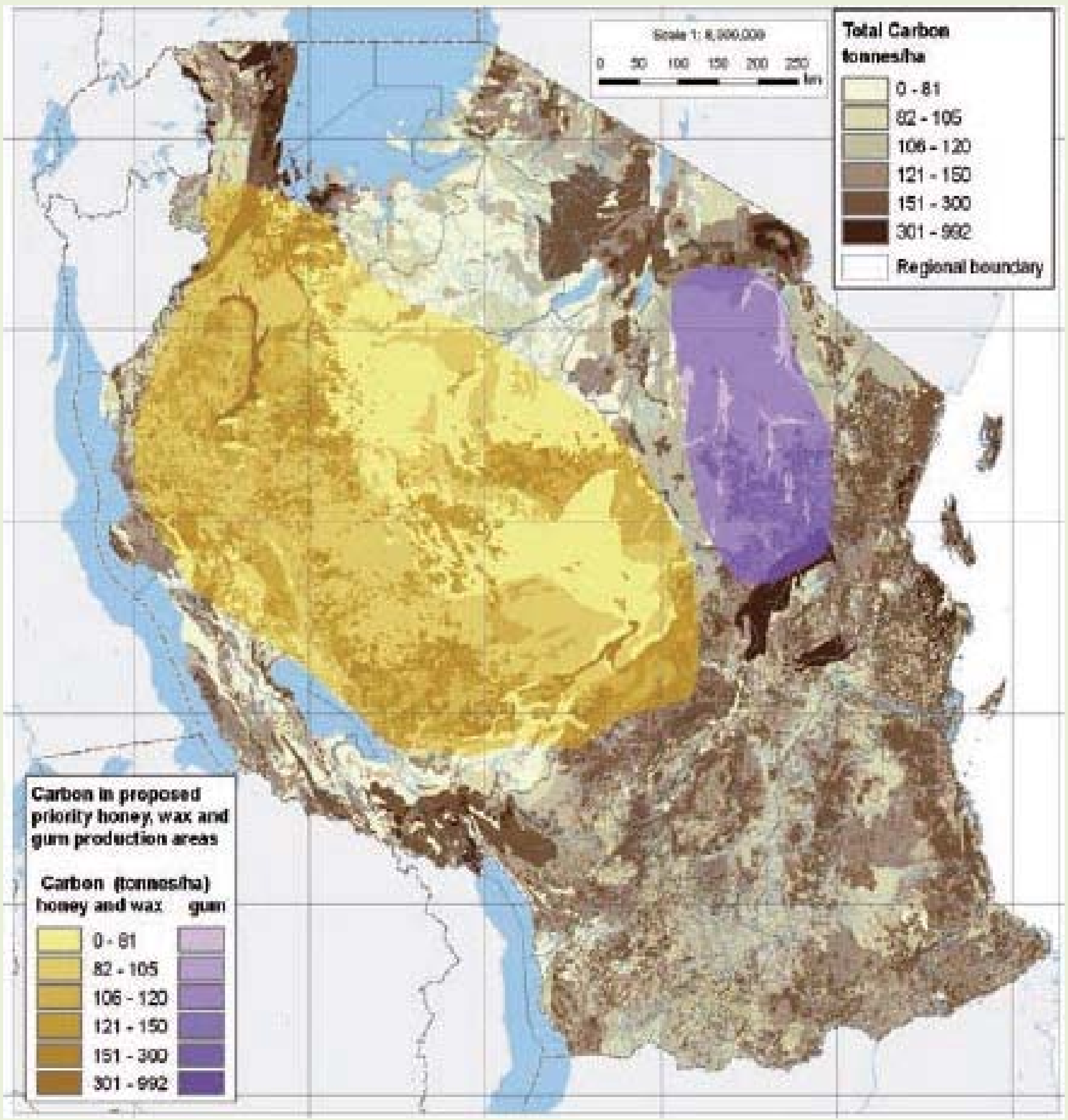

Figure 8.7. A combined NTFP priority areas and soil-biomass carbon map of Tanzania

Source: Miles, et al. 2009.

66. 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,[76] carbon storage,[77] 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.

67. 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 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.

An example of co-benefit analysis

68. Although the value of co-benefits is very difficult to estimate and even more challenging to convert into per hectare values, opportunity cost analysis can guide where:

a. quantification and perhaps valuation efforts are priority,
b. the identification of land uses to include in a REDD+ program.

69. Figure 8.8 contrasts five emission abatement situations with different abatement costs and water co-benefits. For the purposes of illustration, these situations refer to a change from forest to agricultural land use with co-benefits from downstream water quality and availability. In order to directly compare both carbon and water benefits, the same unit of analysis must be used. This example converts the typical $/ha estimate of water co-benefits to a $/tC02e measure (requires dividing the water co-benefits by the associated tCO2e of the land use). Water co-benefits can be considered REDD+ cost reductions, as represented by lighter green area.

70. Options A, B, and C have REDD+ costs less than the price of carbon (Pc). In contrast, option E has REDD+ costs higher than Pc. Only options A, B, D and E have water co-benefits. Even without the water co-benefits Options A, B and C would be priorities for REDD+ program inclusion given their low REDD+ costs. With the large water co-benefits, options B and D would be more of a priority that option A.

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[76] Net annual rate of atmospheric carbon added to existing biomass carbon pools.
[77] Amount of carbon stored in vegetation both aboveground and belowground.

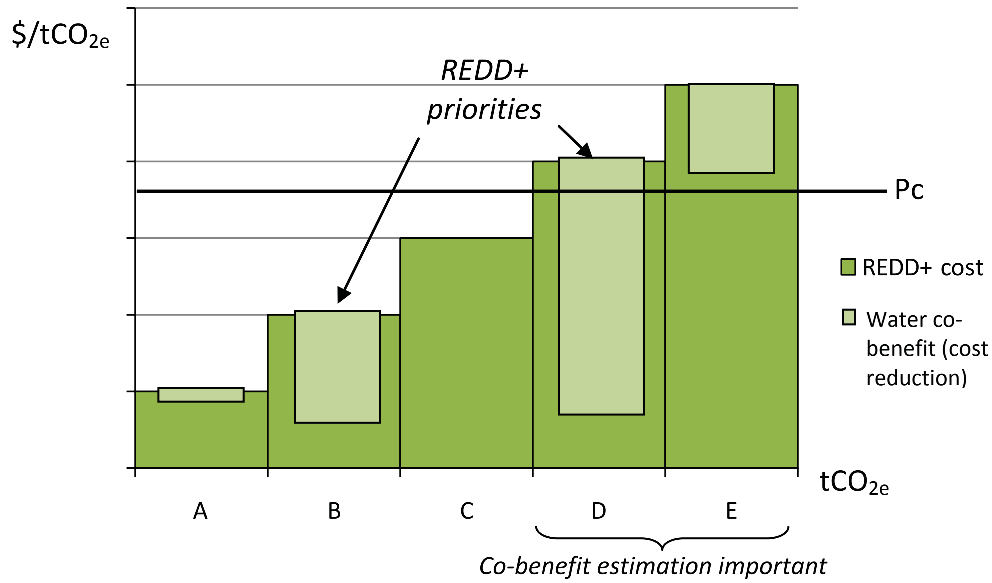

Figure 8.8. Identifying priority co-benefit analyses
Adapted from: Pagiola, 2010 personal communication.

71. Options D and E have higher REDD+ costs than the carbon price and would normally not be included in a REDD+ program. With consideration of water co-benefits, however, the option D would viable. Estimating benefits is more important for the case where the REDD+ costs exceed the price of carbon. In cases where the carbon costs are less than carbon price (Options A, B, C, D), estimation of co-benefits is less of a priority.

72. With respect to biodiversity co-benefits, an analysis would be similar – except that benefits can rarely be realized by a country. Protecting high biodiversity areas typically generate benefits outside the country (especially if tourism is not linked to biodiversity). Within Figure 8.8, avoiding deforestation in Area E based on carbon payments and water co-benefits may not be in the best interest of the country. The alternative land use poses greater benefits. Nevertheless, the country could try to attract a biodiversity-oriented donor to complement the carbon payments in order to make conservation viable.

