Australian Government

Australian Centre for International Agricultural Research

Economic potential of land-use change and forestry for carbon sequestration and poverty reduction

ACIAR Technical Reports 68

Economic potential of land-use change and forestry for carbon sequestration and poverty reduction

Oscar Cacho
School of Economics, University of New England, Australia

Robyn Hean
NSW Department of Primary Industries, Australia

Kirsfianti Ginoga
Center for Economic and Social Research in Forestry (CESERF), Indonesia

Russell Wise
School of Economics, University of New England, Australia

Deden Djaenudin, Mega Lugina, Yuliana Wulan, Subarudi
Center for Economic and Social Research in Forestry (CESERF), Indonesia

Betha Lusiana, Meine van Noordwijk, Ni'matul Khasanah
The World Agroforestry Center (ICRAF), Indonesia

Australian Centre for International Agricultural Research
Canberra
2008

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and developing country researchers in fields where Australia has a special research competence.

Where trade names are used this constitutes neither endorsement of nor discrimination against any product by the Centre.

ACIAR TECHNICAL REPORTS SERIES

This series of publications contains technical information resulting from ACIAR-supported programs, projects and workshops (for which proceedings are not published), reports on Centre-supported fact-finding studies, or reports on other topics resulting from ACIAR activities. Publications in the series are distributed internationally to selected individuals and scientific institutions, and are also available from ACIAR's website at <www.aciar.gov.au>.

Published by the Australian Centre for International Agricultural Research (ACIAR)
GPO Box 1571, Canberra ACT 2601, Australia
Telephone: 61 2 6217 0500
<aciar@aciar.gov.au>

Cacho, O., Hean, R., Ginoga, K., Wise, R., Djaenudin, D., Lugina, M., Wulan, Y., Subarudi, Lusiana, B., van Noordwijk, M. and Khasanah, N. 2008. Economic potential of land-use change and forestry for carbon sequestration and poverty reduction. ACIAR Technical Reports No. 68, 98 pp.

ISBN 978 1 921434 33 4 (print)
ISBN 978 1 921434 34 1(online)

Technical editing and design by Clarus Design Pty Ltd
Printing by Goanna Print Pty Ltd

Foreword

Concerns over global warming have led to the establishment of markets for greenhouse gas emissions, in particular for carbon dioxide (CO_2).

Tree-based systems are a convenient way of reducing net emissions by sequestering CO_2 from the atmosphere, and forest plantations are an element of the carbon-trading schemes currently in existence or under development. Carbon credits do not require transport to markets, and are thus appealing as a commodity for rural smallholders in developing countries. However, as for any other commodity, profitability is related to prices received, costs of production (greenhouse gas abatement), and transaction costs. Production and transaction costs, in particular, remain largely unknown for smallholders in developing countries.

Climate change and greenhouse gas abatement are now the subjects of major international activity. The Australian Government is a major supporter of greenhouse gas abatement, with the 2007 launch of its $200 million Global Initiative on Forests and Climate (GIFC). Targeting Indonesia in particular, the GIFC is designed to facilitate significant and cost-effective reductions in greenhouse gas emissions in developing countries through reductions in deforestation, encouraging reforestation and the promotion of sustainable forest management.

ACIAR has been a pioneer in supporting research in this area. The work reported in this publication focused on several agroforestry systems that have been adopted by smallholders in three regions of Indonesia, and addressed three questions:

- How do smallholders compare with other landholders in terms of efficiency in sequestering carbon?
- How likely is it that smallholders will want to adopt carbon-sequestering activities?
- What sorts of policies and projects will underpin smallholder involvement?

Fundamental to addressing these questions was the estimation of both abatement and transaction costs for smallholder farmers.

It is anticipated that the results of this work will be broadly applicable to smallholder agroforestry in developing countries, and provide vital underpinning for current and future Australian-sponsored work in the region.

Peter Core
Chief Executive Officer
Australian Centre for International Agricultural Research

Contents

Figures and tables

Figures

Tables

Abbreviations

ADB	Asian Development Bank
AIJ	Activities Implemented Jointly [UNFCCC]
AR	afforestation–reforestation
ASB	Alternatives to Slash-and-Burn [program]
CDM	Clean Development Mechanism [of the Kyoto Protocol]
CER(s)	Certified Emission Reduction(s) [of the Kyoto Protocol]
CIFOR	Center for International Forestry Research
CMAI	carbon mean annual increment
CO_2e	carbon dioxide equivalent(s)
DNA	designated national authority
DOE	designated operational entity
ENT	East Nusa Tenggara
EU-ETS	European Union Emissions Trading Scheme
ICRAF	International Center for Research in Agroforestry
IFSP	Indonesia Forest Seed Project
IPB	Institut Pertanian Bogor (Bogor Agricultural University)
IPCC	Intergovernmental Panel on Climate Change
JIFPRO	Japan International Forestry Promotion and Cooperation Center
KomNas MPB	National Commission for CDM (Komisi Nasional Mekanisme Pembangunan Bersih)
LUCF	land-use change and forestry [sector]
NPV	net present value
OECF	Overseas Economic Cooperation Fund
PDD	project design document
PFF	project feasibility frontier
SCUAF	Soil Changes Under Agroforestry [model]
tCO_2e	tonnes of carbon dioxide equivalent(s)
UNFCCC	United Nations Framework Convention on Climate Change
WJ	West Java

Summary

This study was motivated by the possibility that markets for greenhouse gas emissions may benefit smallholders in developing countries, by compensating them for adopting agroforestry systems that capture more carbon dioxide (CO_2) from the atmosphere than traditional cropping systems. The research project (PLIA/2002/066) was based in Indonesia, but the principles identified and the techniques developed have application to other countries and, indeed, to environmental services other than carbon sequestration.

Tree-based systems are a convenient way of reducing net carbon emissions by sequestering CO_2 from the atmosphere. Through the process of photosynthesis, trees absorb CO_2 which remains fixed in wood and other organic matter in forests for long periods. This is important for tropical countries such as Indonesia that have large areas of rainforest as well as deforested, degraded land.

The global-warming problem creates a demand for carbon credits, and tropical countries are in a position to supply these credits while reducing problems of deforestation, land degradation and poverty. Carbon sequestration can be an attractive activity for smallholders in remote areas because the 'product' does not need to be transported and there are no quality differences between carbon molecules; they have the same effect on climate regardless of where they are emitted or absorbed.

Landholders who supply carbon credits will incur different abatement costs (the costs per unit of uncertified emission reductions) and transaction costs (the costs of converting those emission reductions into a tradeable commodity). Obviously, smallholders cannot participate directly in the international carbon market, but they could participate in carbon-sequestration projects designed by intermediaries. A possible obstacle to the participation of smallholders in carbon markets is the need for monitoring, verification and enforcement of project activities, and their associated transaction costs.

The analysis in this report focuses on the Clean Development Mechanism (CDM), Article 12 of the Kyoto Protocol, but the analytical techniques can be applied to the exchange of carbon credits under other schemes, such as the Prototype Carbon Fund of the World Bank. The medium of exchange under the CDM is the Certified Emission Reduction (CER), measured in tonnes of CO_2 equivalents (CO_2e), which takes the global-warming potential of other greenhouse gases into account to provide a standard tradeable unit for the carbon market.

The specific objectives of this research project were:

1. to determine the most appropriate land-use change and forestry systems for capturing carbon-credit payments and assisting in poverty reduction.
2. to determine the effect of mechanisms for translating international exchanges of carbon credits into incentives at the individual producer level.
3. to estimate the transaction costs of actual projects and identify principles of project design to minimise these costs.

To achieve these objectives, data on a number of agroforestry systems in three regions of Indonesia were obtained from different sources, and a series of spreadsheets, designed to undertake economic analysis, was produced. Additional data were gathered by visiting 34 farms and measuring 960 trees representing 40 species grown by smallholders. These data allowed estimation of carbon-sequestration potential and calculation of the abatement costs associated with different agroforestry systems.

Data on transaction costs were collected from the literature and through visits to several reforestation projects where stakeholders were interviewed. Total costs of these projects studied ranged from \$477 per ha to \$2,066 per ha. Depending on the carbon-sequestration potential of these projects, these costs would be equivalent to between \$2.17 and \$18.76 per tonne of CO_2.

This report presents a brief review of carbon markets and describes the process of measuring carbon stocks in forests. The carbon pools that need to be measured and the mathematical formulas used to estimate biomass from measurements of tree diameter and height are explained.

The need to consider both abatement and transaction costs when assessing the viability of smallholders undertaking agroforestry projects in order to supply carbon credits is emphasised. Abatement costs can be estimated as the opportunity cost of undertaking a carbon-sequestration activity rather than the most profitable alternative activity, or as the cost of switching from the previous land use (baseline) to the proposed land use. In order to participate in the carbon market, it is not enough for projects to cover just their abatement costs; they must also meet transaction costs incurred in certifying the abatement services they provide. In this report, transaction costs are classified into five categories: search and negotiation, approval, project management, monitoring, and enforcement and insurance. Such a typology provides the means to identify the circumstances under which projects are feasible. Both abatement and transaction costs are described in detail in this report, the process required to estimate them is illustrated, and the effects on these costs of environmental and social characteristics of a project, as well as the institutional capacity of the host country, are discussed.

A model of project participation is developed. The model considers the necessary conditions for a buyer (project developer) and a group of sellers (farmers) to engage in a carbon-sequestration contract. Based on this model, a project feasibility frontier (PFF) is derived that defines the minimum feasible project size for any given CER price. The shifts in the PFF caused by changes in the transaction costs and the carbon-sequestration potential per unit area of project are assessed.

Three important project-design variables were identified: the farm price of carbon, the number of participating farmers, and the area of their farms. These variables are under the control of the project developer, subject to constraints imposed by international carbon prices and the availability in an area of enough farmers able and willing to change land use from the baseline to the project activity. Economies of scale were shown to be an important factor, with costs per tonne of carbon sequestered dropping considerably as the area covered by the project increased. The model was then extended to analyse farm heterogeneity and derive carbon supply curves based on the data collected.

The PFF was found to be a useful tool for project evaluation and to perform sensitivity analysis. Project viability is highly sensitive, not only to transaction costs and carbon-sequestration potential, but also to the size of participating farms. Project viability is particularly hampered when participating farms are smaller than one hectare.

Results indicated that a project involving smallholders with individual contracts required CER prices ranging between \$12 and \$18 per tonne of CO_2e (tCO_2e) to cover abatement and transaction costs. These prices exceed the average market price experienced in 2005 (\$7.22 per tCO_2e). Although recent prices have been higher (\$11.45/tCO_2e), there is no certainty that they will remain high in the future.

Model results indicated that project viability can be increased significantly by contracting with communities or farmer groups instead of individuals. For example, when the participating farms have an average area of 2 ha, a project sequestering 300,000 tonnes of CO_2 over 25 years would require a CER price of \$18/tCO_2e to become feasible. In contrast, when contracts are based on farms with an average area of 20 ha, the project would be feasible at a CER price of \$10/tCO_2e. This means that if smallholders pooled their land they would be more competitive in the carbon market.

It was also found that project viability is significantly enhanced by selecting fast-growing tree species. A one per cent increase in carbon captured was found to decrease the minimum size required for a viable project by three per cent or more. Similarly, a one per cent decrease in transaction costs was found to decrease the minimum size required for a viable project by three per cent or more.

Based on the evidence gathered and the modelling undertaken, it was concluded that some smallholder systems are competitive in terms of abatement costs relative to other activities; and that some smallholders view agroforestry as a desirable activity and have adopted it even in the absence of incentives. A carbon-sequestration project could therefore serve to stimulate adoption by those smallholders who may need only a small incentive to switch land use.

We discuss the following strategies that could help reduce transaction costs:

- generation and dissemination of information on carbon stocks, baselines and potential carbon sequestration by different tree-based systems
- training smallholders to measure carbon
- selecting cohesive communities and encouraging community self-regulation to meet project commitments
- bundling projects and payment schemes

- granting land tenure to smallholders who restore degraded land
- stimulating the creation of outgrower schemes.

We conclude that suitable policies coupled with projects that target land of low opportunity cost may produce the incentives required to enhance the adoption of agroforestry systems while contributing to greenhouse gas abatement. The most desirable policies would be those that reduce transaction costs while ensuring that carbon changes are real, directly attributable to a given project and additional to any changes that would have occurred in the absence of the project.

Acknowledgments

The research that is the subject of this report was funded over 5 years as two consecutive ACIAR projects (ASEM/1999/093 and ASEM/2002/066, later renamed PLIA/2002/066). The authors express their gratitude to Suseno Budidarsono (ICRAF) and to Hendri (IPB) for sharing data on the agroforestry systems of Sumatra. We are also grateful to members of the Indonesian reforestation projects studied (JIFPRO, OECF and IFSP), Indonesian Government officials and farmers who shared their time and knowledge.

1. Introduction

Concerns over global warming have led to the establishment of markets for greenhouse gas emissions. Although there are several important greenhouse gases, the most common in the atmosphere, and the main gas emitted by burning fossil fuels, is carbon dioxide (CO_2). Emission reductions are measured in CO_2 equivalents (CO_2e) and the market in which they are traded is referred to as the 'carbon market'. Other greenhouse gases (such a methane and nitrous oxide) are also traded in the carbon market after conversion into CO_2e based on their global-warming potential. Carbon trading has grown significantly since the Kyoto Protocol was ratified, reaching a value of $10 billion in 2005 (Capoor and Ambrosi 2006). These trades have not occurred in a single market, as several markets have developed around the world, with the largest currently being the European Union Emissions Trading Scheme (EU-ETS).

Article 12 of the Kyoto Protocol, the Clean Development Mechanism (CDM), has the purpose of assisting developing countries to achieve sustainable development while contributing to meet the emission-reduction commitments agreed upon by Annex I countries.[1] The medium of exchange under Article 12 is the CER (Certified Emission Reduction), measured in tonnes of CO_2e. Although this report uses the CDM as the framework for analysis, it is important to point out that the principles and methods developed here would also apply to the exchange of carbon credits under other project-based schemes, such as the Prototype Carbon Fund of the World Bank. We will refer interchangeably to carbon credits and CERs. A CER is a measure of the amount of CO_2 kept from the atmosphere either by avoiding an emission or creating a sink.

Tree-based systems are a convenient way of reducing net emissions by sequestering CO_2 from the atmosphere. Through the process of photosynthesis trees absorb CO_2 which remains fixed in wood and other organic matter in forests for long periods. This is important for tropical countries such as Indonesia which has large areas of rainforest as well as deforested, degraded land. The conceptual framework of this study is presented in Figure 1. On the left-hand side is the global warming problem that creates a demand for CERs; on the right-hand side are tropical countries, which tend to have problems with deforestation, land degradation and poverty, and which can supply CERs.

The demand for CERs will be met mostly by the energy sector, through clean technologies. However, biological mitigation through afforestation and reforestation (AR) projects may also have an important role to play. These projects in tropical countries can be roughly split into industrial plantations and projects involving smallholders. Smallholder projects consist of activities undertaken by farmers who manage small land areas and whose production system may be a mix of subsistence and marketable crops. Industrial plantations generally consist of monocultures of commercial trees for timber, pulp or fruit production. These systems are common in government-owned land and operate through concessions.

Mitigation projects differ in terms of both cost per unit of carbon emissions avoided or carbon sequestered and other environmental and social benefits provided. For example, a complex agroforest may represent an efficient use of family labour, provide sustenance and contain higher bio-diversity than a monoculture of *Acacia mangium* or other fast-growing tree species. A large-scale monoculture plantation, on the other hand, may accumulate more carbon and provide employment, but it may provide little biodiversity and social benefits besides employment. These issues will need to be considered by host countries when designing policies to encourage the adoption of carbon-sequestration projects that also provide environmental and social benefits.

The three sources of supply of CERs illustrated in Figure 1 will exhibit different abatement costs (the costs per unit of emission reductions) and transaction

[1] Annex I countries include the Organisation for Economic Co-operation and Development (OECD) countries (except Mexico and Turkey) and transition economies in eastern Europe.

costs (the costs of converting those emission reductions into a tradeable commodity). In this report we describe both types of costs in detail, illustrate the process required to estimate them, and discuss how these costs are affected by environmental and social characteristics of the project and the institutional capacity of the host country.

In Chapter 2 the process of global warming is explained briefly and an overview of current international policies is presented. The concepts of additionality, baselines, permanence and leakage that arise in CDM projects are explained, and their consequences briefly discussed. The chapter concludes with a description of the Indonesian institutions that are involved in the implementation of the CDM at national and regional levels.