Conclusion

73. 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.

74. Specific suggestions for policy-makers include the following :

- *Biodiversity* [78]
  - 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.
  - 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.
  - 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*
  - 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).
  - 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.
  - 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.

[78] Adapted from Karousakis (2009).

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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

ASB Partnership for the Tropical Forest Margins
CGIAR
Forest Carbon Partnership Facility
World Bank Institute
Carbon Finance Assist

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.

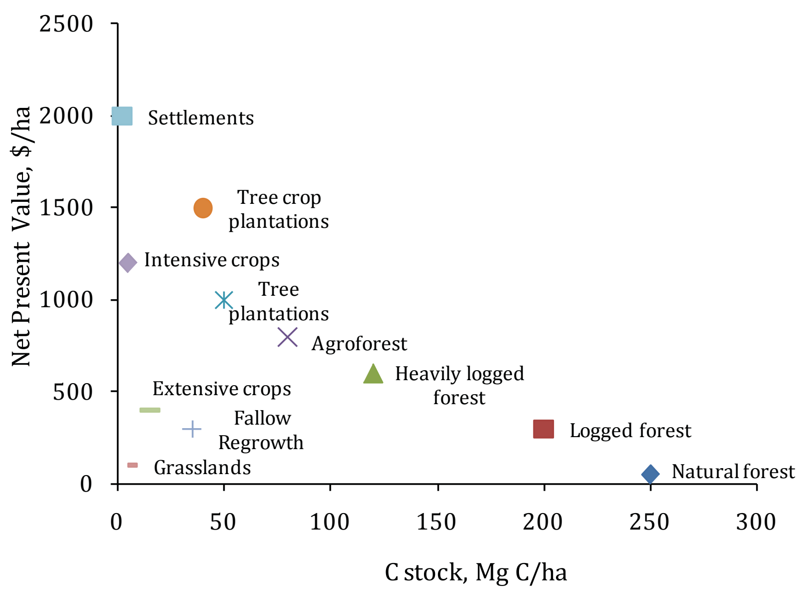

Figure 9.1. Example tradeoff of land uses: NPV profit vs. carbon stock

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

	Employment	Carbon	Biodiversity	Water
Profit	+	-	-	-
Employment		-	-	-
Carbon			+	+
Biodiversity				+

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 or tree species are grown as monocultures.

5. At a landscape level, conservation and development objectives can become less clear. The spatial arrangement of land uses types can raise the question of how to achieve optimal levels of biodiversity within a landscape. Let's illustrate this point with an example. An entire landscape of monoculture oil palm has less biodiversity than a landscape containing a mixture of different-aged forests of native species within a mosaic of smallholder farms.

6. 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). In contrast, 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.).

7. The consequences for biodiversity of the segregate-integrate choices are of a mixed nature (Table 9.2). 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. Yet, at the same time, forest animals can damage crop harvests.

Table 9.2. Biodiversity benefits: segregated versus integrated landscapes

Segregated - Agriculture	Segregated - Natural forest	Segregated landscape with Ag + Forest	Integrated - Agroforestry mosaic
Agrobiodiversity mainly relevant for pest and weed control	Large reserves desirable to maintain viable populations	Sharp (fenced) boundaries reduce conflict but create isolated and potentially unviable populations	Agrodiversity provides benefits or has relatively little negative impacts on human activities

Adapted from: Williams, et al. 2001.

8. Although economic – environmental 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 the consequences of different policy options.

Spreadsheet analysis exercise

9. Let's examine a number of tradeoffs and complementarities. The worksheet entitled **Tradeoffs** (in the **SpreadsheetExercisesREDDplusOppCosts.xlsm** file, or see **Appendix F** for a view) is a simplified version containing four land uses and compares three attributes of the land uses: profits, carbon and employment. The study context is the Peruvian Amazon. 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.

10. While profitability and employment reveal a complementary relationship, both comparisons 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 other criteria exist that make agriculture a valuable land use, such as the importance of staple food produced and ability to generate earnings without a lag time. (See Chapter 6 for further explanation.)

Scenarios

11. 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.

12. While sensitivity analysis (in Chapter 7) considers the effects of marginal changes in specific parameters of land uses both biophysical (e.g. carbon content) and economic (e.g., prices of outputs, efficiency of production, costs of inputs and net present value), scenario analysis can 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).
- **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.

- o **Different carbon estimates.** Increased accuracy or removal of systematic bias in carbon measurements (e.g., LIDAR, improved allometric equations or wood density estimates).
- o **Different carbon prices.** risk of permanence may affect carbon price, and market prices may fluctuate

13. 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
   - Comparison of results with the base scenario
7. Map the results of the scenario and compare the map results for the base case.
8. Interpretation of results and implications.

14. 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. While expert knowledge of parameters 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. In some cases, it can be argued that the best way for determining priority parameters and their likely range is via a participatory process. The choice of methods depends on each country given the skills, capacity and the resources available.

Exercise: the effects of different REDD+ eligibility rules

15. The spreadsheet **Eligibility filter** presents a quick analysis of how REDD rules will affect eligibility of different land use changes (in **SpreadsheetExercisesREDDplusOppCosts.xlsm**). Changes to the yellow highlighted cells reveals REDD+ policy effects on 11 categories of land use.

16. 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 the eligibility of specific land uses is still needed.

17. 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.

18. 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).

- 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'
- REDD = RED + (forest) degradation, or the shifts to lower C-stock densities *within* the forest; details depend on the operational definition of 'forest'
- 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'
- REDD++ = REALU = AFOLU, 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'

19. The approach to estimate opportunity costs within this manual could be selectively applied to any of the four versions. The eligibility filter works in conjuntion with the land cover change matrix that is used in the opportunity cost estimation.

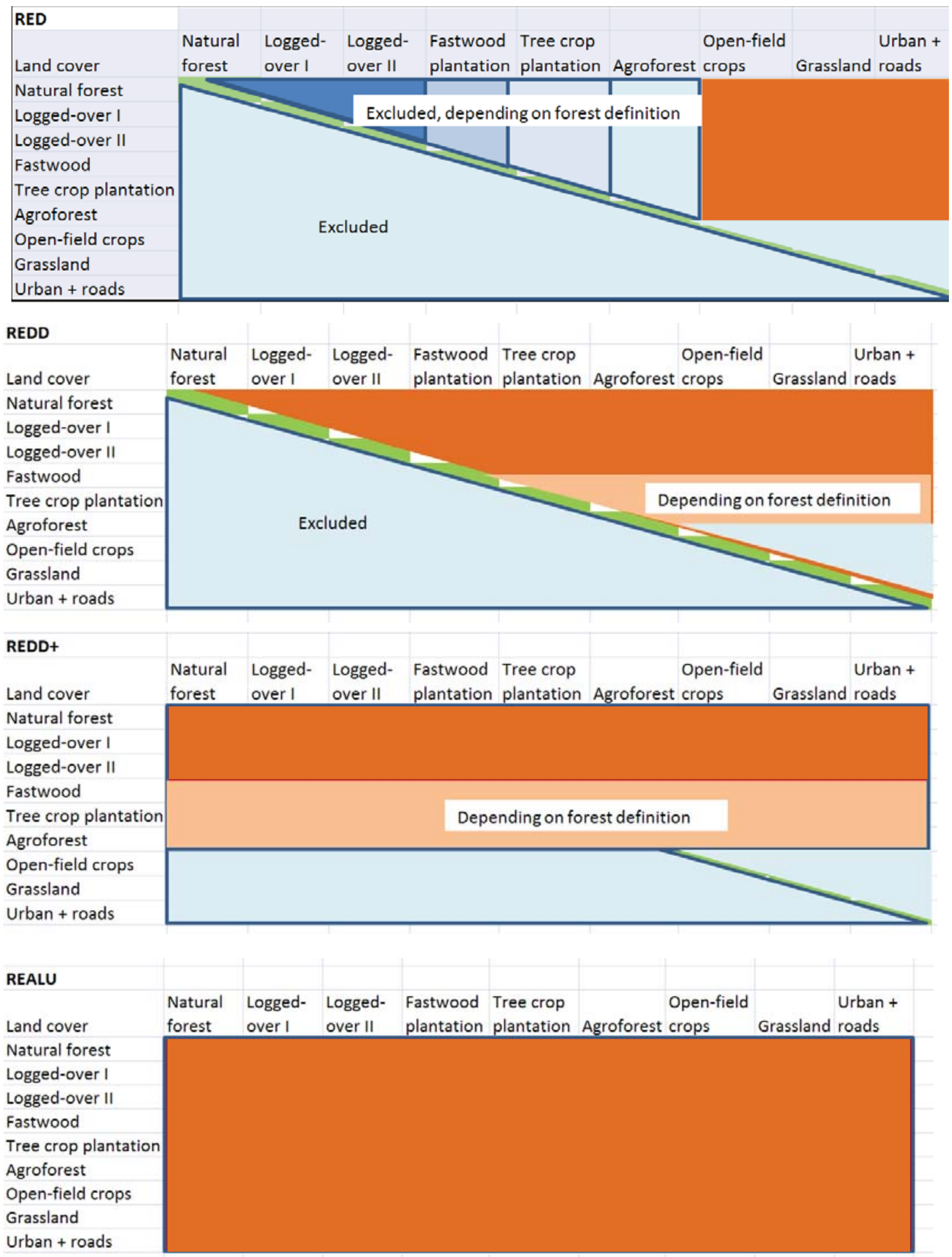

Figure 9.2. Comparisons of eligible land use changes per RED to REALU rules

Note: Land use change is from the initial state in the first column to a land use in one of the other columns. Eligibility of changes is indicated with colors (orange = permitted, blue = excluded)

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 estimates, 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 inter-sectoral 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. Will REDD+ affect food and fiber production at the national level?
g. What level of productivity increases must be achieved to offset production forgone from not expanding cultivate area?
h. 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.

Estimating the opportunity costs of REDD+

A training manual

Version 1.3

Chapter 11. Appendices

Contents

Appendices

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).

Allometric equation. Scaling rule or equation that relates tree biomass (or similar properties) to stem diameter and/or tree height.

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.

Basal area. the cross section area of a tree stem in square cm commonly measured at breast height inclusive of bark (3.14 x radius^2)

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.

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 known as 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 analysis.

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).

Enterprise budget. A detailed accounting of revenues and expenses related to a business (e.g. land use) activity.

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.

Permanence. The longevity of a carbon pool and the stability of its stocks, given the management and disturbance environment in which it occurs.
http://www.ipcc.ch/pdf/special-reports/spm/srl-en.pdf

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. Required capacities for a national monitoring system of emissions

Table 11.1. Capacities required per phase

Phase	Requirement	Capacities
Planning and design	1. Forest monitoring system as part of a national REDD+ implementation strategy	• Knowledge of international UNFCCC process on REDD+ and of guidance for monitoring and implementation • Knowledge of national implementation strategy and objectives for REDD+
	2. Assessment of existing national forest carbon monitoring framework and capacities, and identification of gaps in existing data sources	• Understanding of estimation and reporting guidance provided in the IPCC *Good Practice Guide* and any other relevant guidance under the Convention • 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) • Expertise in estimating terrestrial carbon stocks and related human induced changes, and monitoring approaches • Expertise to assess usefulness and reliability of existing capacities, data sources and information
	3. Design of a forest carbon monitoring system driven by UNFCCC reporting requirements, with objectives for historical period and future monitoring	• Detailed knowledge of the application of methodologies in the IPCC *Good Practice Guide* and any other relevant guidance under the Convention • Agreement on definitions, reference units, and monitoring variables and framework • Institutional framework specifying roles and responsibilities • Capacity development and long-term improvement planning • Cost estimation for establishing and strengthening institutional framework, capacity development, and actual operations and budget planning
Data collection and monitoring	4. Forest area change assessment (activity data)	• Reviewing, consolidating and integrating the existing data and information • Understanding of deforestation drivers and factors, and management practices • If historical data records are insufficient, particularly with the use of remote sensing, the following capacities are required: - Expertise and human resources in accessing, processing and interpretation of multi-date remote sensing imagery for forest area changes - Technical resources (hardware/software, Internet, image database) - Approaches for dealing with technical challenges (i.e. cloud cover, missing data)
	5. Changes in carbon stocks (emission factors)	• Understanding of human-induced processes influencing terrestrial carbon stocks • Consolidation and integration of existing observations and information, that is, national forest inventories or permanent sample plots involving: - National coverage and stratification of forests by carbon density and threat of change - Conversion to carbon stocks & estimates of carbon stock change • Technical expertise and resources to monitor carbon stock changes, including:

		- 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
	6. Emissions from biomass burning	• 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
Data analysis	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
	9. Analysis of drivers and factors of forest change	• 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
Reference emission levels	10. The establishment of reference levels of emissions, which is regularly updated	• 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+
Reporting	11. National and international reporting and verification	Consideration of uncertainties and understanding procedures for independent international review and verification

Source: UNFCCC, 2009.

C. Allometric equations

Table 11.2. Tropical allometric equations

Note: BA= basal area

General classification	Species	Group Equation	Source	Data originating from	Max dbh
Dry (900–1500mm rainfall)	General	Biomass = 0.2035 x $dbh^{2.3196}$	Brown (unpublished)		63cm
Dry (< 900mm rainfall)	General	Biomass = $10^{(-0.535+\log 10 \text{basal area})}$	Brown (1997)	Mexico	30cm
Moist (1500–4000mm rainfall)	General	Biomass = exp(-2.289+2.649 x lndbh-0.021 x $lndbh^2$)	Brown (1997, updated)		148cm
Wet (> 4000mm rainfall)		Biomass = 21.297 – 6.953 x dbh+ 0.740 x dbh^2	Brown (1997)		112cm
Cecropia	*Cecropia* species	Biomass = 12.764 + 0.2588 x $dbh^{2.0515}$	Winrock	Bolivia	40cm
Palms	Palms (*motacu*)	Biomass = 23.487 + 41.851 x $(\ln(height))^2$	Winrock	Bolivia	11m height
Lianas	Lianas	Biomass = exp(0.12+0.91 x log(BA at dbh))	Putz (1983)	Venezuela	12cm

Source: Pearson, et al., 2005.

Table 11.3. Agroforestry allometric equations

Note: BA = basal area.

General classification	Species	Group Equation	Source	Data originating from	Max dbh
Agroforestry Shade Trees	All	Log10Biomass = -0.834 + 2.223 (log10dbh)	Segura et al.	Nicaragua	44cm
Agroforestry Shade Trees	*Inga spp.*	Log10Biomass = -0.889 + 2.317 (log10dbh)	Segura et al.	Nicaragua	44cm
Agroforestry Shade Trees	*Inga punctata*	Log10Biomass = -0.559 + 2.067 (log10dbh)	Segura et al.	Nicaragua	44cm
Agroforestry Shade Trees	*Inga tonduzzi*	Log10Biomass = -0.936 + 2.348 (log10dbh)	Segura et al.	Nicaragua	44cm
Agroforestry	*Juglans olanchama*	Log10Biomass = -1.417 + 2.755 (log10dbh)	Segura et al.	Nicaragua	44cm
Agroforestry Shade Trees	*Cordia alliadora*	Log10Biomass = -0.755 + 2.072 (log10dbh)	Segura et al.	Nicaragua	44cm
Shade grown	*Coffea arabica*	Biomass = exp(-2.719 + 1.991 (ln(dbh))) (log10dbh)	Segura et al.	Nicaragua	8cm
Pruned coffee	*Coffea arabica*	Biomass = 0.281 x $dbh^{2.06}$	van Noordwijk et al. (2002)	Java, Indonesia	10cm
Banana	*Musa X paradisiaca*	Biomass = 0.030 x $dbh^{2.13}$	van Noordwijk et al. (2002)	Java, Indonesia	28cm
Peach palm	*Bactris gasipaes*	Biomass = 0.97 + 0.078 x BA – 0.00094 x BA^2 + 0.0000065 x BA^3	Schroth et al. (2002)	Amazonia	2–12cm
Rubber trees	*Hevea brasiliensis*	Biomass = -3.84 + 0.528 x BA + 0.001 x BA^2	Schroth et al. (2002)	Amazonia	6–20cm
Orange trees	*Citrus sinensis*	Biomass = -6.64 + 0.279 x BA + 0.000514 x BA^2	Schroth et al. (2002)	Amazonia	8–17cm
Brazil nut trees	*Bertholletia excelsa*	Biomass = -18.1 + 0.663 x BA – 0.000384 x BA^2	Schroth et al. (2002)	Amazonia	8–26cm

Source: Pearson, et al., 2005.