In Chapter 3 the carbon market is described, the potential contribution of biomass accumulation in forests to climate-change mitigation is discussed and the role that smallholders may play in this effort is considered. It is argued that carbon sequestration can be an attractive activity for smallholders in remote areas because the 'product' does not need to be transported and because there are no quality differences between carbon molecules; they have the same effect on climate regardless of where they are emitted or absorbed. Three questions are raised to set the stage for the rest of the report. First, will smallholders be competitive in terms of efficiency in sequestering carbon? Second, will smallholders want to adopt carbon sequestering activities? Third, how should projects be designed and what institutions are required to make adoption more likely?

In Chapter 4 the process of measuring carbon stocks in forests is described. The focus is on technical aspects. The chapter presents a description of the carbon pools that need to be measured and the mathematical formulas used to estimate biomass from measurements of tree diameter and height. The chapter concludes with a computer modelling example.

In Chapter 5 a model of project participation is developed. The model considers the necessary conditions for a buyer (project developer) and a group of sellers (farmers) to engage in a carbon-sequestration contract. Implementation of the model requires information on the abatement costs and transaction costs experienced by both buyer and sellers. These costs are associated with switching land use to an agroforestry system and converting the additional carbon sequestered into a marketable commodity. A classification of transaction costs in the context of a CDM project is presented, followed by a summary of published estimates of these costs. It is shown that a considerable proportion is fixed costs, but variable costs can also be significant, particularly for monitoring a large number of participants.

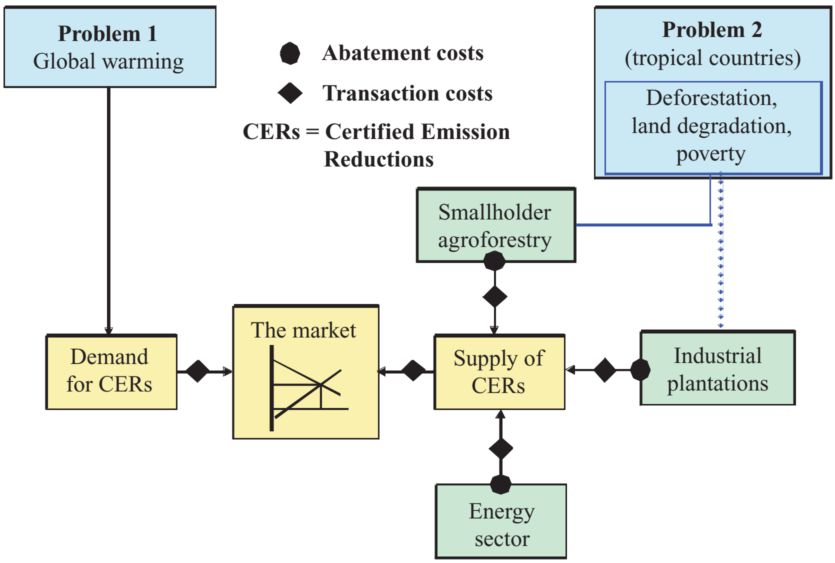


Figure 1. Conceptual framework for the study

In Chapter 6 the model is calibrated based on information presented in the appendixes and an analysis of project design is performed. Three critical project-design variables are identified: the farm price of carbon, the number of participating farmers, and the size of participating farms. Ranges of values of these variables that make a project feasible are identified for given (exogenous) market prices and discount rates. A project feasibility frontier (PFF) is derived that defines the minimum feasible project size for any given CER price. The chapter concludes by identifying the shifts in the PFF as the transaction costs and the carbon-sequestration potential per unit area of project change.

In Chapter 7 we introduce farm heterogeneity into the model and derive supply curves for West Java and East Nusa Tenggara, based on data reported in Appendix 1. We apply the project-feasibility model to the results and note that, when a project developer faces an upward sloping supply curve rather than the flat curve assumed earlier, the feasible range of project sizes may have two bounds. The lower bound is imposed by the need to cover fixed transaction costs, whereas the upper bound is caused by increasing marginal cost of carbon sequestration by farmers. This chapter concludes with some ideas on project design that can help reduce transaction costs.

Chapter 8 presents a summary and conclusions.

Two appendixes present detailed information that was collected for Indonesia. In Appendix 1 several agroforestry systems are described. The systems studied are located in three regions: southern Sumatra, West Java and East Nusa Tenggara. The first two regions represent humid, productive areas in the western part of Indonesia. The third region represents the dry, poor areas of eastern Indonesia. The various agroforestry systems are evaluated in terms of their economic performance, carbon-sequestration potential and labour requirements. This appendix also presents a brief analysis of data collected from visiting 34 farms and measuring 960 trees representing 40 species grown by smallholders. The information presented in this appendix allows us to estimate the abatement costs associated with different agroforestry systems.

In Appendix 2 we turn our attention from farmers to reforestation projects. Our purpose in collecting these data was to obtain information on the transaction costs experienced by projects involving smallholders in Indonesia. We visited four projects and interviewed many people, including project developers, government officials and farmers. The projects visited are described and the actual costs of project design and implementation are presented where available. The appendix concludes with an analysis of five Latin American projects. These projects provide useful additional information because they were primarily designed as carbon-sequestration projects under the Activities Implemented Jointly (AIJ) of the United Nations Framework Convention on Climate Change (UNFCCC).

Throughout the report the convention is to express monetary values in US dollars ($) or Indonesian Rupiah (Rp), because international carbon exchanges generally are quoted in the former currency and the latter is the currency used by the smallholders studied. In the few cases where Australian dollars are used they are expressed as A$. An exchange rate of Rp8,700 per US dollar is used throughout the report.

2. The greenhouse effect and global warming policy

The greenhouse effect

The greenhouse effect is a naturally occurring process whereby gases such as carbon dioxide (CO_2) that prevent infra-red radiation from escaping the earth's atmosphere cause global temperatures to rise. Over the past 150 years, this process has been exacerbated by increasing quantities of greenhouse gas emissions into the atmosphere, largely caused by burning fossil fuels. The greenhouse effect is expected to result in global climate change that, in turn, will lead to sometimes severe socioeconomic and environmental consequences (McCarthy et al. 2001).

CO_2 is cycled through four main global carbon stocks: the atmosphere, the oceans, fossil fuels, and terrestrial biomass and soils (Figure 2). According to Watson et al. (2000, p. 30), over the period 1989–1998, activities in the energy and building sectors increased atmospheric carbon levels by 6.3 gigatonnes of carbon per year[2] (Gt C/year). Land-use change and forestry (LUCF) activities released 60 Gt C/year into the atmosphere and absorbed 60.7 Gt C/year, with a net effect of decreasing atmospheric carbon levels by 0.7 Gt C/year. Oceans removed about 2.3 Gt C/year from the atmosphere. The net result of these fluxes over the last 10–15 years is that atmospheric carbon levels have increased by about 3.3 Gt C/year.

Although the main contributor to mitigation of global warming will have to be the energy sector (represented by reducing the size of C_E in Figure 2), the focus of this report is on the flow between terrestrial ecosystems and the atmosphere. The rate C_{LA} (Figure 2) includes emissions caused by respiration and deforestation, whereas C_{AL} includes carbon sequestered by afforestation and reforestation projects. Mitigation can be achieved by the land-use change and forestry (LUCF) sector by decreasing C_{LA}, increasing C_{AL}, or both. The balance of these exchanges is referred to as *biological mitigation*.

[2] A gigatonne is 10^9 tonnes.

Biomass accumulation as a carbon sink

Biological mitigation can occur through three strategies: (i) conservation of existing carbon pools; (ii) sequestration by increasing the size of existing pools; and (iii) substitution of sustainably produced biological products, such as using biomass to replace energy production from fossil fuels. Options (i) and (ii) result in higher terrestrial carbon stocks but can lead to higher CO_2 emissions in the future (e.g. through fires or land clearing for agriculture), whereas (iii) can continue indefinitely (IPCC 2001).

The global potential of biological mitigation has been estimated at 100 gigatonnes of carbon (cumulative) by 2050, equivalent to about 10–20% of projected fossil-fuel emissions during that period (IPCC 2001). The large opportunities for biological mitigation in tropical countries cannot be considered in isolation from broader policies in forestry, agriculture and other sectors. Barriers to reaching the potential level of mitigation include: (i) lack of funding and human and institutional capacity to monitor and verify mitigation outcomes; (ii) food supply requirements; (iii) people living off the natural forests; (iv) existing incentives for land clearing; (v) population pressure; and (vi) switch from forests to pastures because of demand for meat (IPCC 2001).

Much of the land in the tropics is managed by semi-subsistence farmers and shifting cultivators, so their degree of willingness to participate in biological mitigation is a factor that must be considered (de Jong et al. 2000). The CDM requires sustainable development goals to be met as well as sequestration goals. This means that smallholders have the potential to be an important group contributing to climate mitigation. However, the rules state that projects must be in line with the sustainable development criteria set by the host country. This means that large plantations will qualify for CDM if their employment benefits meet the host country's sustainable-development objectives.

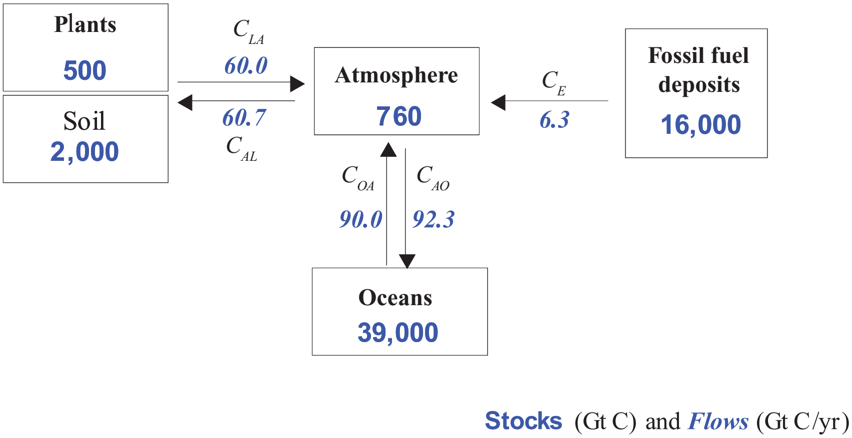


Figure 2. The global carbon cycle; based on Watson et al. (2000)

A potential role for smallholders in tropical countries

Selling carbon-sequestration services has the advantage that the output does not need to be transported. Another attractive feature of carbon is that there are no quality differences from place to place; a molecule of carbon extracted from the atmosphere has the same effect no matter where it resides. So the problems often faced by smallholders in not being able to achieve the quality required by international markets [see, for example, Glover and Kusterer (1990)] or not being able to obtain transportation for their perishable goods does not apply in carbon markets.

Deforestation is a major cause of land degradation, and population pressure is one of the major causes of deforestation. Forest conversion for farming by shifting cultivators and migrants, as well as the establishment of large plantations for timber and tree crops, are common in Indonesia. Suyanto et al. (2001, p. 103) state that 'as population pressure increases, the comparative advantage of agroforestry[3] over shifting cultivation tends to increase'. The establishment of agroforestry requires significant investment in terms of labour and capital. Hence, compared to slash-and-burn systems, agroforestry has the potential of increasing employment opportunities (Suyanto et al. 2001; Otsuka and Place 2001b), while also contributing to sustainable land management. However, there are obstacles to adoption of agroforestry, mostly in the form of lack of credit and technical skills, but also in terms of limited farm-family labour availability.

In order to determine whether it is realistic to expect smallholders to contribute to climate mitigation and benefit from it, three questions must be answered: (i) how do smallholders compare with other landholders in terms of efficiency in sequestering carbon? (ii) how likely is it that smallholders will want to adopt carbon sequestering activities? (iii) what sorts of policies and projects will make this more likely? The answers to these questions depend partly on biophysical characteristics of specific sites and partly on socioeconomic characteristics, as well as the institutional environment provided by national and local governments.

The first question refers to the need to determine whether it is likely that smallholders will be efficient providers of sequestration services in terms of abatement costs. Factors such as current land uses, agroclimatic zone, technology utilised and human-capital availability will determine this. The second question refers to incentives. If landholders perceive agroforestry satisfies their goals better than their current land-use practices, and if they believe that it does not introduce unacceptable risks, they are likely to adopt it. The third question is related to a number of policy issues such as land-tenure security, the costs of participating in the carbon market, the level of technical

[3] Agroforestry refers to land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land-management unit (ICRAF).

expertise required, and the availability of training and finance.

In Appendix 1 we describe and evaluate several agroforestry systems for three regions of Indonesia. This analysis provides the tools required to estimate the abatement costs of carbon sequestration through various agroforestry systems. We also describe, in Appendix 2, several reforestation projects to assess the types of expenses involved and to learn from past experiences. In Chapter 5 we will develop a model of project participation that includes abatement costs, transaction costs and carbon payments. We will then be in a position to answer the three questions posed above for selected Indonesian case studies by undertaking numerical analysis of various scenarios.

The Kyoto Protocol and the Clean Development Mechanism

The Kyoto Protocol has provided the context within which much of the policy debate on global warming occurs. The withdrawal of the United States (US) from the Kyoto Protocol represents a temporary setback. Agreement on the protocol has been reached by a number of countries without US participation. An important question is whether the US will eventually join under the Kyoto Protocol or whether a new climate-change treaty will emerge to which the US agrees. Considerable scientific contributions have been made to the United Nations Framework Convention on Climate Change (UNFCCC) over the past decade, particularly through the Intergovernmental Panel on Climate Change (IPCC), which has produced a number of technical reports. Many of these contributions will influence the shape of the agreement that may eventually be reached to replace the Kyoto Protocol. The Kyoto Protocol contains two articles of special relevance to this paper (Kyoto Protocol 1997):

Article 6, Joint Implementation (JI)**,** states that 'any Party included in Annex I[4] may transfer to, or acquire from, any other such party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy', subject to certain provisos. The proposed medium of exchange under this Article is the ERU (Emission Reduction Unit).

Article 12, The Clean Development Mechanism (CDM), has the purpose of assisting 'Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments ...'. The proposed medium of exchange under this Article is the CERs (Certified Emission Reductions).

In order to receive certification and enter the CER market, a project will have to incur various transaction costs in showing that it is reducing net emissions compared with its absence. In other words, emission reductions must be additional to a business-as-usual scenario. This means that the project proponents will have to estimate a baseline and demonstrate 'additionality'. Also, the project will have to account for possible 'leakage' and the problem of 'permanence'. The impacts of projects on carbon sequestration will also have to be monitored. These various aspects of accounting for carbon sequestration are briefly explained below. The UNFCCC provides a number of useful documents detailing methodologies and procedures for CDM afforestation and reforestation projects.[5]

Additionality

Under the Kyoto Protocol, projects that qualify for credits have to satisfy the *additionality* requirement that 'reductions in emissions must be additional to any that would occur in the absence of the project'. This means that 'sequestration projects, such as reforestation, qualify only if the project is not financially viable without CDM, or if CDM funding is required to overcome other barriers to implementation' (Smith et al. 2000).

Additionality can be established by showing that reforestation would be less profitable than the land-use systems it replaces, or by showing there are barriers to tree establishment. Adoption may be limited by lack of finance for establishment costs, access to planting materials, or lack of technical assistance and marketing infrastructure (Smith and Scherr 2002). Additionality could also be expressed in terms of

4 Annex I countries include the Organisation for Economic Co-operation and Development (OECD) countries (except Mexico and Turkey) and transition economies in Eastern Europe.

5 <http://cdm.unfccc.int/methodologies/ARmethodologies/index.html>

higher risk than a conventional investment (Moura Costa et al. 2000).

In order to establish additionality, it is necessary to establish a baseline. Only those emission offsets above the baseline will be eligible in the CER market.

Baselines

The baseline over the period of a proposed project could be static, if the project replaces a stable system such as a pasture, or dynamic, when expected trends in deforestation and land-use changes must be accounted for. In general, baselines should be easier to establish for reforestation and afforestation projects on degraded land, as opposed to forest protection projects that require assumptions about future rates of deforestation in the absence of the project. The baseline is an important area of uncertainty and may need to be revised as the project progresses.

Establishing baselines will require information such as identification of pressures on the land and its resources, history of land use in the project area, soil types and topography, and socioeconomic activities (Brown 2001) as well as the likely evolution of these factors through time. Possible approaches to baseline estimation range from a case-by-case basis to a generic estimate based on sectoral and regional characteristics (Moura Costa et al. 2000).