D. 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) x 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}) x 0,46 = C (Mg C ha^{-1})
  Output 5: C Soil organic matter (Mg ha^{-1}) x 0,47 = 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 a 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}.

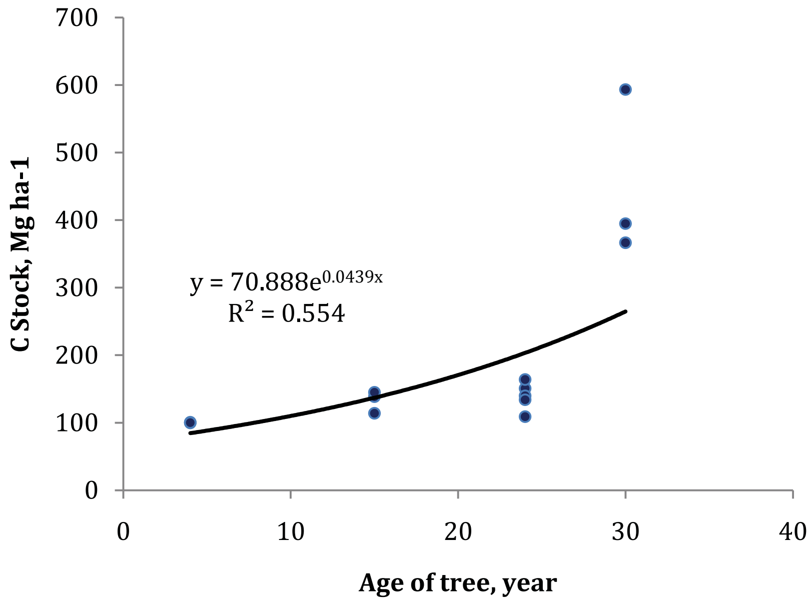

Figure 11.1. Carbon stock changes in Mahogany-monoculture system, East Java

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) x 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}) x 0,46 = C (Mg C ha^{-1})
  Output 5: C Soil organic matter (Mg ha^{-1}) x 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}.

E. 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 may seem little or not even be 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 has 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.

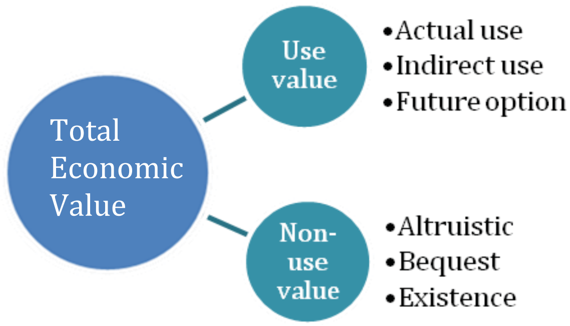

Figure 11.2. Economic values attributed to environmental assets

10. 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.

11. An array of methodologies is available for eliciting and estimating economic values.[79] 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.

12. 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.

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[79] 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).

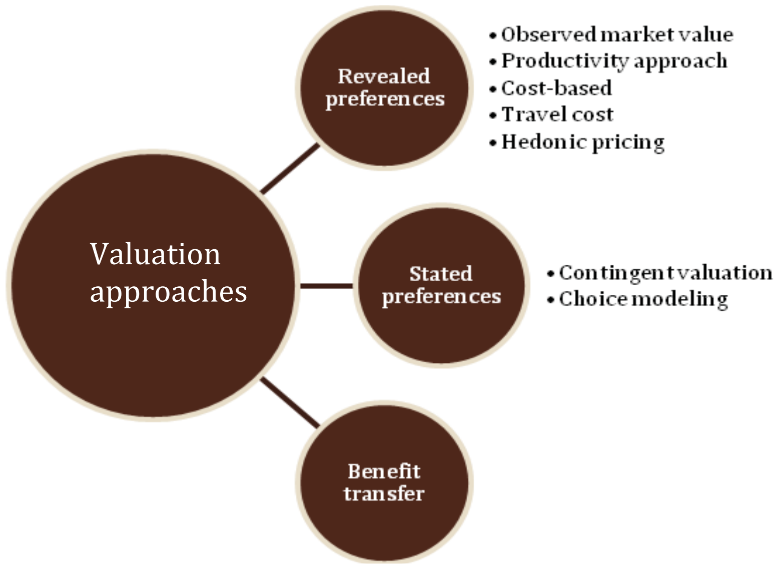


Figure 11.3. Valuation methods for biological diversity and resources

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).

14. Details on the above are available in numerous publications. For more information see OECD (2002), Arrow, 1993, Pearce and Moran (1994). Issues of applicability and validity continued to be refined in the scientific literature.

F. Spreadsheet examples

15. This appendix contains pertinent sections of computer spreadsheets described in Chapters 7 and 9.

Figure 11.4, OppCost Spreadsheet (a): example inputs and outputs (Chapter 7)

Opportunity cost estimate worksheet (national level)

Data inputs:	**Outputs:**
1. Land uses (LU) initial & changes	1. Final land use estimates
2. C stock per LU	2.Opportunity cost curve
3. Profit per LU	3. National level summary
4. Workdays per LU	

All numbers in yellow cells are parameters that you can change

Land use legend	**Time-averaged C stock** (Mg C/ha)	**Profit-ability** (NPV, $/ha)	**Employment** (workdays/year)
Natural forest	250	30	5
Logged forest	200	300	15
Agro-forestry	80	800	120
Extensive agriculture	10	600	100

Period of analysis	**30**	years
Size of country	**2,000,000**	km2
Total population	**1,000,000**	
Pop working age	**60%**	
Workdays / year	**230**	days

Performance at national scale:	
Total LU-based emission, Pg CO2e/yr	0.00
Total C stock in land use, Pg C	34.00
Total NPV of land uses (M$)	60,400
Total rural employment	0.56
Emissions as percentage of C stock	0.0

(vertical axis)

Opportunity costs of land uses changes: $ per tCO2

Initial \ Final	Natural forest	Logged forest	Agro-forestry	Extensive agriculture
Natural forest	0.00	1.47	1.24	0.65
Logged forest	-1.47	0.00	1.14	0.43
Agro-forestry	-1.24	-1.14	0.00	0.78
Extensive agriculture	-0.65	-0.43	-0.78	0.00
Carbon	*250*	*200*	*80*	*10*
NPV Profits	*30*	*300*	*800*	*600*

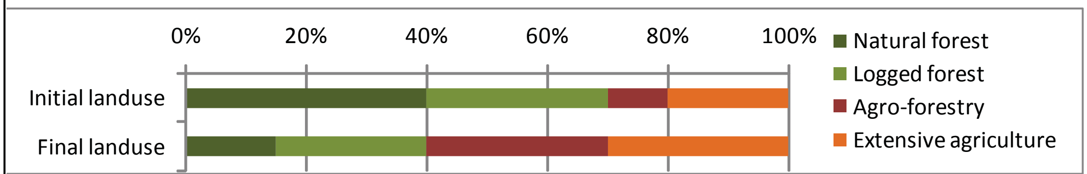
(horizontal axis)

Emissions, Tg CO2e/yr

Natural forest	0.0	305.6	0.0	0.0
Logged forest	0.0	0.0	293.3	928.9
Agro-forestry	0.0	0.0	0.0	0.0
Extensive agriculture	0.0	0.0	-171.1	0.0

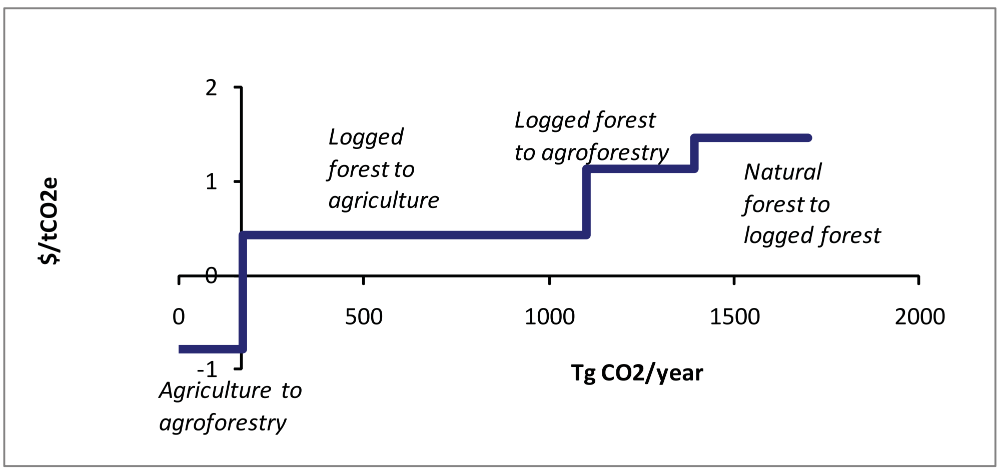
Figure 11.5, OppCost Spreadsheet (b): example inputs and outputs (Chapter 7)

Land use distribution



Land use change matrix	Final landuse	Natural forest	Logged forest	Agro-forestry	Extensive agriculture	*Inconsis-tency check*
Initial landuse		**15%**	**25%**	**30%**	**30%**	
Natural forest	**40%**	15%	25%	0%	0%	*0.0%*
Logged forest	**30%**	0%	0%	10%	20%	*0.0%*
Agro-forestry	**10%**	0%	0%	10%	0%	*0.0%*
Extensive agriculture	**20%**	0%	0%	10%	10%	*0.0%*
LU change (%/year)	**100%**	2.1	1.3	0.8	0.8	

Original



Scenario 2 Logged forest $300 -> $400 NPV/ha

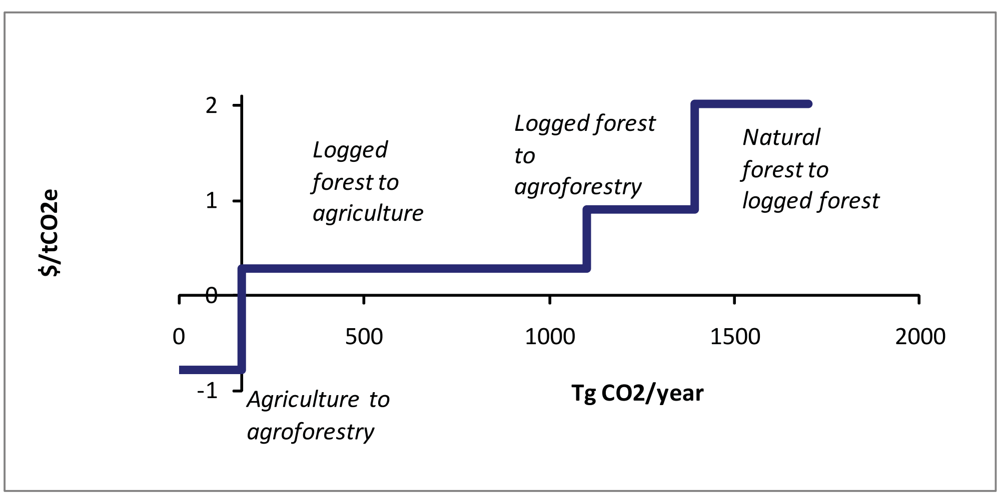


Figure 11.6. Tradeoffs (Chapter 9)

Tradeoff comparisons

Data inputs:

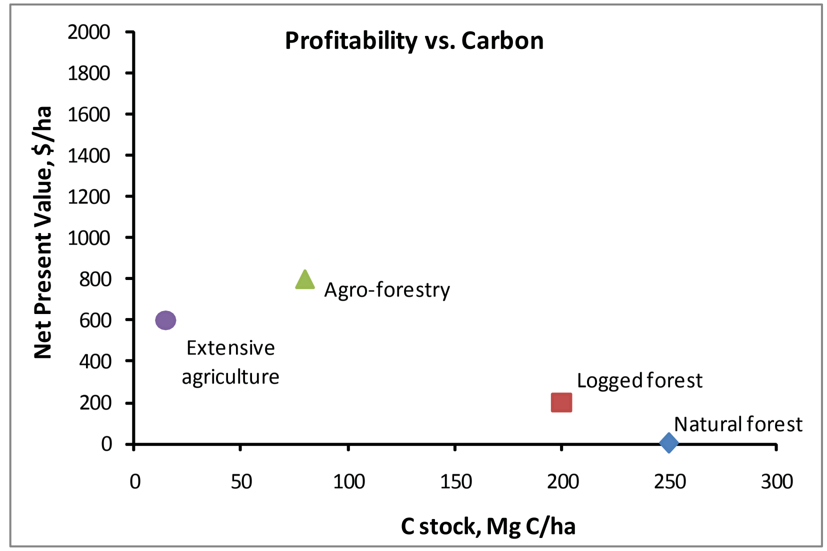
1. C stock per LU
2. Profit per LU
3. Workdays per LU

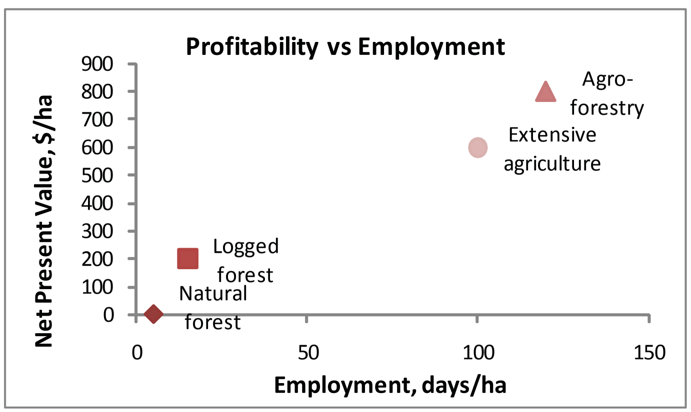
Output:

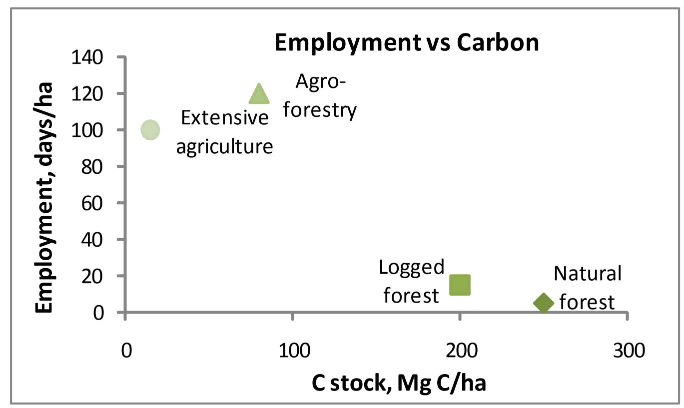
Tradeoff graphs:

1. Profitability v Carbon
2. Profitability v Employment
3. Employment v Carbon

Land use legend	**Time-averaged C stock** (Mg C/ha)	**Profitability** (NPV, $/ha)	**Rural employment** (workdays/year)
Natural forest	250	2	5
Logged forest	200	200	15
Agro-forestry	80	800	120
Extensive agriculture	15	600	100







G. Example analysis using REDD Abacus

16. On the REDD Abacus website (www.worldagroforestry.org/sea/projects/allreddi/softwares), a sample file representing a context in Indonesia (Project Examples–Project.car file) can be examined within the REDD Abacus program (downloadable on the same website). To open, click **File** on the Toolbar, then click **Open Project**. A dialogue box opens for files stored on the computer. The file is called: **sample_project.car**. When opened, a reviewing pane is on the left of the screen, which shows one's location within the program. On the right section of the screen is a box for data entry and of results.