One way of estimating a baseline was illustrated by de Jong et al. (2000) who used a series of land-cover maps of Mexican forests and estimated historical rates of carbon storage depletion. On the basis of these historical rates, they projected trends of carbon losses 50 years into the future. Another strategy has been followed by the Forests Absorbing Carbon Dioxide Emission (FACE) Foundation, which uses a monitoring and information system (MONIS) to estimate the amount of carbon sequestered. The system stores graphical site information as well as administrative, financial and technical information. The CO2FIX model is used for establishing baseline and project scenarios. The project partners collaborate with national and international research institutes to acquire the measurements needed (FACE 2001). Appendix 1 gives further details.

Permanence

The problem of permanence arises because LUCF projects tend to be temporary, since CO_2 captured during forest growth is released upon harvest. In contrast, projects in the energy sector that reduce emissions are permanent, in the sense that an avoided emission will never reach the atmosphere. Smith et al. (2000) state ‘non-permanent forestry projects slow down the build up of atmospheric concentrations, unlike energy projects, which actually reduce emissions. Non-permanent forestry projects should therefore be regarded as an intermediate policy option’. Grainger (1997) points out that biological mitigation can sequester large amounts of carbon over a much shorter timescale than is required for energy consumption patterns to change.

The problem of permanence must be solved before LUCF projects are acceptable in a CER market. Proponents of LUCF projects point to several advantages of temporary sequestration, such as: (i) some proportion of temporary sequestration may prove permanent; (ii) deferring climate change has benefits; (iii) temporary sequestration ‘buys time’ while affordable energy technologies are developed; and (iv) temporary sequestration projects have value in saving time to gain information on the process of global warming (Lecocq and Chomitz 2001). Cacho et al. (2003a) explored the issue of permanence and incentives under different accounting methods and found that some of the proposed approaches offer very little incentive to sequester carbon beyond that provided by the timber market.

Many authors believe that permanence is not an insurmountable problem [see, for example, Sedjo (2001) and Sedjo and Toman (2001)]. Sedjo (2001, p. 17) argues that ‘carbon sequestration should be viewed more as a temporary activity like the parking of a car than a long-term activity like the purchase of a parking space’. He advocates the development of rental markets for carbon. This and similar ideas, such as the Colombian proposal for ‘expiring CERs’ (Blanco and Forner 2000) may provide feasible alternatives, but they require further economic analysis to determine if they will provide incentives adequate to effect desired behavioural change.

An important question concerns whether smallholders are more likely to have incentives for liquidating sequestered carbon earlier than other participants. It is reasonable to expect that smallholders are likely to default if they face population pressure and limited food supply, leading to land clearing for agriculture. This is related to the issue of leakage and the need to increase agricultural-land productivity (see below). In general, we may expect that land under stable community management will be subject to longer planning horizons than private land not subject to such management, and therefore to have advantages in terms of permanence, provided a clear stream of benefits is obtained by the community. This issue is discussed in more detail later.

Leakage

Leakage occurs 'when the emission reduction achieved within the project causes increased emissions outside the project boundary, or at a later period of time. Leakage could occur for example if local communities agree to preserve a forested area, with the intention of increasing deforestation in other areas, as compensation' (Smith et al. 2000). Leakage may work through the price system, as reduced wood supply may lead to price increases and hence provide incentives to increase forest clearing elsewhere. Leakage is not unique to LUCF projects. It can arise in the energy sector as well.

According to IPCC (2001), leakage of 5–20% may occur through relocation of carbon-intensive industries from Annex 1 to non-Annex 1 countries. Almost all tropical forests have people living in or around them, so failure to compensate communities for forest protection projects can lead to leakage. To prevent leakage in LUCF reforestation projects, productivity of agricultural land will have to be increased (Smith and Scherr 2002) to ensure that food supply is not reduced. It may also be necessary to promote labour-using technologies (such as agroforestry) to provide employment for those displaced from forests.

Ideally, project leakage could be accounted for by country-wide baselines, but a second-best alternative may be to have 'rules of thumb' for rough corrections in the amount of CERs obtained depending on type of project and location (Sedjo and Toman 2001).

Indonesian institutions

In order to participate in CDM projects, a country must create a designated national authority (DNA). The role of the DNA is to receive the project design document (PDD) from the project developer, ensure that it complies with national and international rules, and issue approval of the PDD to the CDM Executive Board (Winrock/IPB 2005). In August 2005 the Government of Indonesia created the National Commission for CDM (KomNas MPB) to serve as the country's DNA.

KomNas MPB is responsible for all CDM activities in Indonesia, including inter-organisational collaboration. It has a National Executive Board (NEB) with members from the ministries of Environment, Energy and Mineral Resources, Forestry, Industry, Foreign Affairs, Home Affairs, Transportation, Agriculture, and Development Planning (Bappenas). The head of the board is the Secretary of the Ministry of Environment (MOE). This inter-agency structure is intended to make available a wide range of expertise and encourage cooperation between the agencies involved.

The NEB is responsible for: (i) conducting the initial review and final approval of all CDM proposals; (ii) acting as the focal point in the MOE for all matters related to climate change and the UNFCCC; (iii) acting as liaison on national climate change issues with the UNFCCC; and (iv) setting policy and guidelines for implementation.

In performing its task, the NEB is assisted by a secretariat, a permanent technical team (PTT) and a non-permanent technical team (NPTT). The secretariat (hosted at the MOE) functions as a clearing house for CDM proposals; their specific responsibility is to receive PDDs and all related correspondence. The PTT consists of technical experts from the KomNas MPB member agencies plus one representative of non-government organisations (NGOs) concerned with climate-change issues. The World Wide Fund for Nature (WWF) is the current NGO representative in the PTT. The NPTT provides KomNas MPB with the option of recruiting outside experts to assist with the evaluation of proposals that require special knowledge.

The PTT is responsible for: (i) evaluating the technical aspects of project proposals within the framework of sustainable development and, when necessary, conducting public meetings to gain additional inputs; (ii) reporting the evaluation results and providing technical recommendations to KomNas MPB; and (iii) providing advice to KomNas MPB to assist in promoting implementation of the CDM in Indonesia. The process of approval for afforestation–reforestation (AR) CDM projects is represented in Figure 3. Either the NEB or the PTT may request the input of outside technical experts. In addition, the PTT may call a one-day meeting with project stakeholders if the information provided in the PDD is not sufficiently clear. After the review, the PTT provides a technical report on each PDD to the NEB through the secretariat. Based on the technical report, the NEB approves the PDD or requests revision. The project proponent has 3 months to resubmit the revised PDD. The complete PDD evaluation process, from the first meeting of the NEB to approval or request for revision, is expected to require no more than 1 month.

Currently in Indonesia there are many research institutions, universities, policymakers, practitioners, potential project developers and NGOs involved in trying to make AR CDM projects a reality. A consensus is emerging that certain LUCF activities offer win–win opportunities from the points of view of climate change and sustainable development. Properly designed AR CDM projects can conserve and increase carbon stocks while improving rural livelihoods. The relevant question then is whether Indonesia has the right institutions to enable such projects to be implemented and whether the associated transaction costs are low enough to make them economically feasible.

Table 1 presents the CDM project cycle in an Indonesian context. The process starts with the development of a project proposal and a PDD. Based on Ministry of Forestry Decree No. P. 14/Menhut-II/2004, the proponents can be individual farmers, private-sector entities, national or regional state corporations, or cooperatives.

The format of the PDD is as follows:

1. General description of project activity
2. Project baseline and additionality report
3. Project monitoring plan
4. Environmental impacts of the project and socioeconomic benefits
5. Stakeholder comments
6. Other documents relevant to the project.

A precondition for developing a PDD is that the proposed area be eligible. A necessary, but not sufficient, condition for land eligibility is that the land was not covered by forest on 31 December 1989. Another condition is that the area be free from land conflicts. This must be certified by a letter from the head of district/subdistrict and accompanied by a map. If the land is categorised as forest land, the project proponent must also obtain either an environmental service permit (Ijin Usaha Pengelolaan Jasa Lingkungan, IUPJL) or a wood forest product permit (Ijin Usaha Pengelolaan Hasil Hutan Kayu, IUPHHK) from the regional forestry office or the Ministry of Forestry.

National approval of the PDD is issued by the DNA (Komnas MPB), but the Ministry of Forestry will also be involved. The process of validation, submission to the CDM Executive Board, verification and certification could be undertaken through a broker that has experience in dealing with international bodies and is familiar with the regulations.

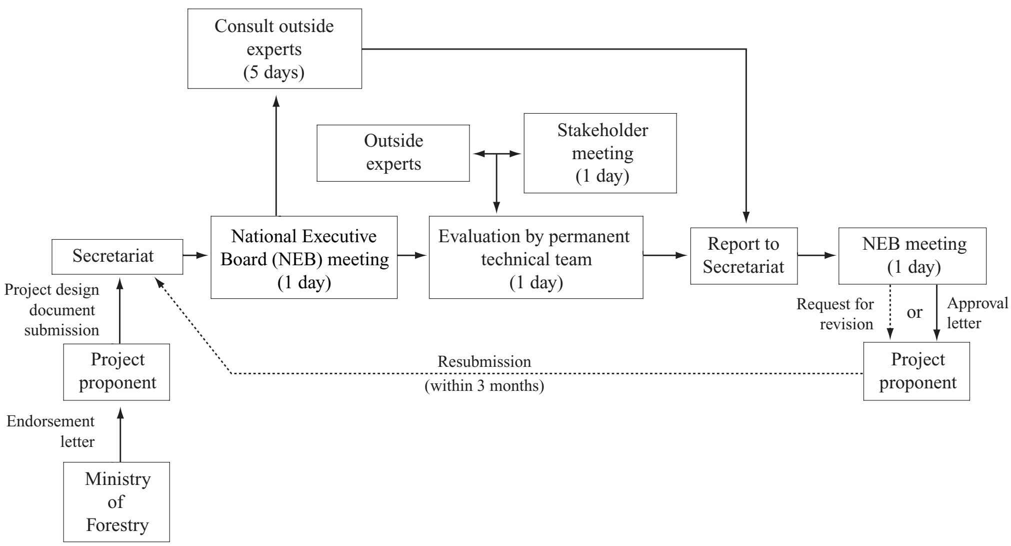


Figure 3. The approval process for afforestation–reforestation Clean Development Mechanism projects in Indonesia; based on Winrock/IPB (2005)

Validation of the PDD must be executed by a designated operational entity (DOE) that has been accredited by the CDM Executive Board. Currently there is no accredited DOE in Indonesia, and the costs validation by an international DOE may be high. This cost will depend partly on access to the project site and partly on the quality of project management. Good project management and documentation will reduce the time required by the DOE in collecting background information for validation. The DOE is also responsible for submitting the PDD to the CDM Executive Board. This step ends the pre-implementation (ex ante) phase of the project.

Once the project has been approved by the CDM Executive Board, it can be implemented. Obtaining funds for implementation and monitoring will require a loan or an agreement with investors, because revenues from the sale of CERs will not occur until much later, when the carbon is sequestered and certified.

The foregoing discussion illustrates that designing and implementing an AR CDM project will require coordination among several organisations at local, regional, national and international levels (see Table 2). This presents a challenge to project developers as well as policymakers.

Table 1. Steps required to implement an afforestation–reforestation Clean Development Mechanism (CDM) project in Indonesia

Steps, actors, organisations	Requirements
1. *Project design document (PDD) development* Project proponent	• Letter of land eligibility for CDM from head of district/ subdistrict with map at1:10,000 scale • Project proposal • Environmental service permit or wood forest-product permit for forest land; or usufruct right for other state land • Land certificate (for private land) or land community right (for community land)
2. *PDD national approval* Project proponent to designated national authority (DNA) with copy to Ministry of Forestry	• PDD in CDM format
3. *Validation of PDD* Designated operational entity (DOE) hired by project proponent	• Letter from Ministry of Forestry stating that the project complies with forestry sustainable development • Approval from DNA stating that the project complies with sustainable development • Availability of funds for validation in the field
4. *Validation report and registration with CDM Executive Board (EB)* DOE to CDM EB	• PDD is valid
5. *Implementation* Project proponent	• PDD has been approved by CDM EB • Funds are available
6. *Monitoring* Project proponent	• Monitoring capacity is available • Funds are available
7. *Verification and certification* DOE to CDM EB	• Monitoring report produced by project proponent • Funds are available
8. *Issuance of Certified Emission Reductions* CDM EB to project proponent	• Carbon sinks are certified • All other requirements are fulfilled

Table 2. Institutions likely to be involved in the development and implementation of an afforestation–reforestation (AR) Clean Development Mechanism (CDM) project in Indonesia

Institution	Location	Role
Project proponent	Local/regional/ national	• Developing project design document
Governor/head of district/ head of subdistrict	Regional	• Issuance of CDM land eligibility certificate
Governor/head of district	Regional	• Issuance of environmental service permit
State Forestry Office	Regional	• CDM land verification and environmental service permit • Wood forest-product permit • Usufruct right and land certificate • Community land certificate
Ministry of Forestry	National	• Check criteria and indicators of environmental service permit • Issuance of wood forest product permit
National Land Agency	Regional	• Issuance of usufruct right and land certificate
Regional Planning Agency (BAPEDA)	Regional	• Monitoring
Regional Environmental Agency (BAPEDALDA)	Regional	• Monitoring
University	Regional	• Technicians and experts in technical and socioeconomic aspects of AR projects

3. The market for emission reductions

The potential supply of emission offsets

The supply of CERs depends on availability and costs of different technologies and resource endowments, and these will be partly determined by location. In Figure 4 the potential supply function in the absence of transaction costs (S_A) represents the marginal abatement costs of providing different cumulative levels of emission reductions through feasible projects in the energy, forestry and agricultural sectors.

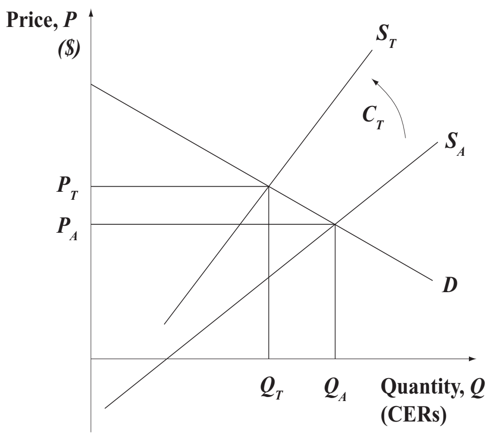


Figure 4. The market for Certified Emission Reductions (CERs) and the role of transaction costs

For a given supply function, as determined by current technology and land availability, the equilibrium levels of quantity and price (Q_A, P_A) depend on the demand function (D). The position and slope of the demand function will depend to a large extent on the success of international mitigation agreements, regulations imposed by individual governments, channelling of overseas development-assistance funds and the extent to which the private sector is required to offset emissions. The curve S_A shows the prices that would be required to motivate different levels of abatement, or mitigation, in a world of zero transaction costs, where supply decisions depend simply on abatement costs.

In order to participate in the market, however, projects will incur transaction costs to certify the abatement services they provide. Transaction costs (C_T) make the supply function shift up and to the left (from S_A to S_T), hence reducing the size of the market (Figure 4). The new equilibrium point (Q_T, P_T) represents a lower quantity of CERs at a higher price than the original equilibrium (Q_A, P_A). If the transaction costs are too high, the market will not develop at all.

If we could reduce transaction costs and move from S_A towards S_P, we could obtain more mitigation services at a lower cost. Transaction costs can be decreased through innovation in institutional design (e.g. through devising standardised contracts and simplified guidelines for verification and reporting, as discussed later in this report). Transaction costs will differ between projects, affecting their market shares and even possibly driving some projects out of the market. This report focuses on the supply side of the market and concentrates on agroforestry projects involving smallholders.

Distribution of market share

The market supply is made up of the summation of individual supply functions. This is illustrated graphically in Figure 5a for a simple market with two suppliers and zero transaction costs. These suppliers are assumed to reside in a small country, so the demand they face is perfectly elastic at a fixed price (P). For the sake of our argument, we assume that s_1 represents the supply of CERs by the smallholder sector and s_2 the supply by the plantation sector. The horizontal summation of s_1 and s_2 results in the potential market supply S_P. This results in an equilibrium quantity $Q_P = q_1 + q_2$, with q_1 CERs supplied by smallholders and q_2 CERs supplied by plantations. Note that the individual supply curves are also the marginal abatement cost curves for each sector, and thus will shift with changes in abatement technologies.