Data entry

17. The first screen (**test1**) is a context description of the analysis – which can either be a sub-national project or national program. The right box contains subsections with the *Project label*, *Description*, *Time Scale (Year)* and an option of including *belowground emissions*. Two other subsections are for the *Zone Partition* and *Land Cover List*. The *Zone Partition* contains a box to enter the *Size of the Total Area* (ha). Each identified Zone is a fraction of the Total Area, in decimal terms, and can be classified (via a checkmark) as being eligible or not within a REDD policy scenario. The *Land Cover List* is where the names of the land covers are entered, along with a brief description (if needed). Each of land covers can be identified as either eligible or ineligible within a REDD policy scenario. The (**+**) adds an addition land cover to the list, while the (**–**) erases the highlighted cover. The **sample_project** example has 4 zones and 20 land covers (Figure 11.7).

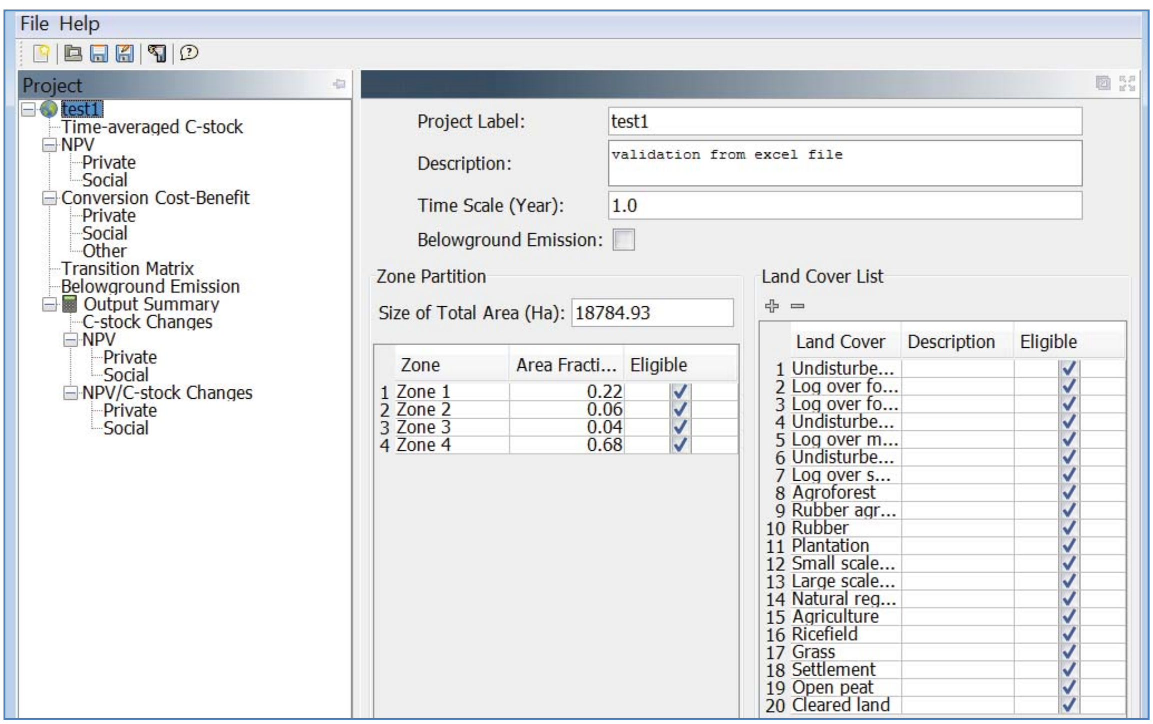
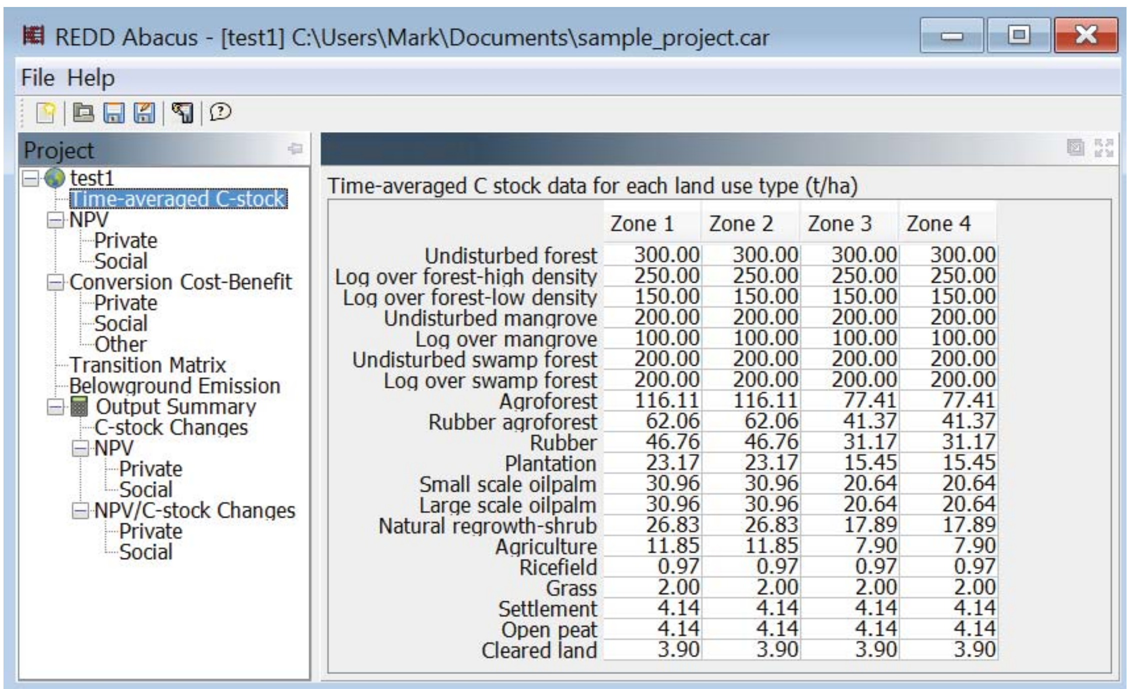


Figure 11.7. Context description screen of REDD Abacus example

18. If starting a new file, a series of dialogue boxes will prompt the user for information on:

- title
- description
- number of zones
- total area

19. The second screen, *Time-averaged C-stock*, accepts data for each of the land uses per zone (Figure 11.8). For the example, 20 land uses in the 4 zones requires carbon data (t/ha) for 80 different land use contexts.