In this example there is scope for both types of projects, smallholders and plantations, to participate in the market, but this analysis accounts for only abatement costs. Now assume that market participation by the smallholder and plantation sectors involves transaction costs that cause the supply functions to shift to st_1 and st_2, respectively (Figure 5b). The new (actual) aggregate supply is S_A and the equilibrium quantity of CERs is $Q_A = qt_2$ (where qt_2 is the supply from the plantation sector), since the smallholder sector has been driven out of the market by high transaction costs. This is an arbitrary example used to illustrate the problems that may be faced by projects involving smallholders. To understand the potential of these projects, however, it is important to review recent development in the carbon market which, not surprisingly, has been dominated by the energy sector.

Overview of the carbon market

The international carbon market has been likened to a currency market, rather than an undifferentiated commodity market, because there are several fragmented markets that coexist and some of them are interconnected (Capoor and Ambrosi 2006). Carbon transactions can be classified into two types: *allowance based* and *project based*. Allowance-based transactions are based on a cap-and-trade mechanism, where emission allowances are allocated by regulators and (mostly power) firms trade these allowances based on their marginal abatement costs. The largest allowance market is the European Union Emission Trading Scheme (EU-ETS). Under project-based transactions, a buyer purchases emission credits from a project that has been independently certified (Capoor and Ambrosi 2006). The largest representative of this type of market is currently the CDM. An important difference between these two markets is that project-based transactions can occur even in the absence of a regulatory regime, the only requirement being that two parties agree on the transaction (Lecocq 2004). A linking directive approved by the European Parliament in 2004 allows participants in the EU-ETS market to use emission-reduction credits from the CDM. Once these credits are delivered, they effectively become allowances. However, as pointed out by Capoor and Ambrosi (2006), while CERs need to be created and certified before they can be delivered, allowances are created when they are issued by regulators. Furthermore, there is a lag between the time a CER contract is signed and the time it delivers emission credits; this, coupled with the fact that project performance is uncertain, means that CERs have certain risks not present in allowance markets. We would therefore expect CER buyers to offer lower prices to compensate for these risks. In the literature it is generally assumed that project-based transactions will exhibit higher transaction costs than allowance transactions and these costs are largely borne by the project developer (Betz 2006).

In 2003 the carbon market was dominated by Kyoto pre-compliance transactions. The main buyers were the government of the Netherlands and the Prototype Carbon Fund of the World Bank and the main suppliers were projects in Latin American countries (Lecocq and Capoor 2003). More recently, Japanese

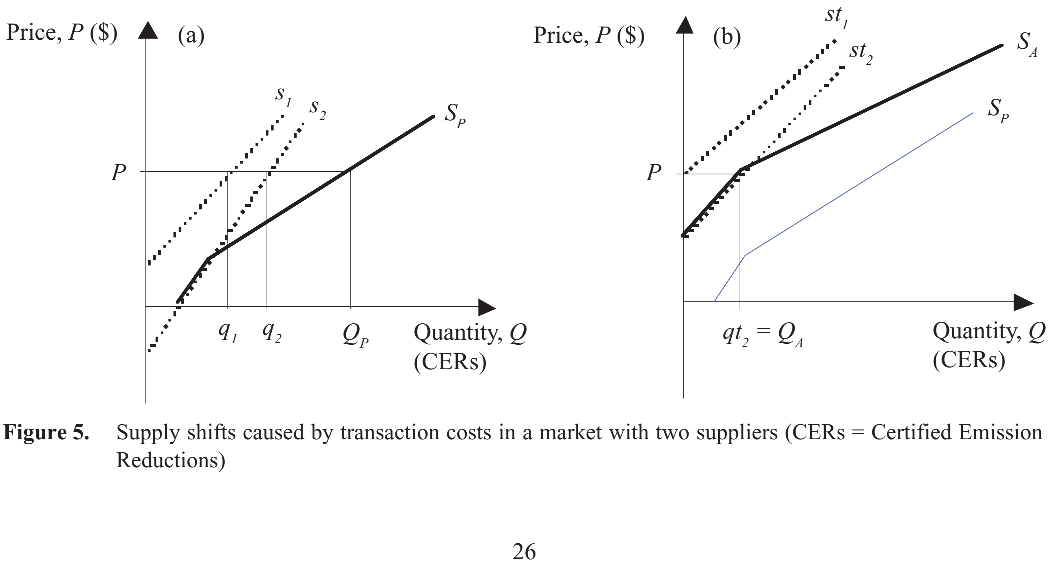


Figure 5. Supply shifts caused by transaction costs in a market with two suppliers (CERs = Certified Emission Reductions)

firms have increased their profile as buyers in the market and Asia has overtaken Latin America as a source of credits (Lecocq 2004; Capoor and Ambrosi 2006). The aggregated value of the international carbon market in 2005 exceeded \$10 billion. Of this, \$8.2 billion comprised European Union Allowances (EUAs) with a volume of 322 million tonnes of CO_2e. Within the CDM, 374 million tonnes of CO_2e were traded, with a value of \$2.7 billion. A rough calculation indicates that the average price of EUAs was considerably higher (\$25.46/tCO_2e) than the average price of CERs (\$7.22/tCO_2e). The current price of CERs is higher than this average according to Capoor and Ambrosi (2006), who report that, in the first 3 months of 2006, project-based transactions reached prices of \$11.45/tCO_2e.

The New South Wales (NSW) Greenhouse Gas Abatement Scheme is small by world standards but represents an important development within Australia. This is an allowance market (established in January 2003) that imposes mandatory emission benchmarks on all NSW electricity retailers and other parties. Participants are required to reduce their emissions to the level of the benchmark. Excess emissions can be offset by surrendering abatement certificates that can be traded. Excess emissions that have not been offset at the end the compliance year attract a penalty (Lecocq 2004). Some 6.1 million certificates were traded in the NSW market in 2005, with an estimated value of \$57.2 million. Recent prices have been between A\$11 and A\$15/tCO_2e (\$8.14–11.10). These prices have exceeded the fine for non-compliance of A\$11/tCO_2e. Explanations for this seemingly irrational behaviour have included corporate image (firms do not want to be perceived as 'dirty') and expectations that fines will increase in the future. The latter explanation is backed by the fact that forward contracts have been trading well above the cost of the fine (Capoor and Ambrosi 2006).

In this report the focus is on project-based transactions in general and the CER market in particular. As of May 2006, 176 projects had been registered with the CDM Executive Board (Table 3), representing 53 million tonnes of CO_2e/year. Of these, 40% were large-scale projects with an average of 638,000 tCO_2e/year, and 44% were small-scale projects with an average of 29,500 tCO_2e/year. In terms of regions, Asia dominated with 69% of emission reductions, followed by Latin America with 30% (Table 4).

Table 4. Summary of Clean Development Mechanism registered projects by region as of May 2006

Region	Certified Emission Reductions per year	
	(tCO_2e/year)	(%)
Asia	36,454,664	68.67
Latin America	16,082,912	30.30
Eastern Europe	182,343	0.34
Other	367,432	0.69
Total	53,087,351	100.00

Source: own calculations based on data available from UNFCCC at <http://cdm.unfccc.int/Projects/registered.html>.

Regarding the share of technologies in CDM projects, destruction of industrial hydrofluorocarbon (HFC) gases amounted to 58% of the volume transacted in 2005. These gases have very high global warming potential and are relatively cheap to destroy per tonne of CO_2e. Biomass, wind, hydro and other renewables accounted for 10% of transactions by volume, and the LUCF sector for only 1%. LUCF assets face two disadvantages. First, they require complex methodologies and only one methodology has been approved by the CDM Executive Board so far. Second, the EU-ETS denies market access to LUCF projects (Capoor and Ambrosi 2006). Thus, the current lack of LUCF projects has been caused by

Table 3. Summary of Clean Development Mechanism registered projects by type as of May 2006

Type	Certified Emission Reductions per year (tCO_2e)		Projects	
	Sum	Mean	Number	(%)
Consolidated	5,474,676	202,766	27	15.34
Large	45,307,446	638,133	71	40.34
Small	2,305,229	29,554	78	44.32
Total	53,087,351	301,633	176	100.00

Source: own calculations based on data available from UNFCCC at <http://cdm.unfccc.int/Projects/registered.html>.

methodological complications (explained in Chapter 3) rather than by any obvious lack of competitiveness of biological mitigation relative to energy efficiency. A few LUCF projects are likely to be submitted once standard methodologies for afforestation/reforestation are approved by the CDM Executive Board, including five candidates that are currently being designed in Indonesia with funding from the Asian Development Bank (see Appendix 2).

4. Accounting for carbon sequestration

Measuring carbon stocks

Carbon sequestered and stored in agroforestry projects needs to be accounted for in a way that ensures the carbon changes are real, directly attributable to the project, and additional to any changes that would have occurred in the absence of the project. The recommended approach to measuring carbon sequestration is to use permanent sampling plots to monitor both the baseline and the project. Well-established statistical techniques can be used to determine the sampling design and intensity required to achieve a given level of precision (McDicken 1997). For large projects, random subsamples of permanent sampling plots can be monitored each year. Larger projects may also benefit from imaging techniques and remote sensing based either on satellites or low-flying aircraft (Brown 2001).

Accounting for carbon in sequestration projects entails measuring four pools (Hamburg 2000):

- above-ground living biomass
- below-ground living biomass
- soil organic and mineral layers
- necromass (dead vegetation).

Not all of these are likely to be acceptable as sources of sequestration in a carbon market, and not all pools need to be measured at the same level of precision or at the same frequency during the life of the project. In the initial inventory, the relevant carbon pools must be measured to establish the baseline, but in subsequent monitoring only selected pools need to be measured, depending on the type of project (Brown 2001). The level of precision to which each pool can be measured at reasonable cost was estimated by Hamburg (2000). Table 5 presents a summary of these estimates. The measurement of each pool is briefly explained below.

Only a summary of estimation methods is presented here. The reader is referred to Cacho et al. (2004), and references therein, for more details on the four pools. The IPCC (2006) presents detailed instructions on generic methodologies for forest land.

Above-ground living biomass

There are three general methods for evaluating changes in carbon stocks and their respective baselines (Vine et al. 1999; Brown 2002): computer modelling; remote sensing; and field/site measurements. Modelling is a convenient way of estimating the size of carbon pools in periods between inventories to minimise the cost of doing field measurements. Sampling of permanent plots at predefined intervals should be combined with these models to validate the changes in carbon stocks predicted by the model.

Table 5. Level of accuracy and ease of implementation from measuring different carbon pools in a forest ecosystem; based on Hamburg (2000, p. 34)

Pool	Coefficient of variation (%)	Ease of implementation
Above-ground biomass	5–10	Simple
Below-ground biomass	10–20	Simple, but requires high initial investment
Soil, organic layer	10–20	Moderate
Soil, mineral layer	Highly variable	Difficult
Necromass	40	Difficult

The simplest procedure for measuring above-ground living biomass carbon consists of measuring a sample of trees and using allometric equations to estimate biomass. Allometric equations relate tree biomass to metrics such as diameter and height that can be measured by non-destructive means. Such equations exist for practically all forests of the world; some are species specific and others more generic (Brown 2002). Allometric methods have been shown to be robust among species and genera, and can predict biomass of closed-canopy forests to within

±10%. The assumption that biomass contains 50% carbon (on a dry weight basis) is well accepted (Hamburg 2000; Brown 2002), so it is straightforward to convert measured biomass to carbon units. Parameter values available in the literature can often provide acceptable levels of precision.

A popular allometric equation for tropical trees is that proposed by Brown et al. (1995):

$$B = 0.049\rho D^2 H \qquad (4.1)$$

where B is biomass (kg/tree), D is diameter at breast height (cm), ρ is wood density (g/cm^3) and H is tree height (m).

Ketterings et al. (2001) proposed the allometric equation:

$$B = 0.11\rho D^{2+c} \qquad (4.2)$$

where c is a parameter that can be estimated for the site. Ketterings et al. (2001) estimated $c = 0.59$ for forests in Sumatra.

Brown (1997) presents other allometric equations for different types of forests, as well as wood density values for a large number of species.

The biomass of a tree equals the product of its volume and its density, so it is also possible to estimate the carbon content of trees when their volume is known. This is useful for commercially important timber species for which volume measurements are available. Biomass is estimated from volume by first estimating the biomass of the main stem of the measured tree and then 'expanding' this value to take into account the biomass of the other above-ground components (leaves and branches):

$$B = \rho V \delta \qquad (4.3)$$

where V is timber volume (m^3), δ is the biomass expansion factor, and B is now measured in tonnes. If it is known that the stem represents 3/4 of the tree biomass, for example, then $\delta = 4/3$. Density (ρ) generally ranges between 0.5 and 0.7.

In Indonesia the 'Vademicum equation' (Direktorat Jenderal Kehutanan 1976) is widely used to estimate volume from diameter and height data:

$$V = \pi(D/2)^2 0.7H \qquad (4.4)$$

where both D and H are measured in metres.

Modelling of biomass accumulation can be based on simple single-equation models, or on process-based models of different levels of complexity. Two common mathematical functions for predicting tree growth are the Richards-Chapman equation (4.5) and the Gompertz equation (4.6):

$$C_{P,t} = \alpha[1 - \exp(-\beta t)]^{\gamma} \qquad (4.5)$$

$$C_{P,t} = \beta(\alpha/\beta)^{\exp(-\gamma t)} \qquad (4.6)$$

where α, β and γ are parameters to be estimated for a particular species and site, and t represents time, generally measured in years. These equations usually represent only above-ground biomass.

Below-ground living biomass

Below-ground living biomass consists mostly of roots. This is an important pool that can represent up to 40% of total biomass (Cairns et al. 1997). Direct sampling requires destructive techniques and can be very expensive (Brown 2001). This pool can be estimated with some accuracy but at lower precision than above-ground biomass.

The simplest approach to estimating below-ground biomass is to apply a constant root/shoot ratio (R/S ratio). Although the R/S ratio varies with site characteristics and stand age, a range of R/S ratios can be obtained from the scientific literature (Hamburg 2000). To avoid measuring roots, a conservative approach recommended by MacDicken (1997) is to estimate root biomass at no less than 10–15% of above-ground living biomass. Hamburg (2000) recommends a default R/S ratio for regrowing forests of 0.15 in temperate ecosystems and 0.1 in tropical ecosystems. Although ratios as high as 0.4 have been measured in temperate forests, the author recommends erring on the side of caution to avoid the possibility of crediting non-existent carbon. Brown (2002), on the other hand, states that mean R/S ratios from a number of studies are 0.26, with an inter-quartile range of 0.18–0.30. Multiplying the above equations by 1.26 can therefore provide a rough estimate of total biomass.

Soil carbon

Soil carbon can also be expensive to measure directly, particularly because of the strong influence that soil characteristics have on carbon dynamics. Hamburg (2000) argues that by using a few generalised principles it should be feasible to measure soil carbon to an acceptable level of accuracy for biological mitigation projects. Hamburg (2000) recommends that the soil carbon be measured to at least 1 m depth, and that measurements of soil carbon and bulk density[6] be taken from the same sample.

Fortunately, for projects that are known to not reduce soil carbon, it may not be necessary to measure soil carbon after the baseline is established. Rates of soil oxidation (a process that releases CO_2) under different land uses are available in the literature (Brown 2001). As a general rule, reforestation projects in agricultural or degraded land will tend to increase soil carbon. If the marginal cost of measuring this carbon pool is greater than the marginal benefit of the carbon credits obtained, the project developer would be better off not measuring this pool.

The Alternatives to Slash-and-Burn (ASB) group has argued that most of the sequestration potential in the humid tropics is above ground rather than in the soil. In tree-based systems planted to replace degraded pastures, it has been found that the time-averaged above-ground carbon stock increased by 50 t/ha in 20 years, whereas the stock of carbon in soil increased by 5–15 t/ha (Tomich et al. 1998; Palm et al. 1999).

Modelling can complement monitoring techniques (Brown 2001). This can be particularly useful to forecast slow changes in soil carbon pools.

Necromass

The necromass pool includes the carbon in dead trees, leaves, branches and other vegetation. Annual leaf litter inputs do not need to be accounted as part of the necromass pool, since this input is balanced by decomposition losses within the soil and the net effect is included in the measurement of the soil pool (Hamburg 2000).

The amount of necromass varies considerably with forest type and disturbance history, and estimating this component accurately can be very time consuming and subject to high uncertainty. Fortunately, this component can be ignored (Hamburg 2000) if we are confident that it will not decrease as a result of the project. Brown (2001) states that dead wood, both fallen and standing, is an important carbon pool in forests and should be measured. According to this author, methods for this component have been tested and require no more effort than measuring living biomass.

Modelling

Several detailed tree-growth and carbon-accumulation models exist, some covering soil as well as biomass carbon. Five of these models are briefly described below.

WaNuLCAS (Water, Nutrients, Light and Carbon in Agroforestry Systems) was developed by International Center for Research in Agroforestry (ICRAF). It is designed to simulate the daily above- and below-ground, complementary and competitive processes between trees and crops. To do so, the soil can be divided vertically into four layers of user-defined depth, and horizontally into four spatial zones of user-defined width. Parameter values defining the soil profile, the slope and the climate are required. Some of the soil parameters required include those defining the physical and chemical properties of the soil (e.g. clay and silt content, soil bulk density, and initial nitrogen and phosphorus levels), the water balance, root distribution, and rates of nutrient mineralisation, decomposition and leaching. These parameters may be applied heterogeneously across each of the layers and spatial zones. If input parameters are not known, defaults for a range of tree and crop species and Indonesian soil types are provided. The model and its potential applications are described in detail by van Noordwijk and Lusiana (2001). Wise and Cacho (2005a,b) used WaNuLCAS to simulate a gliricidia–maize system in Sumatra. A summary of their results is presented below.

SCUAF (Soil Changes Under Agroforestry) was developed by ICRAF with funding by ACIAR. The code of this model was completely rewritten as part of the research leading to this report, to make it functional in the Windows environment and to create a link between the model and spreadsheet files. SCUAF does not directly model plant-growth processes but estimates the effects of changes in soil properties (nutrients, soil carbon and soil depth) based upon user-defined productivity rates of crops and trees (Young et al. 1998). SCUAF is easy to use and has default parameter values for different environments. Wise et al. (2007) used this model to determine the optimal mix of crops and trees in an agroforestry system in the presence of carbon credits. Wise and Cacho (2005c) applied the model in a dynamic programming study to determine optimal combinations of tree and crop areas, as well as cycle lengths.

The BEAM Rubber agroforestry model was developed by the Bioeconomic Agroforestry Modelling project at the School of Agricultural and Forestry Sciences at the University of Wales, Bangor, with partial funding from ACIAR. The model deals with the biophysical components of a rubber-based agro-

[6] Bulk density is greatly affected by soil organic matter concentrations.

forestry system. It accounts for bioclimatic, topographic and silvicultural factors. The model also has an economic component to estimate revenues, costs and profits (Grist et al. 1998). The original model was updated and renamed BRASS (Bioeconomic Rubber Agroforestry Support System). The essence of the original model was not changed. The equations remain the same, except for a few minor corrections to the economic component. Ginoga et al. (2002) used this model in an evaluation of rubber agroforestry systems in Sumatra.

CO2Fix was developed by Centro Agronomico Tropical de Investigación y Enseñanza in Costa Rica. The authors describe it as 'a carbon bookkeeping model that simulates stocks and fluxes of carbon in (the trees of) a forest ecosystem, the soil, and (in case of a managed forest), the wood products. It simulates these stocks and fluxes at the hectare scale with time steps of one year' (Nabuurs et al. 2001). This software package has been used by several teams designing CDM projects and is currently being used by the Center for International Forestry Research (CIFOR) to estimate the carbon-sequestration potential of proposed projects in Indonesia.

CenW (Kirschbaum 1999) simulates the effects of changes in environmental factors such as CO_2 concentration, temperature and rainfall on tree-plantation biophysical processes such as biomass accumulation (photosynthesis), water use, soil carbon storage and nutrient cycling in soil organic matter. It does this by simulating fluxes of carbon, nutrients and water between and within the soil, the plant components and the atmosphere on a daily time step. Cacho et al. (2004) used this model to simulate an *Acacia mangium* plantation in Sumatra.

A modelling example based on a gliricidia–maize system in Jambi

Wise and Cacho (2003, 2004, 2005a,b,c) report on a series of simulation studies that investigated the attractiveness of agroforests in the presence of carbon-sequestration payments, particularly as alternatives to continuous cropping systems. The focus was on incentives to farmers, and simulation runs were based on the WaNuLCAS and SCUAF models. The models were calibrated to simulate above- and below-ground biomass, carbon and nutrient fluxes of a hedgerow intercropping system in Jambi, Sumatra. The agroforestry system was represented by one tree species (*Gliricidia sepium*) and one crop (maize) under a range of management regimes. The data generated were used in an economic evaluation over a 25-year period. The objective was to maximise net present value (NPV) by finding the optimal combination of three variables under the control of the farmer: the relative area of trees and crops, the pruning and harvesting regime, and the fertiliser regime. Results indicated that carbon payments would stimulate a switch from monocropping to agroforestry under certain conditions. The total value of this land-use switch was \$109/ha. Of this, \$85 could be attributed to slowing down land degradation and the remaining \$24 to participation in the carbon market. In other words, 22% of the benefits were attributable to carbon trading and the remaining 78% to a reduction in land degradation. The latter benefits were experienced by the farmer in the form a higher present value of income as a result of better future crop yields.

The series of papers by Wise and Cacho demonstrate the importance of baselines (Figure 6). Their first important finding was that carbon-sequestration projects are unlikely to be economically feasible on good-quality land that has been recently deforested, but they can be attractive in land that has been under continuous cropping for a decade or two after it was deforested. Not only does the former type of land have a higher opportunity cost, but it also experiences a loss of soil carbon (shown in Figure 6c, f and i), even in the case of low harvest intensity where tree prunings are returned to the soil. Land that has been degraded through continuous cropping, in contrast, has the potential to increase soil carbon when tree harvest intensity is medium or low (Figure 6d and g).

The second important finding of Wise and Cacho was obtained by comparing a static and a dynamic baseline. The dynamic baseline represents continuous cropping that results in loss of soil carbon over time. The static baseline may represent a grassland that contains a stable level of soil carbon. Wise and Cacho (2003) showed that, if landholders were to convert *Imperata* grassland into a gliricidia–maize system and enter the carbon market, they would be liable for carbon emissions in several years, making this option unattractive. In contrast, the dynamic baseline provided an incentive to plant trees and sell carbon (Table 6).

Even though the analysis revealed that, under some conditions, it would be optimal for farmers to sell carbon, it was found that the amount of carbon sequestered would be very small (less than 3 t/ha) because the optimal area of trees to plant was 5–18% of the plot, with the remaining area planted to maize. The cost of monitoring this small amount of carbon to an acceptable level of precision would probably exceed its value in the carbon market, and such a project would not therefore be feasible in the presence of transaction costs. This suggests that we should concentrate on projects that involve agroforestry systems with a larger component of trees (such as the damar and rubber systems detailed in Appendix 1) rather than intercropping systems where food crops are the main component.

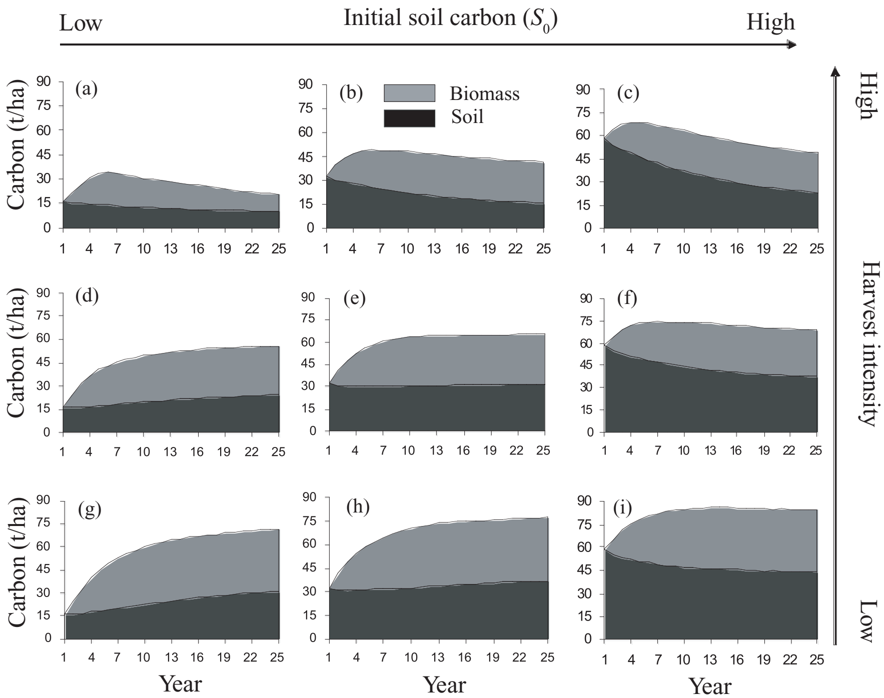


Figure 6. Trajectory of carbon stocks at three initial levels of soil carbon and with three levels of wood harvest

Table 6. Optimal strategies under a range of discount rates and prices with a dynamic baseline

Exogenous variables			Optimal results			
Discount rate (%)	Carbon price ($/tC)	Maize price ($/t)	Carbon trading	Net present value ($/ha)	Tree area (ha)	Eligible C (tC/ha)
5	10	20	Yes	212	0.18	2.75
25	10	20	Yes	66	0.17	2.59
5	15	20	Yes	224	0.18	2.75
25	15	20	Yes	73	0.18	2.59
5	20	20	Yes	237	0.18	2.75
25	20	20	Yes	80	0.18	2.59
5	10	40	Yes	1,441	0.05	2.03
25	10	40	No	399	0.00	0.00
5	15	40	Yes	1,451	0.05	2.03
25	15	40	No	399	0.00	0.00
5	20	40	Yes	1,460	0.05	2.03
25	20	40	No	399	0.00	0.00

Source: Wise and Cacho (2003)

5. A model of project participation

In Chapter 3 we explained that some carbon-sequestration projects that are technically feasible may not be economically feasible because they do not provide enough incentives to sellers to supply the service at a price that buyers are willing to pay. In this chapter we discuss these issues and develop a model of project participation that accounts for abatement costs and transaction costs.

Consider a project composed of one buyer and many sellers. The buyer is an NGO (the project proponent) and the sellers are smallholders. The sellers are paid for adopting agroforestry land uses that sequester carbon above a baseline. The buyer purchases these carbon offsets and sells them in the CER market. So the buyer acts as an intermediary between the smallholders and the international carbon market.

For simplicity, define a representative farmer with a given farm area *a* and current land use, call this the 'average' seller and assume there are *n* identical sellers. The representative seller will participate in the project if the reward received for carbon sequestration (v_C) is larger than the opportunity cost of switching land uses (the abatement cost, v_A) plus the transaction cost of participating in the project (v_T). The condition for seller participation is:

$$v_C > v_A + v_T \tag{5.1}$$

with the three variables measured in terms of present value. The present value of carbon payments received by the seller is:

$$v_C = a\sum_t C_t\, p_F \left(1+\delta_s\right)^{-t} \tag{5.2}$$

where C_t represents the expected stock of carbon above the baseline per hectare of land in year *t*, p_F is the farm price of carbon and δ_S is the seller's discount rate. The abatement cost to the seller is:

$$v_A = a\sum_t R_t \left(1+\delta_s\right)^{-t} \tag{5.3}$$

where R_t represents the opportunity cost experienced in year *t* as a result of having switched land use to a tree-based system in year zero. The transaction cost experienced by the seller is the discounted sum of a stream of annual transaction costs (q_t):

$$v_T = \sum_t q_t \left(1+\delta_s\right)^{-t} \tag{5.4}$$

Now consider the buyer. The buyer will implement a project if the present value of carbon payments received in the CER market (V_C) is at least equal to the present value of payments to smallholders (the abatement cost to the buyer, V_A) plus the transaction costs of designing and implementing the project (V_T). The condition for buyer participation is:

$$V_C \geq V_A + V_T \tag{5.5}$$

V_C is the discounted sum of payments obtained by accumulating the carbon offsets produced by all landholders in the project, certifying them and selling them in the CER market:

$$V_C = n\cdot a\sum_t p_C C_t \left(1+\delta_B\right)^{-t} \tag{5.6}$$

where p_C is the rental price per tonne of carbon and δ_B is the buyer's discount rate. The abatement and transaction costs for the buyer are, respectively:

$$V_A = n\cdot a\sum_t p_F C_t \left(1+\delta_B\right)^{-t} \tag{5.7}$$

$$V_T = \sum_t Q_t \left(1+\delta_B\right)^{-t} \tag{5.8}$$

where Q_t represent the annual transaction costs. The buyer must set the farm price of carbon (p_F) at a level that satisfies conditions (5.1) and (5.5). This decision is influenced by the size of the project and the number of participants, as explained later.

Projecting carbon-sequestration rates and payments

The carbon available for credits in a given year (C_t) is only that amount above the baseline; that is, only the 'additional' carbon relative to the business-as-usual scenario is eligible. In any given year:

$$C_t = C_{P,t} - C_{C,t} \tag{5.9}$$

where $C_{P,t}$ and $C_{C,t}$ are the expected carbon stocks in the proposed land use and the current land use, respectively, in year t. If time-series data on diameter and height of trees are available for the site, the amount of carbon sequestered by above-ground biomass can be estimated using allometric equations as explained in Chapter 4. Alternatively, projections of carbon stocks can be based on models calibrated for the site, as illustrated by Wise and Cacho (2005a,b).

On the matter of carbon payments, Cacho et al. (2003a) explain that the present value of the 'ideal' carbon-accounting system is equivalent to that obtained under a rental market, as proposed by Marland et al. (2001). The difference between the purchase and the rental system is that the former represents a purchase of carbon flows with redemption of payments upon project termination (or failure), whereas the latter involves a rental of carbon stocks with no redemption of credits required. The latter system is clearly more convenient, and is also compatible with temporary CERs for AR projects under the CDM.[7]

The range of farm prices (p_F) that the buyer can pay is influenced by the market price of carbon (p_C). Here we express both these variables as annual rental prices per unit of biomass carbon stored in trees. To understand the relationship between rental prices and purchase prices, consider the present value (PV) of an asset that yields a perpetual stream of annual payments Y discounted at rate i:

$$PV = Y/(1 - e^{-i}) \tag{5.10}$$

In a perfect market, the ratio Y/PV is equivalent to the rental price of the asset expressed as a proportion of the asset's value. If we let the asset be a CER (expressed as a tonne of CO_2e) valued at price p_{CER}, and consider that the process of photosynthesis converts 3.67 units of CO_2 into one unit of biomass carbon, then the rental price of biomass carbon is:

$$p_C = 3.67(1 - e^{-i})p_{CER} \tag{5.11}$$

The value of the discount rate in the rental carbon market (i) depends on the rate of return expected by investors. For simplicity we assume the carbon market discount rate is the same as the buyer's. The value of i in equations (5.10) and (5.11) is therefore calculated by converting the rate for discrete discounting δ_B into a continuous rate $i = \ln(1 + \delta_B)$, where ln is the natural logarithm.

The CER price places an upper limit on the feasible farm price because the buyer would set $p_F \leq p_C$ even in the absence of transaction costs. Estimates of CER prices in the literature vary widely but generally fall within the range \$5 to \$50 per tonne of CO_2, with lower values being more common because of the risk of investing in developing countries that may have weak institutions. Lecocq and Capoor (2003) state that prices for emission reductions from 'small projects with a strong sustainable development contribution command premiums in the marketplace, with prices ranging from \$5–12/tCO_2e'. They also point out that 'Retailers report a marked preference by customers for community-based agroforestry and other forestry deals'.

In our analysis we assume a perfect market and use equation (5.11) to derive p_C. It is worth mentioning, however, that the relationship between the purchase price and the rental price is affected not only by the discount rate, as is obvious in equation (5.11), but also by expected price trends. Figure 7 shows this for a p_{CER} of \$10/tCO_2e. With a constant CER price (where the expected price trend is 0), the rental price of carbon (p_C) is \$2.08/tC at a discount rate of 6%, and p_C is \$3.93/tC at a discount rate of 12%. If the carbon price is expected to increase in the future (the price trend is positive), the rental price will be lower. For example, with an expected price increase of \$0.5/tCO_2/year, p_C decreases to \$1.37/tC and \$3.03/tC for discount rates of 6% and 12%, respectively. If the carbon price is expected to fall in the future (the price trend is negative), the rental price will be higher. For example, with an expected price decrease of \$0.5/tCO_2 per year, p_C increases to \$6.17/tC and \$7.27/tC for discount rates of 6% and 12%, respectively. These results are intuitively obvious because those renting today know that an increasing price trend will result in a more expensive purchase price tomorrow, and therefore will be willing to pay a lower price to forego the option of purchasing today. It is evident from Figure 7 that the rental price is considerably more sensitive to expected price falls than to rises.