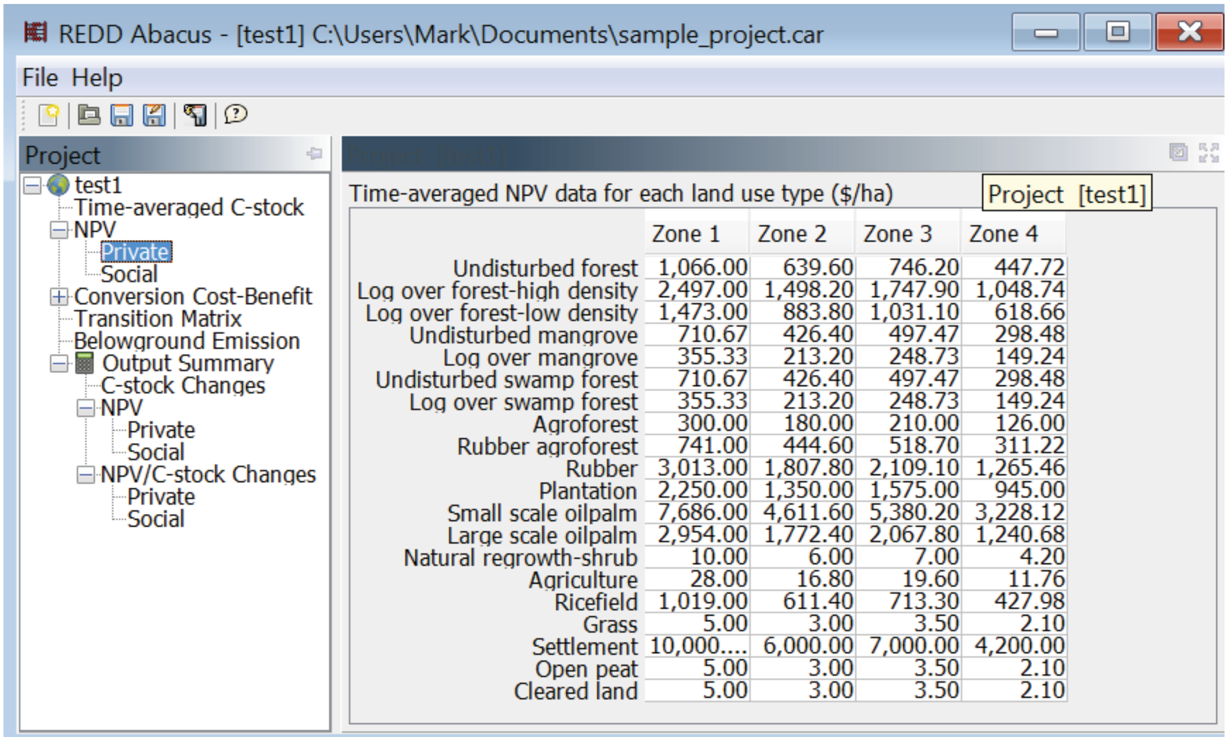


	Zone 1	Zone 2	Zone 3	Zone 4
Undisturbed forest	300.00	300.00	300.00	300.00
Log over forest-high density	250.00	250.00	250.00	250.00
Log over forest-low density	150.00	150.00	150.00	150.00
Undisturbed mangrove	200.00	200.00	200.00	200.00
Log over mangrove	100.00	100.00	100.00	100.00
Undisturbed swamp forest	200.00	200.00	200.00	200.00
Log over swamp forest	200.00	200.00	200.00	200.00
Agroforest	116.11	116.11	77.41	77.41
Rubber agroforest	62.06	62.06	41.37	41.37
Rubber	46.76	46.76	31.17	31.17
Plantation	23.17	23.17	15.45	15.45
Small scale oilpalm	30.96	30.96	20.64	20.64
Large scale oilpalm	30.96	30.96	20.64	20.64
Natural regrowth-shrub	26.83	26.83	17.89	17.89
Agriculture	11.85	11.85	7.90	7.90
Ricefield	0.97	0.97	0.97	0.97
Grass	2.00	2.00	2.00	2.00
Settlement	4.14	4.14	4.14	4.14
Open peat	4.14	4.14	4.14	4.14
Cleared land	3.90	3.90	3.90	3.90

Figure 11.8. Time-averaged carbon stock of REDD Abacus example

20. Profit data from land uses are entered in the third screen (in NPV - net present value per hectare). Profit levels can differ according to accounting stance (sectors being: private or social) in addition to the distinct zones. Although the discount rate is typically a major difference between the two stances, the example employs the same rate for both. (Private sector typically has a higher discount rate given the time value of money corresponding to a prevailing interest rate.) In the example, all social NPVs are higher than private NPVs - except for the rice field land cover. The lower social NPV of rice fields is the result of a 30% government tariff policy on rice imports, which artificially inflates the farm gate price of

rice. In contrast, export taxes on oil palm and rubber depress the prices that farmer receive, thus the social NPVs are higher than the private NPVs (Figure 11.9).

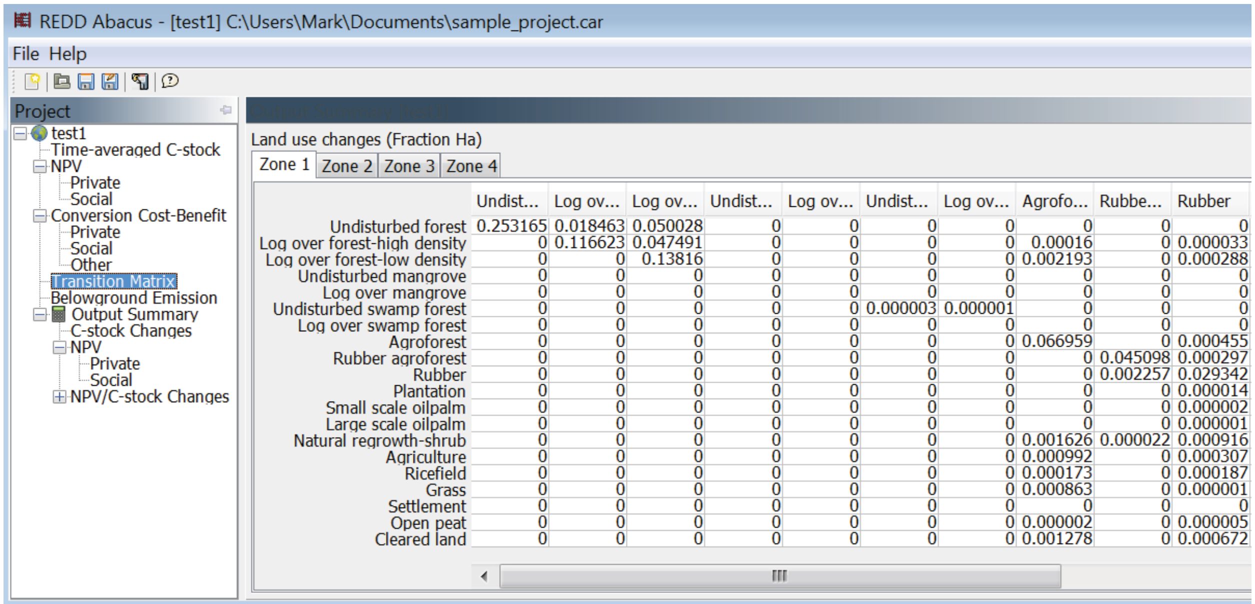


	Zone 1	Zone 2	Zone 3	Zone 4
Undisturbed forest	1,066.00	639.60	746.20	447.72
Log over forest-high density	2,497.00	1,498.20	1,747.90	1,048.74
Log over forest-low density	1,473.00	883.80	1,031.10	618.66
Undisturbed mangrove	710.67	426.40	497.47	298.48
Log over mangrove	355.33	213.20	248.73	149.24
Undisturbed swamp forest	710.67	426.40	497.47	298.48
Log over swamp forest	355.33	213.20	248.73	149.24
Agroforest	300.00	180.00	210.00	126.00
Rubber agroforest	741.00	444.60	518.70	311.22
Rubber	3,013.00	1,807.80	2,109.10	1,265.46
Plantation	2,250.00	1,350.00	1,575.00	945.00
Small scale oilpalm	7,686.00	4,611.60	5,380.20	3,228.12
Large scale oilpalm	2,954.00	1,772.40	2,067.80	1,240.68
Natural regrowth-shrub	10.00	6.00	7.00	4.20
Agriculture	28.00	16.80	19.60	11.76
Ricefield	1,019.00	611.40	713.30	427.98
Grass	5.00	3.00	3.50	2.10
Settlement	10,000....	6,000.00	7,000.00	4,200.00
Open peat	5.00	3.00	3.50	2.10
Cleared land	5.00	3.00	3.50	2.10

Figure 11.9. NPV estimates for REDD Abacus example

21. The fourth screen, *Conversion Cost-Benefit*, allows the user to include the per hectare cost-benefit associated with each land use change. In other words, the NPVs given up when converting one specific land use into another, e.g., converting (clearing) of undisturbed forest implies US$ 1,066 US$/ha of forgone profits.

22. The fifth screen, *Transition Matrix*, is a summary of each type of land use change within the area of analysis (Figure 11.10). This is the same as the **Land use change matrix**, mentioned within this manual (in Chapter 4). Each cell represents the fraction of change per sub-national Zone. (The sum of all cells is equal to 1.) As can be seen in the example, although 400 different land use changes are possible, changes did not occur for all land use covers.