Abatement costs

Abatement costs for the seller are defined as the costs of producing one unit of (uncertified) carbon-sequestration services, or the cost of producing one unit of

[7] A temporary CER or 'tCER' is a CER issued for an AR project activity that expires at the end of the commitment period following the one during which it was issued (UNFCCC document FCCC/CP/2003/6/Add.2).

biomass carbon. In any given location, abatement costs can be estimated as the opportunity cost of undertaking a carbon-sequestration activity rather than the most profitable alternative activity, or the cost of switching from the previous land use to the new land use, as represented in equation (5.3). This cost includes the present value of the stream of revenues foregone as a result of participating in the project. It may also include additional risk exposure or loss of food security arising from this participation (Cacho et al. 2003b). As Suyanto et al. (2001, p. 141) observed from their study of agroforestry management in Sumatra, 'we have to recognize that rural people in hilly and mountainous areas, such as our study sites, are generally very poor and that in such areas agroforestry has a comparative advantage over food production'. However, a considerable barrier to adoption will exist if agroforestry involves foregoing subsistence production, leading to high opportunity costs by jeopardising food security. Another barrier is that the costs of obtaining credit are likely to be high for poor smallholders (Otsuka and Place 2001a).

If we ignore risk perceptions and other barriers to adoption that could be overcome by participating in the project, abatement costs are relatively straightforward to estimate through discounted cash flow techniques based on the inputs and outputs of both the baseline and the agroforestry system being proposed.

The annual opportunity cost required to estimate abatement cost as defined in equation (5.3) is:

$$R_t = R_{C,t} - R_{P,t} \tag{5.12}$$

where $R_{C,t}$ and $R_{P,t}$ are the annual net revenues of the current land use and the proposed land use, respectively. In agroforestry systems with multiple outputs (e.g. fruit, timber and spices) the annual revenue is the sum of the revenues obtained from the different products. In a system with J land uses and I inputs, we have:

$$R_{P,t} = \sum_j y_{j,t}\, p_j - \sum_i x_{i,t}\, c_i \,, \qquad j \in (1,\ldots,J),\ i \in (1,\ldots,i) \tag{5.13}$$

where, as defined in connection with equation (A1) in Appendix 1, $y_{j,t}$ is the yield of output j in year t, p_j is the price per unit of output, $x_{j,t}$ is the amount of input i used in year t and c_i is the cost of input i.

Tomich et al. (2002) estimated the opportunity cost of several agroforestry systems in Sumatra, Indonesia. Based on discounted cash flow analysis, they estimated the minimum price required per tonne of carbon to encourage smallholders to participate in a carbon-conservation project. They found that carbon payments necessary to shift incentives from forest conversion to conservation vary from \$0.10/tC for community-based forest management to \$4/tC for large-scale oil palm plantations and \$10/tC for rubber

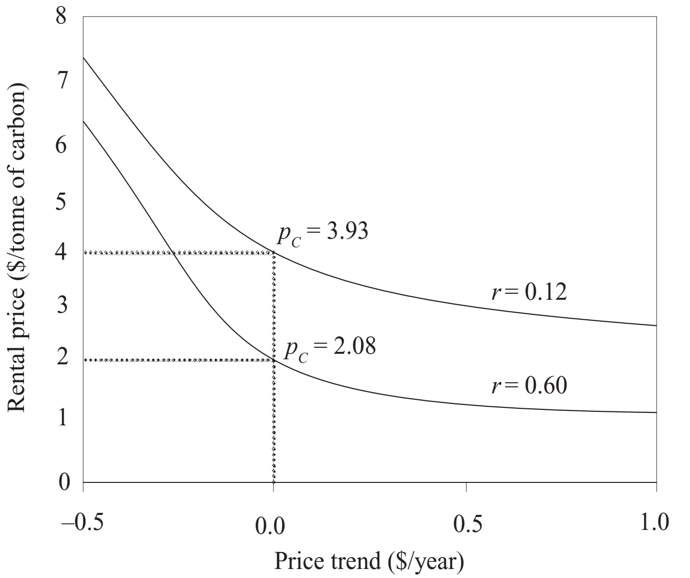


Figure 7. The effect of expected carbon price trends and discount rate on the rental price of carbon

agroforests. However, when the option for logging the forest was included as an opportunity cost, the incentive payments required increased significantly (to \$8.50/tC, \$10/tC and \$16/tC for community forestry, oil palm and rubber agroforestry, respectively). These figures include only abatement costs, so if transaction costs are high these projects may be economically infeasible.

Transaction costs

Williamson (1985) distinguished the costs of contracting as ex ante and ex post transaction costs. These correspond with activities undertaken in the processes of achieving an agreement and then continuing to coordinate implementation of the agreement, respectively. Stavins (1995, p. 134) stated: 'transaction costs are ubiquitous in market economies and can arise from the transfer of any property right because parties to exchange must find one another, communicate, and exchange information'. In the case of carbon markets, transaction costs tend to be higher because the property right to be exchanged is difficult to measure and its exact size is subject to uncertainty. Stavins (1995) also states that transaction costs can take two forms: inputs of resources (including time) and a margin between the buying and the selling price. Our model accounts for both forms of transaction costs.

Thompson (1999) also considered the costs of enacting policy by a legislature. He defined this type of cost as including lobbying expenditures by interest groups. These costs of lobbying are one element of what Horn (1995, pp. 30–31) has called 'political transaction costs'. Challen (2000) has argued that transaction costs of this kind need to be accounted for more explicitly than has conventionally been the case when comparing alternative institutional arrangements. In this report we consider only the costs of achieving and implementing the agreement, as these are the relevant costs at the project level. Political transaction costs are out of the scope of this study, but they should be considered by governments when they design institutions to enable carbon-sequestration activities.

Cacho et al. (2003b, 2005) present a typology of transaction costs applicable to carbon-sink projects, largely based on Dudek and Wiener (1996). Here we aggregate the seven categories of Cacho and colleagues into five, and distinguish between the costs borne by buyers and by sellers (Table 7). The transaction costs experienced by buyers and sellers in time period t are, respectively:

$$Q_t = W_{S,t} + W_{A,t} + W_{P,t} + W_{M,t} + W_{E,t} \qquad (5.14)$$

$$q_t = w_{S,t} + w_{A,t} + w_{P,t} + w_{M,t} + w_{E,t} \qquad (5.14)$$

where the subscripts represent search and negotiation (S), approval (A), project management (P), monitoring (M), and enforcement and insurance (E). Using the CDM project cycle as a basis (Figure 8), we can relate these costs to the design and implementation of projects.

Search and negotiation

The CDM project cycle starts with the preparation of a project design document (PDD). This requires the project developer to identify a suitable region; gather agricultural, social and economic information about the region to develop the baseline; identify suitable land uses and estimate their carbon-sequestration potential; contact and establish relationships with the local people; negotiate the terms of the project and the schedule of payments for carbon-sequestration services; and possibly undertake environmental and social impact studies. These activities are included within *Search and negotiation* costs in Table 7. Estimates of these costs in the literature vary widely depending on the nature of the activities within the project, the scale of the project, assumptions about the presence of local NGOs and farmer groups that may facilitate the process of contacting local people, and the availability of local experts to design the monitoring strategy and prepare the PDD. With smallholder projects, the cost of negotiating with individuals, including farm visits and establishment of personal relationships, can be high. Also, the cost of writing contracts when literacy is limited, and the need to legitimise contracts through a village committee or headman, can be important (Simmons 2003).

Approval

Steps 2, 3 and 4 of the CDM cycle (Figure 8) fall within the *Approval* costs category. They include approval by the designated national authority (DNA) of the host country; validation of the PDD by a designated operational entity (DOE) accredited by the CDM Executive Board; and registration of the project when submitted to the executive board. The costs of these activities depend on several factors, including the institutional infrastructure of the host country and the availability (as a cheaper alternative to an international consultant) of a local DOE that can validate the PDD.

Monitoring

Steps 5, 6 and 7 of the CDM cycle (Figure 8) fall within the *Monitoring* costs category of Table 7. These are the costs of measuring the CO_2 abatement actually achieved by the project, including certification and verification by a DOE. Once the CDM Executive Board issues the appropriate number of CERs the project developer (the buyer) becomes a seller in the international carbon market. Any additional

Table 7. Classification of transaction costs in afforestation–reforestation projects for carbon sequestration

Cost type	Buyer (Q)	Seller (q)
Search and negotiation	ex ante	
	W_S	w_S
	• Find sites, establish contact, organise information sessions, draft contracts, provide training, promote project • Establish baseline for region • Estimate potential carbon (C) stocks and flows of project • Design individual farm plans • Produce project design document	• Attend information sessions • Undertake training • Design farm plan
Approval	ex ante	
	W_A	w_A
	• Obtain approval by host country (designated national authority) • Validate the project proposal (designated operational entity) • Submit to Clean Development Mechanism Executive Board	• Obtain permit
Project management	ex ante	
	W_P	w_P
	• Buy computers and software, establish office • Establish permanent sampling plots	• Purchase tape and equipment for measuring trees and sampling soil
	ex post	
	• Maintain database and administer payments • Coordinate field crews, pay salaries • Distribute payments to landholders • Pay interest on loans	• Attend regular project meetings
Monitoring	ex post	
	W_M	w_M
	• Enter data from farmers' sheets, calculate C payments • Process soil C samples • Measure random sample of plots to check farmer estimates • Provide verification and certification of carbon (designated operational entity)	• Measure trees, fill in form and deliver to project office • Sample soil C
Enforcement and insurance	ex post	
	W_E	w_E
	• Maintain buffer of C • Purchase liability insurance • Settle disputes	• Protect plot from poachers and fire • Participate in dispute settlement

transaction costs that may be associated with selling CER in the international market are not accounted for below. It is assumed that the project developer can access the full price per CER, although it is a simple matter to reduce the price by a brokerage fee if applicable. Monitoring costs are recurrent, as they are incurred every time a new batch of carbon is submitted for CER crediting. Certification is given only on real accomplishments, so it occurs ex post, once sequestration has occurred (Moura-Costa et al. 2000). MacDicken (1997) points out that projects that fix less than 2–3 tonnes of carbon per hectare per year cannot be monitored in a cost-effective way because the cost of measuring these quantities is similar to the cost of measuring 10–15 tonnes of carbon per hectare per year. Cacho et al. (2004) estimated the costs of carbon monitoring of a monoculture plantation (in present-value terms) to be between \$0.45/tC and \$2.11/tC depending on the spatial variability of tree growth, the variable costs of measuring carbon and the discount rate.

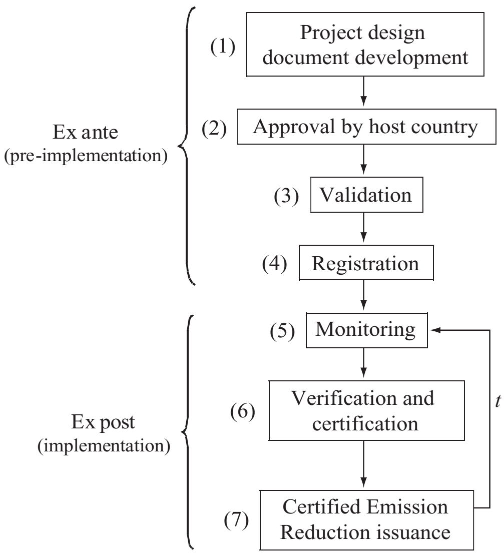


Figure 8. The Clean Development Mechanism project cycle

Two types of transaction costs listed in Table 7—*Project management* and *Enforcement and insurance*—do not fit neatly within the CDM project cycle; nonetheless, they are necessary for the approval and operation of the project.

Project management

Project-management costs include the cost of keeping records of project participants and administration of payments to sellers, as well as salaries and transportation costs of project employees. Ex-ante project-management activities include the establishment of a local project office and the training of staff. Project management costs are not normally recognised explicitly in the literature on transaction costs of Kyoto mechanisms, but they are expenses incurred in buying and selling carbon-sequestration services, and should be considered.

Enforcement and insurance

Enforcement and insurance costs arise from the risk of project failure or underperformance, which might be caused by fire, slow tree growth, or leakage. Enforcement costs may be incurred in the form of litigation and dispute-resolution expenses. Insurance options may include purchase of an insurance policy, deduction of a risk premium from the price of carbon, and maintenance of buffer carbon stocks that are not sold. These activities form part of the risk-management strategy required within the PDD. When dealing with developing-country smallholders, there may be limited legal recourse to enforce contracts due to the slowness of court proceedings, and the difficulty and cost of recovering small debts. So the project needs to provide smallholders with credible prospects and sufficient incentives to prevent abandonment (Simmons 2003). Strategies to reduce risk of contract default include channelling loans through farm groups, monitoring within the community, and strict rules and harsh penalties for dealing with defaulters (Eaton and Shepherd 2001).

Case studies of abatement costs

Some simple case-study analyses are presented in this section to illustrate how abatement costs can be estimated. The analysis focuses on agroforestry systems that are common on the island of Sumatra, Indonesia: rubber, cinnamon, damar and oil palm (for details of these systems see Appendix 1). The data for the oil palm system are based on an actual plantation-run project covering 10,700 ha, whereas the data for the other three systems are based on actual smallholder-run projects. This section is based on the paper of Cacho et al. (2005).

The amount of carbon sequestered by above-ground biomass for each of the four systems, assuming good-quality land, was estimated with simple growth models based on available data and using allometric equations (see Chapter 4). The simulated growth in carbon stocks of the four agroforestry systems over 70 years is presented in Figure 9. A planning horizon of 70 years was used, based on the age of damar systems sampled by Vincent et al. (2002).

The average stock of carbon in each system can be calculated by dividing the area under the corresponding curve in Figure 9 by 70 years. This is an estimate of the 'permanent' increase in carbon stocks, assuming that the land use will not change and land productivity does not fall with subsequent production cycles.

Good-quality land is likely to be recently deforested and therefore not eligible for a CDM project. Our case studies therefore must also consider reforestation of degraded land, which should be an acceptable CDM activity under both sustainability and additionality criteria. The productivity of degraded land, and hence its carbon-sequestration capacity, will be considerably lower than that of good-quality land. For the analysis that follows, we defined a simple land-productivity index (*LPI*) to represent yields of crops and trees. The index has a value of 1.0 in good-quality land and decreases linearly as land productivity declines. In our base case, we assumed that the yields of the four agroforestry systems are one half of those obtained on good-quality land (*LPI* = 0.5). This assumption is subjected to sensitivity analysis later.

The opportunity cost of changing to a particular agroforestry system depends on the current (i.e. without-project) land use. Common land uses in the peneplains of Sumatra are upland rice/bush-fallow rotation, and cassava monoculture degrading to *Imperata* grassland (Tomich et al. 1998). The former land use is unprofitable, whereas the yields of the latter vary considerably. Whitmore et al. (2000) state that cassava yields in Sumatra can be as high as 40 t/ha; they assume a target yield of 20 t/ha in acid, weathered, upland soils in Lampung, Sumatra. Using their data, we estimated the NPV of continuous cassava production, our without-project land use, to be $287/ha (calculated over 70 years at a discount rate of 20%). The opportunity cost of a given agroforestry system was estimated by subtracting its NPV from the NPV that would have been obtained with continuous cassava cropping. In other words, the opportunity cost was calculated as *NPV without project minus NPV with project*. This is the opposite of the common project

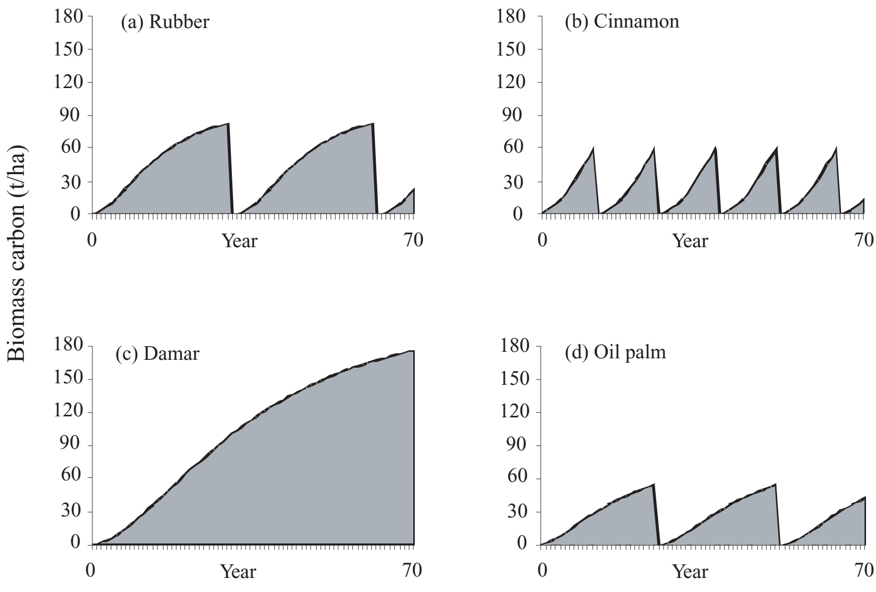


Figure 9. Carbon-sequestration trajectories of selected agroforestry systems: simulated results for southern Sumatra, Indonesia

evaluation criterion used to estimate additionality, so a positive opportunity cost indicates that the proposed system meets the additionality requirement on financial grounds (i.e. the project is less profitable than the current land use). Note that above-ground carbon associated with continuous cassava production is assumed to be zero because the carbon is removed at harvest every year.

The financial analyses of the four agroforestry systems are summarised in Table 8. The base-case analysis assumes a discount rate of 20%. This is a realistic estimate of rates of discount faced by smallholders in Indonesia who may not have access to formal credit markets. Further details on the assumptions and methods used in the analyses, including prices, costs and formulas used to estimate carbon-sequestration rates, can be obtained from Ginoga et al. (2002).

The results of the financial analysis for degraded land (Table 8) indicate that only the cinnamon system would be financially attractive to landholders, as the NPVs of the other three systems are negative. Calculating the opportunity cost of changing to an agroforestry system helps to answer the question ‘given existing prices, how much do we need to pay landholders to entice them to change land-use practices?’ The positive opportunity costs for all systems in Table 8 suggest that landholders would not adopt those systems in order to supply to the CER market unless they were paid an inducement not less than the opportunity cost in each case.

A measure of the average abatement cost is presented in the last row of Table 8. These values were obtained by dividing the opportunity cost of changing to a system by its average biomass carbon. In this example, damar is the cheapest option for sequestering carbon ($6.22/tC), with oil palm the most expensive ($28.48/tC), and rubber and cinnamon intermediate ($17.92/tC and $15.19/tC, respectively). Therefore, a rational carbon investor faced with these options would select damar first, followed by cinnamon, rubber and oil palm. For agroforestry projects to compete in carbon markets, their sequestration cost needs to be lower than the market price of carbon. The sequestration costs for rubber, cinnamon and damar fall within the price bounds observed in the carbon market (see Chapter 3), while the sequestration costs for oil palm exceeds the upper bounds.

Even although the opportunity cost per hectare for cinnamon ($172/ha) is about half of that for damar ($319/ha), the damar system captures almost five times as much carbon (51 t/ha versus 11 t/ha). Hence, damar provides the cheapest alternative for carbon sequestration. Incidentally, the damar system also provides more biodiversity benefits than the other three systems. Typically, a mature damar agroforest exhibits about 70% of the bird biodiversity of a natural forest (ASB 2001).

As shown above, it is possible to estimate abatement costs associated with agroforestry-based carbon-sequestration projects through fairly simple economic analysis. This can be useful as a screening device to identify potential agroforestry systems for a particular site. However, the actual costs of a project must be estimated based on local data, because the opportunity costs and baselines, as well as transaction costs, can vary considerably between sites.

Estimates of transaction costs

Dudek and Wienar (1996) observed that the various categories of transaction costs are likely to differ in the degree to which they represent fixed and variable costs. For instance, approval costs may be relatively fixed since the task of seeking approval is unlikely to be affected much by whether the proposed project is small or large. On the other hand, monitoring and insurance costs would be relatively variable,

Table 8. Financial performance and costs of selected agroforestry systems: modelling results for Sumatra, Indonesia. Net present values (NPVs) were calculated for a period of 70 years at a discount rate of 20% and a land productivity index of 0.5.

	Agroforestry system			
	Rubber	Cinnamon	Damar	Oil palm
Average biomass carbon (tC/ha)	21.29	11.34	51.34	13.30
NPV (US$/ha)	–94.04	115.32	–31.58	–91.31
Opportunity cost[a] ($/ha)	381.54	172.18	319.08	378.81
Abatement cost ($/t C)	17.92	15.19	6.22	28.48

[a] The cost in terms of forgone NPV of switching land use from cassava to each agroforestry system

increasing with the size of the transaction. In a study of selected projects, Cacho (2003b) detected evidence of economies of scale caused by the large proportion of fixed costs.

A selection of CDM transaction-cost estimates published in the literature is presented in Table 9. The search and negotiation costs (W_S) range between \$22,000 and \$160,000; the approval costs (W_A) range between \$12,000 and \$120,000; and the monitoring costs (W_M) range between \$5,000 and \$270,000. Only one source in Table 9 presents risk-mitigation costs, which are classified under enforcement and insurance (W_E); these values were calculated based on the assumed price of \$3 per CER used in the original source. The wide range of values in all categories illustrates the fact that transaction costs are highly sensitive to the type and size of project assumed.

The CDM user's guide (EcoSecurities and United Nations Development Programme 2003) assumes a biomass plant with a 20-year lifetime. The low and high estimates for this source correspond to a small plant (35,000 tCO_2/year) and a large plant (350,000 tCO_2/year), respectively. Their feasibility assessment values were classified under 'Search' in Table 9, and their legal fees estimates under 'Negotiation'. In addition to verification and certification, monitoring costs also include an adaptation fee that goes to a fund established by the UNFCCC to help vulnerable countries adapt to the effects of climate change. The cost estimates in Table 9 are largely based on energy projects (including biomass energy) rather than AR projects, and do not involve negotiation with a large number of smallholders.

Useful additional information about transaction costs of projects involving smallholders is provided by the *Scolel Te* project in Southern Mexico, which has developed a useful management system called 'Plan Vivo'. De Jong et al. (2004) outline the transaction costs associated with designing the Plan Vivo management system. Under the search and negotiation category we could include the costs of undertaking the feasibility study, the carbon inventories, the land-use analysis, and the development of the regional baseline. The total cost of these activities was approximately \$830,000. Trained technicians develop a Plan Vivo in their community, either with individual farmers or with the community as a whole. Designing a Plan Vivo requires about 3 days of training by a professional technician. Salary, transport and lodging are the main expenditures for training sessions, which typically cost between \$400 and \$500 each (de Jong et al. 2004).

Table 9. Transaction costs estimates for Clean Development Mechanism projects in the literature

	Source					
	A (€)	B (\$)	C (low) (\$)	C (high) (\$)	D (low) (\$)	D (high) (\$)
Search	15,000		19,000	29,000	5,000	20,000
Negotiation	25,000		10,500	10,500	20,000	25,000
Baseline determination	35,000	18,000				
Preparation of project design document		3,618	6,500	120,000	25,000	40,000
W_S total	75,000	21,618	36,000	159,500	50,000	85,000
Approval	40,000		1,000	10,000		
Validation	15,000	28,000	6,000	80,000	10,000	15,000
Registration	10,000	4,000	5,000	30,000	10,000	10,000
W_A total	65,000	32,000	12,000	120,000	20,000	25,000
Monitoring	10,000	750	6,550	6,550		
Verification + certification	8,000	20,500	10,112	50,559	3,000	15,000
Adaptation fee			10,193	212,349	2,100	21,000
W_M total	18,000	21,250	26,855	269,458	5,100	36,000
Risk mitigation (percentage of Certified Emission Reductions)					1	3
W_E total					1,050	10,500

Sources: A. Michaelowa et al. (2003), low-cost scenarios; B. de Gouvello and Coto (2003), hydroelectric project in Guatemala; C. Krey (2004), survey of projects in India; D. EcoSecurities and UNDP (2003), biomass power generation.

Arifin (2005) presents estimates of the transaction costs incurred by community-based forestry management groups in Sumber Jaya, Indonesia. These groups are participating in the RUPES[8] project. Activities cited by Arifin included under 'search and negotiation' are obtaining information and joining farmer groups; under 'approval' is the cost of obtaining a permit to participate; under 'project management' is the cost of attending meetings; and under 'enforcement and insurance' are the costs of guarding crops and participating in dispute settlement. Arifin calculated these costs as the per-household time allocated to perform activities multiplied by the wage rate.

To implement this model for empirical analysis and gain an understanding of the project-design parameters that most influence project feasibility, it is necessary to obtain estimates of the transaction costs and abatement costs experienced by buyers and sellers (Table 10). The model can be implemented on a spreadsheet by integrating the economic evaluations of Appendix 1 with transaction-cost estimates derived from the project studies in Appendix 2. However, we implemented the model in the MATLAB environment (The MathWorks 2002) to gain more flexibility in undertaking complex analyses.

Table 10. Variable definitions for project participation model

Variable	Description	Units
V_C, v_C	Carbon payments received by buyer, seller	$ (present value)
V_A, v_A	Abatement costs experienced by buyer, seller	$ (present value)
V_T, v_A	Transaction costs experienced by buyer, seller	$ (present value)
C_t	Carbon stock above the baseline in year *t*	tC/ha
$C_{P,t}$	Carbon stock of project activity in year *t*	tC/ha
$C_{C,t}$	Carbon stock of current activity (baseline) in year *t*	tC/ha
R_t	Opportunity cost of land-use change in year *t*	$/ha
$R_{P,t}$	Net revenue of project activity in year *t*	$/ha
$R_{C,t}$	Net revenue of baseline in year *t*	$/ha
a	Average farm area	ha
p_F	Farm price of carbon	$/tC
p_C	Rental price of carbon	$/tC
p_{CER}	Purchase price of Certified Emission Reduction	$/t$CO_2$e
P_L	Price of labour	$/per day
n	Number of participating farms	farms
δ_B	Buyer discount rate	%
δ_S	Seller discount rate	%
$y_{j,t}$	Yield of product *j* in year *t*	units/ha[a]
p_j	Price of product *j*	$/unit[a]
$x_{i,t}$	Quantity of input *i* in year *t*	units/ha[b]
c_j	Cost of input *i*	$/unit[b]
Q_t	Total buyer's transaction costs in year *t*	$
q_t	Total sellers' transaction costs in year *t*	$

[a] Output units vary (e.g. kg, t, m^3) depending on the type of product
[b] Input units vary (e.g. per day, kg, bag) depending on the type of input

[8] RUPES stands for Rewarding the Upland Poor for the Environmental Services they provide.

6. Analysis of project design

Assumptions

In this chapter we apply the model developed in Chapter 5 to a complex agroforestry system in Sumatra, based on information presented in Appendix 1. A hypothetical 25-year project is simulated and used to identify critical project-design variables. The baseline is assumed to be a cassava crop with an NPV of $4,376/ha and the project activity is a damar tree (*Shorea javanica*) agroforestry system (see Appendix 1) with an NPV of $4,372/ha. The carbon stock of the baseline is assumed to be zero because cassava biomass is harvested every year and soil carbon is not accounted for. The carbon accumulation pattern of the damar system (Figure 10) is represented by a Gompertz equation with parameter values $\alpha = 0.5$, $\beta = 471.6$ and $\gamma = 0.0958$ (see equation (4.6) for the functional form). These parameter values result in an average carbon stock of 89.3 tC/ha over the 25-year period of the project. Note that this system will continue to capture carbon after the project ends.

A series of computer experiments was performed for this hypothetical project. The project consists of n identical farms each consisting of a hectares. The project developer establishes individual contracts whereby farmers agree to change their land use from cropping to agroforestry and receive payments for the carbon captured in their trees. In designing the project, the buyer decides on the number of participants (n), the carbon price paid to farmers (p_F) and other features such as monitoring and risk-mitigation strategies.

Transaction-cost assumptions are presented in Table 11. Note that the units of measurement of these costs vary. In the case of the buyer, costs can be ex-ante fixed costs ($), annual fixed costs ($/year), or variable costs dependent on the number of participating farms ($/farm) or the size of the project ($/ha/year). In the case of the seller, costs are expressed in terms of labour. The original five transaction-cost categories are disaggregated to account for variation in the units of measurement. The expanded classification is presented under ‘Cost type’ (Table 11, column 1), where

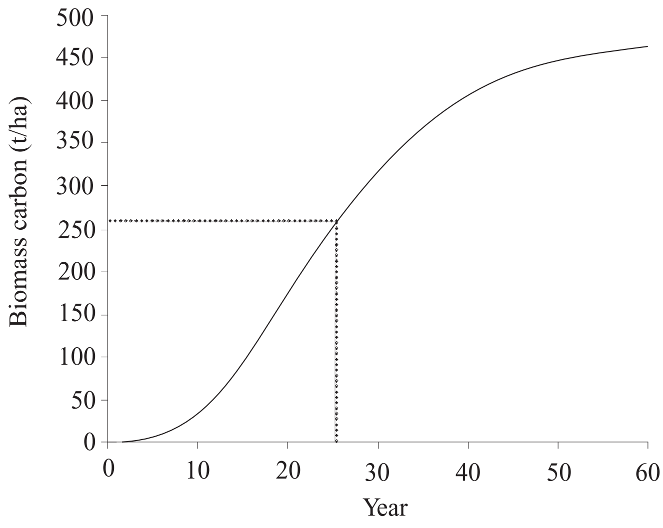


Figure 10. Simulated biomass carbon trajectory for damar (*Shorea javanica*) in Sumatra; the hypothetical project duration is indicated by a dotted line

number subscripts denote the different cost types. For example, there are three types of monitoring costs: W_{M1} (\$/ha/year), W_{M2} (\$/year), and W_{M3} (CER/year).

Monitoring costs for AR projects can be high, and designing the right monitoring strategy is important. Monitoring also involves verification and certification of carbon stocks by a designated operational entity (DOE). This is assumed to cost \$10,000 per year (Table 11), but the cost could be higher if international experts were required or the project sites were scattered over a large area.

Designing individual farm plans (W_{S2}) involves a technician visiting each farm and designing a land-use change plan in consultation with the farmer. This is assumed to cost \$200 per farm to the buyer, which would cover 1–2 days of a local technician's time plus travel expenses. This activity would also take 4 days of the seller's time (Table 11).

Enforcement and insurance is assumed to involve maintaining a buffer of 10% of biomass carbon not sold as CERs, plus an average cost of \$100 per farm per year to settle disputes (Table 11); this expense would include any legal fees involved. The buffer is a risk-mitigation strategy to account for leakage or the possible loss of trees.

Using the expanded notation introduced in Table 11, transaction costs can now be calculated using equations (6.1) and (6.2) (see next page).

Assumptions about prices and discount rates are presented in Table 12. The price of CERs is set initially at a high value (\$20/tCO_2) to ensure the project is feasible.