	Undist...	Log ov...	Log ov...	Undist...	Log ov...	Undist...	Log ov...	Agrofo...	Rubbe...	Rubber
Undisturbed forest	0.253165	0.018463	0.050028	0	0	0	0	0	0	0
Log over forest-high density	0	0.116623	0.047491	0	0	0	0	0.00016	0	0.000033
Log over forest-low density	0	0	0.13816	0	0	0	0	0.002193	0	0.000288
Undisturbed mangrove	0	0	0	0	0	0	0	0	0	0
Log over mangrove	0	0	0	0	0	0	0	0	0	0
Undisturbed swamp forest	0	0	0	0	0	0.000003	0.000001	0	0	0
Log over swamp forest	0	0	0	0	0	0	0	0	0	0
Agroforest	0	0	0	0	0	0	0	0.066959	0	0.000455
Rubber agroforest	0	0	0	0	0	0	0	0	0.045098	0.000297
Rubber	0	0	0	0	0	0	0	0	0.002257	0.029342
Plantation	0	0	0	0	0	0	0	0	0	0.000014
Small scale oilpalm	0	0	0	0	0	0	0	0	0	0.000002
Large scale oilpalm	0	0	0	0	0	0	0	0	0	0.000001
Natural regrowth-shrub	0	0	0	0	0	0	0	0.001626	0.000022	0.000916
Agriculture	0	0	0	0	0	0	0	0.000992	0	0.000307
Ricefield	0	0	0	0	0	0	0	0.000173	0	0.000187
Grass	0	0	0	0	0	0	0	0.000863	0	0.000001
Settlement	0	0	0	0	0	0	0	0	0	0
Open peat	0	0	0	0	0	0	0	0.000002	0	0.000005
Cleared land	0	0	0	0	0	0	0	0.001278	0	0.000672

Figure 11.10. Transition matrix for REDD Abacus example

23. The sixth screen, *Belowground Emissions,* provides a way to examine the effects of including belowground carbon pool of different land uses within an opportunity cost analysis. Belowground emissions or sinks, which typically occur at a slower rate, can be substantial, especially in peatlands.

Analysis results

24. The *Output summary* screen presents results from the opportunity cost analysis. The program calculates carbon emissions, sequestration and eligible emission (according to the REDD policy selected). The six summary results include: *Average Emission* per hectare per year (Mg CO_2e/ha/year), *Total emission* per year (Mg CO_2e/ha/year), *Average sequestration* per hectare per year (Mg CO_2e/ha/year), *Total sequestration* per year (Mg CO_2e/year), *Average Eligible Emission* per hectare per year (Mg CO_2e/ha/year) and *Total Eligible Emission* per year (Mg CO_2/year).

25. In addition, it is possible to examine the effect of a cost threshold, which can represent a carbon price, to identify which emission abatement options have a lower opportunity cost. The threshold can be changed by altering the value in the box or dragging the corresponding line in the graph. The analysis also generates a summary measure of *Net Emission by Threshold*, which is the cumulative level of abatements and sequestrations that have opportunity costs less than the cost thresholds. By clicking the **Detail**, the associated NPV and Emission for each of the contributing land use change options are displayed. (represented by the vertical axis labeled: Changes in NPV/C-stock (\$/Mg CO_2)). Bars to the

left and below the dotted lines have opportunity costs of emissions abatement that are lower than the stated threshold.

26. The **Chart** tab in the *Output Summary* screen displays an opportunity cost curve. All the land uses changes in each of the sub-national zones are represented. The different colors of the bars identify the zones, while the specific land use changes can be highlighted with the cursor. Three different charts can be generated: *Emission*, *Sequestration*, *Mixed* [Both]. For any of the charts, labels that correspond to each bar can be temporarily highlighted by moving the cursor over the bar, or be added to the chart by right clicking on the desired bar and clicking *Add Label* in the dialogue box.

27. In Figure 11.11, a cost threshold value of $5 corresponds to an emission level of 47.59 Mg CO_2e/ha/year. Most of the land use changes have opportunity costs lower than the threshold level. For example, the land use change of Undisturbed mangrove to Log over mangrove has an opportunity cost of -$0.9 and contributes approximately 11 Mg CO_2e/ha to the (total) emission level. (Note: some of the land use options may not be readily apparent in the graph. This could be a result from either:

a) the opportunity cost is close to or equal to zero. In such a case, the height of the bar is the same as the horizontal axis.
b) the amount of emission reduction is relatively small. Therefore, the width of the bar is very narrow with only the gray color of the borders showing.

Enlarging the graph can help reveal the less visible land use change emissions.

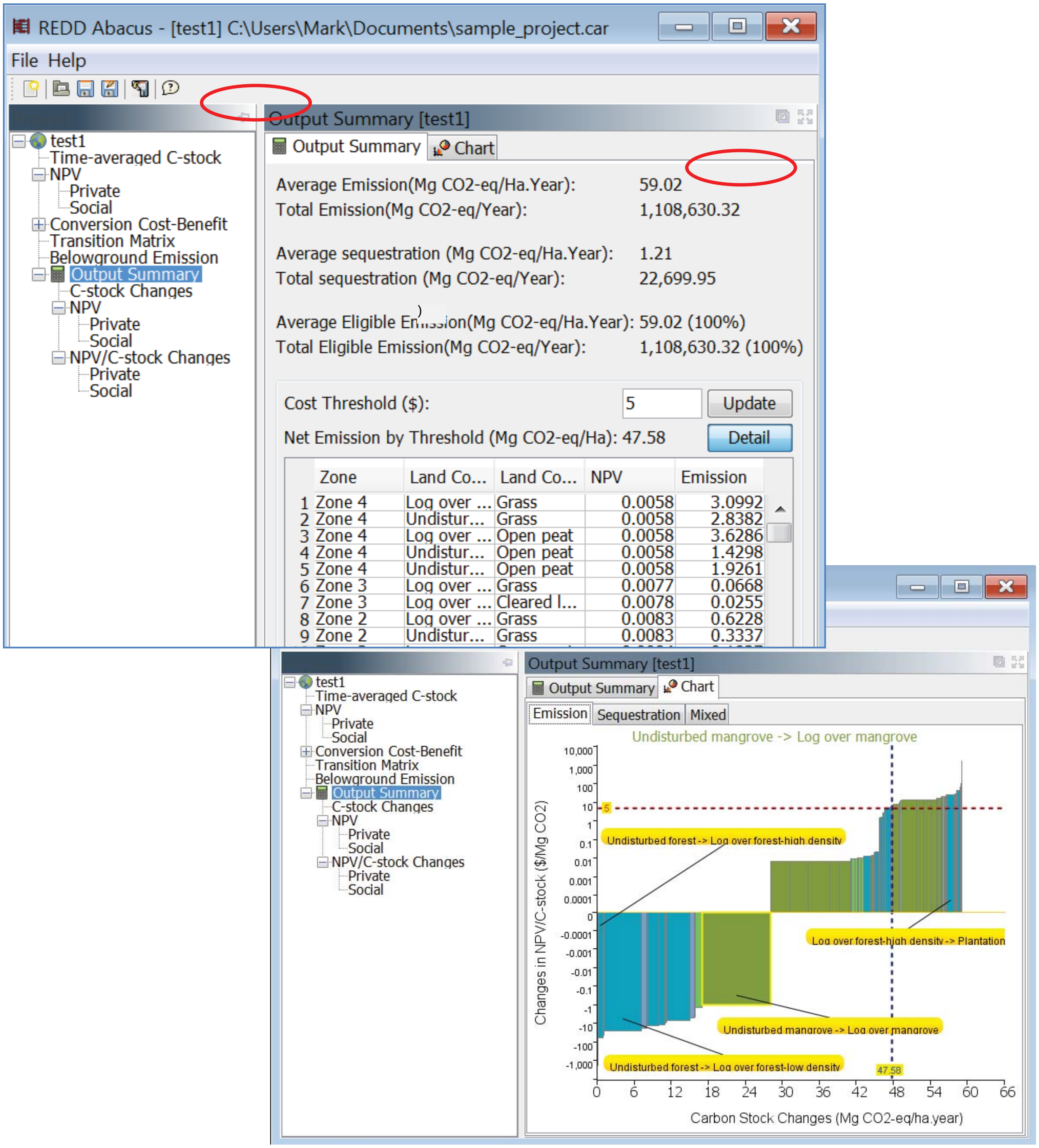


Figure 11.11. Output Summary and associated Chart from REDD Abacus example

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For specific information on the training manual and workshops, please contact fcpfsecretariat@worldbank.org.

www.worldbank.org/wbi