Replacing equations (5.4) and (5.8) with (6.1) and (6.2), respectively, and inserting parameter values in the appropriate equations, we can now solve the model developed in Chapter 5 and determine under what conditions the project is feasible. Based on conditions for project participation [equations (5.1) and (5.5)], the project is feasible if conditions (6.3) and (6.4) are satisfied. The expressions on the left of these inequalities

Table 11. Transaction cost assumptions in base case

Cost type	Activity	Cost	Units
Buyer (project manager)			
W_{S1}	Consultation and negotiation	20,000	\$
W_{S1}	Establish baseline and carbon (C) flows of project for region	20,000	\$
W_{S1}	Design monitoring plan, establish permanent sampling plots	5,000	\$
W_{S1}	Prepare project design document	6,500	\$
W_{S2}	Design individual farm plans	200	\$/farm
W_A	Approval by host government	1,000	\$
W_A	Validate the project proposal (designated operational entity, DOE)	6,000	\$
W_A	Submit to CDM Executive Board (registration fee)	See table footnote[a]	\$
W_{P1}	Purchase IT infrastructure, establish local office	20,000	\$
W_{P2}	Maintain database/software and administer payments	10,000	\$/year
W_{P2}	Coordinate field crews, pay salaries	40,000	\$/year
W_{M1}	Randomly check C stocks reported by farmers	8	\$/ha/year
W_{M2}	Verification and certification of carbon by DOE	10,000	\$/y
W_{M3}	Adaptation fee	0.02	CER/year
W_{E1}	Maintain buffer of C	0.10	CER/year
W_{E2}	Settle disputes	100	\$/farm/year
Sellers (farmers)			
w_S	Attend information sessions	6	days
w_S	Undertake training	10	days
w_S	Design farm plan	4	days
w_A	Obtain permission to participate in project	4	days
w_P	Attend regular project meetings	5	days/year
w_M	Measure trees, fill in form and deliver to project office	3	days/ha/year
w_E	Protect plot from poachers and fire	10	days/year
w_E	Participate in dispute resolution	2	days/year

[a] Registration fees vary with project size: <15,000 CER = \$5,000; 15,000 to <50,000 CER = \$10,000; 50,000 to <100,000 CER = \$15,000; 100,000 to < 200,000 = \$20,000; >200,000 CER = \$30,000.

$$V_T = W_{S1} + W_A + W_{P1} + nW_{S2} + \sum_t \begin{bmatrix} W_{P2} + W_{M2} + n(W_{E2} + aW_{M1}) + \\ (W_{M3} + W_{E1})(C_{jt} - C_{0t})p_C \end{bmatrix} (1+\delta_B)^{-t} \tag{6.1}$$

$$v_T = \left[w_S + w_A + \sum_t \left[w_P + w_E + a\,w_M \right](1+\delta_S)^{-t} \right] p_L \tag{6.2}$$

$$v_C(a, p_F, C(t), \delta_S) - v_A(a, p_L, R(t), \delta_S) \geq v_T(p_L, q(t), \delta_S) \tag{6.3}$$

$$V_C(a, n, p_{CER}, C(t), \delta_B) - V_A(a, n, p_F, C(t), \delta_B) \geq V_T(a, n, p_{CER}, C(t), Q(t), \delta_B) \tag{6.4}$$

are the carbon margins; the expressions on the right are transaction costs (in present-value terms). Experiments consist of solving the model for different values of the arguments (in particular p_{CER}, p_F, a and n) and determining when both (6.3) and (6.4) are satisfied.

Farm price

The first step in the numerical analysis is to determine bounds for the farm price (Figure 11). This involves finding the minimum price acceptable to the seller and the maximum price the buyer is willing to pay. First, p_F is set such that $v_C - v_A = v_T$ and the resulting value is called p_S; then p_F is set such that $V_C - V_A = V_T$ and the resulting value is called p_B. The project is feasible only if $p_B \geq p_S$, and the farm price falls within the range $p_S \leq p_F \leq p_B$. The actual value of p_F depends on the market power of the participants, the objectives of the buyer and the outcome of negotiations between the buyer and seller.

The carbon margin for the seller ($v_C - v_A$ in Figure 11a) increases linearly with p_F, whereas the carbon margin for the buyer ($V_C - V_A$ in Figure 11b) decreases linearly with p_F. The intersections of the carbon margin curves with their respective transaction-cost curves indicate the price bounds (p_S, p_B). Given the assumptions in Tables 11 and 12, the feasible farm price ranges between \$0.83/tC and \$1.31/tC (Figure 11). For simplicity we now set the base price as $p_F = (p_S + p_B)/2$ to determine the effects of other project design variables; therefore p_F = \$1.07/tC in the base case.

Minimum farm size

The assumptions in Table 12 imply that the project covers 1,000 ha (500 farms of 2 ha each) and increases the biomass carbon stock by 89,300 tC above the baseline. This corresponds to a total of 327,731 CER produced by the project (89,300 tC × 3.67 tCO_2/tC). Given that we are dealing with smallholders, it is important to determine to what extent the size of participating farms affects the feasibility of the project. To answer this question, we solve the model for a range of values of a, while simultaneously adjusting n to keep project size constant at

Table 12. Other assumptions for base case

Variable	Value	Description
p_{CER}	20	Price of Certified Emission Reductions (\$/tCO_2e)
p_C	4.28	Farm price of carbon (\$/tC)
p_L	1.72	Price of labour (\$/day)
n	500	Number of farms in project
a	2	Average area of farm (ha)
δ_B	0.06	Buyer discount rate
δ_S	0.15	Seller discount rate
i	$\ln(1+\delta_B)$	Discount rate in carbon rental market
	89.3	Mean carbon stock (tC/ha) for damar[a]
	0	Mean carbon stock (tC/ha) for cassava (baseline)[a]
	4,372	Net present value (\$/ha) of damar[a]
	4,375	Net present value (\$/ha) of cassava (baseline)[a]

[a] Source: Ginoga et al. (2002)

1,000 ha (or 327,731 CER). While this operation does not affect the carbon margin, it has a significant effect on transaction costs for the buyer (Figure 12).

As farm size increases, the buyer's transaction costs fall at a decreasing rate and become relatively flat at farm sizes beyond 5 ha or so. Reducing farm

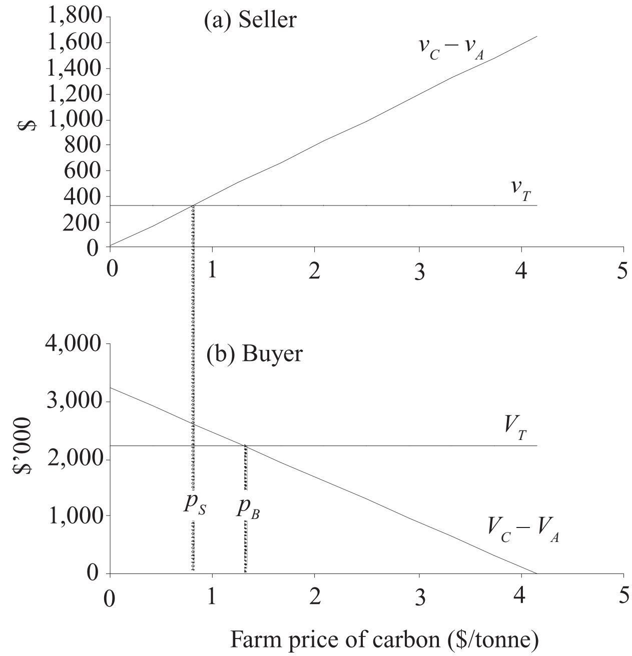


Figure 11. The range of farm prices within which the project will be feasible is derived by finding the minimum price acceptable to the seller in (a) and the maximum price acceptable to the buyer in (b).

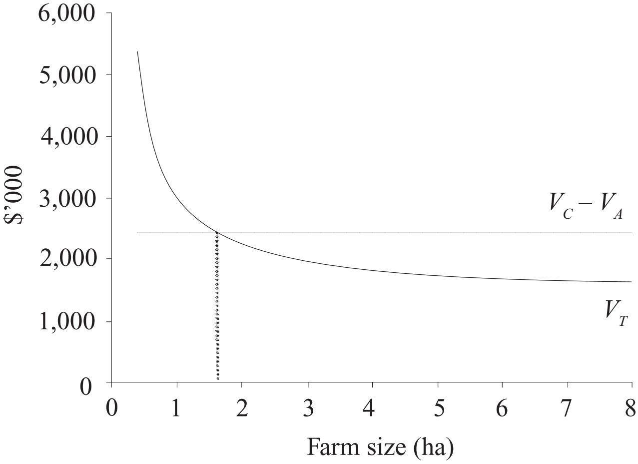


Figure 12. Minimum feasible farm size is indicated by the dotted line at the intersection of the carbon margin ($V_C - V_A$) and the transaction costs (V_T) for the buyer

size below 1 ha causes transaction costs to increase exponentially. The minimum farm size for the parameters given is 1.6 ha (Figure 12), which would require 625 participating farms to maintain total project area at 1,000 ha. At this point the buyer's transaction costs would be approximately \$2.42 million, which translates into \$7.39/CER. By comparison, for a project with 5-ha farms (requiring 200 farms to maintain the project area at 1,000 ha), the buyer's transaction costs would be \$1.75 million, or \$5.34/CER. Many farmers in Indonesia work areas of 1 ha or less and they would be excluded from this hypothetical project unless they could contract with the project as a group offering a larger area of land.

De Jong et al. (2004) report that families participating in the *Scolel Te* project in Mexico are able to initiate reforestation activities on 0.5–1.5 ha without a significant drain in their labour resource. According to our results, these farms would not be acceptable in the hypothetical project unless their carbon-sequestration potential could be increased, their transaction costs reduced, or both. These questions are considered later, through sensitivity analysis.

Corbera (2005) reports that Fondo Bioclimatico, the organisation that runs the *Scolel Te* project, increased the number of contracts between 1997 and 2004, from 43 farmers in 6 communities to 650 farmers in 33 communities. During the same period the reforestation area increased from 78 ha to 845 ha. This implies that the average farm area has fallen from 1.8 ha to 1.3 ha and may indicate that it has been feasible to accept smaller farms into the project as the initial infrastructure has been established and learning costs have been covered.

Minimum number of farms

Now assume that farm size remains constant at 2 ha, but it is possible to change the total project area by regulating the number of contracts with farmers (Figure 13). As the number of participating farms increases, both the carbon margin ($V_C - V_A$) and transaction costs (V_T) for the buyer increase linearly, but the former increases faster. Under this scenario, a minimum of 415 farms is required for a feasible project (with p_F fixed at \$1.07/tC). This will result in transaction costs of approximately \$2 million for a total project area of 830 ha capturing 272,017 tCO_2, and translates into transaction costs of about \$7.37/CER, which totally offsets the carbon margin. By comparison, with 1,000 farms transaction costs represent 73% of the carbon margin.

Now consider the possibility that, as the total project area increases, the maximum farm price the buyer would be prepared to pay may also increase. To confirm this, we solve the model for different values of *n*, while holding farm size constant at 2 ha and adjusting p_F until all carbon profits are dissipated; that is, for any given value of *n* we solve for the buyer's break-even value of p_F that makes $V_C - V_A = V_T$. Results of this analysis are presented in Figure 14. The buyer's farm price increases at a decreasing rate, from \$0.81 to \$1.91/tC, as the number of farms under contract increases from 355 to 1,000 and the total project area increases from 700 ha to 2,000 ha.

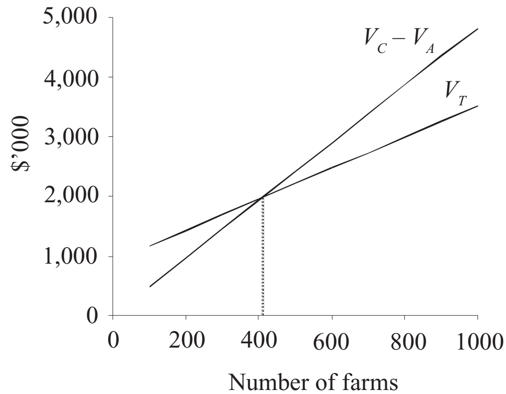


Figure 13. The minimum number of farms required for a feasible project is indicated by the dotted line. Note that the total project area increases as the number of farms increases because the farm size is fixed at 2 ha; farm price of carbon is \$1.07/tonne.

In Figure 14, the minimum number of farms (355) is that at which the buyer's maximum farm price is the same as the minimum price acceptable to the seller ($p_B = p_S$). Note that this number of farms differs from that associated with Figure 13 (415). Here p_F is endogenously determined as a break-even price for any given value of *n*, whereas in Figure 13 p_F was exogenously set at \$1.07 as the average between p_B and p_S.

Effects of CER price

The CER price used above (\$20/tCO_2e) is rather high, so it is important to determine how a lower price will affect project feasibility. In particular, it is of interest to evaluate how the CER price affects the critical values of p_S, p_B, *n* and *a*. Essentially, this involves changing p_{CER} and repeating the above analysis to identify the points at which the buyer's carbon margin ($V_C - V_A$) equals the transaction cost (V_T). Results are presented in Table 13.

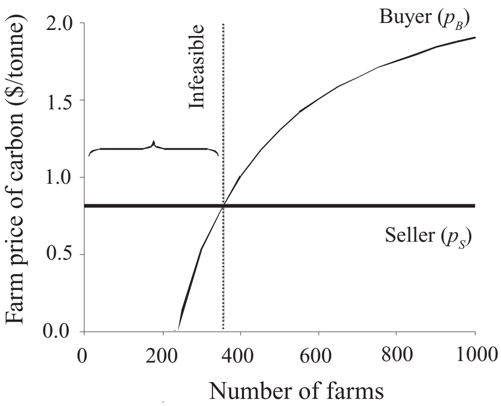


Figure 14. The break-even number of farms, indicated by the dotted line, is calculated as the point at which the maximum price the buyer is willing to pay (p_B) equals the minimum price the seller is willing to accept (p_S).

The middle column of results shows the base case already discussed; the other two columns are the results with p_{CER} values of \$25 and \$15. Given the transaction costs assumed and the default number of farms (500) and farm size (2 ha), a p_{CER} of \$15 is not feasible. At this CER price the buyer's price ($p_B = 0.39$) is below the seller's price ($p_S = 0.83$). Setting the farm price p_F at its lowest feasible value of \$0.82/tC, we find that the minimum farm area with constant project size (1,000 ha) is 3.43 ha, and the minimum number of farms at constant farm area (2 ha) is 771. The former result (the block labelled (a) in Table 13) is represented by downward shift of the $V_C - V_A$ line in Figure 12 as the CER price decreases, causing the new intersection with V_T to occur at a larger farm size. The latter result (block (b) in Table 13) is represented by a downward shift of the $V_C - V_A$ line in Figure 13, causing the new intersection with V_T to occur at a larger number of farms.

The last three rows of Table 13 (block (c)) are the most interesting because they show the absolute minimum possible project size (when $p_F = p_S$), or the break-even project size, rather than the minimum project size with p_F arbitrarily set at the mean between buyer's and seller's prices. The break-even number of farms increases from 355 at a p_{CER} of \$20 to 772 at a p_{CER} of \$15. This shift represents a doubling in project area from 710 ha to 1,544 ha and is equivalent to an increase in project size (in terms of CER) from 233 ktCO_2e to 506 ktCO_2e.

To put our results in perspective, consider that in May 2006 there were 176 CDM projects registered, claiming to reduce emissions by an average of 301,633 tCO_2e/year. Classified by size, there were 71

Table 13. Effect of Certified Emission Reduction (CER) price on critical values of project design variables

	Price of CERs (\$/tCO_2e)		
	25	20	15
Seller minimum carbon price (\$/tC), p_S	0.83	0.83	0.83
Buyer maximum farm price (\$/tC), p_B	2.22	1.31	0.39
Farm price (\$/tC), p_F	1.52	1.07	0.82
(a) *With project area constant (1000 ha):*			
Minimum farm area (ha)	1.18	1.61	3.43
Corresponding number of farms	846	622	291
Project CERs (tCO_2e)	327,891	327,891	327,891
(b) *With farm size constant (2 ha):*			
Minimum number of farms	312	415	771
Corresponding project area (ha)	624	829	1542
Project CERs (tCO_2e)	204,549	271,874	505,731
(c) *With minimum farm price ($p_F = p_S$):*			
Break-even number of farms	230	355	772
Corresponding project area (ha)	460	709	1,544
Project CERs (tCO_2e)	150,875	232,552	506,250

large-scale projects with average emission reductions of 638,133 tCO_2e/year and 78 small-scale projects claiming an average of 29,554 tCO_2e/year. To convert our results from stocks of carbon to flows of CO_2 and compare them with existing projects, note that the above-ground biomass carbon stock of the damar system is assumed to increase from 0 to 252 tC/ha in 25 years (Figure 10); this represents an annual CO_2 reduction of 37 tonnes (3.67 × 252/25); multiplying this value by the break-even project areas in Table 13, we obtain 17,020 tCO_2/year, 26,233 tCO_2/year and 57,128 tCO_2/year for CER prices of \$25, \$20 and \$15, respectively. So our hypothetical project may fit within the small-scale category at a CER price of \$20 or above.

The effect of CER price (p_{CER}) on minimum project size is nonlinear (Figure 15). The minimum number of farms required for the project to break even decreases rapidly as p_{CER} increases and the rate of decrease diminishes as p_{CER} increases. This curve will be used to derive a project feasibility frontier.

The project feasibility frontier

We have seen above that smaller projects become feasible as the CER price increases. So far, project feasibility has been expressed in terms of the number of participating farms of a given size. Often, it is convenient to express project size in terms of total CERs rather than number of farms, as this allows comparison with other projects, including those in the energy sector. Figure 16 shows how the minimum project size (in terms of CERs) decreases as the CER price increases. This curve forms a frontier because projects falling below or to the left of this curve are not feasible under the given transaction costs, whereas projects that fall above or to the right of the frontier are feasible. We call this curve the project feasibility frontier (PFF).

In essence, the PFF is derived by converting the inequalities in the expressions (6.3) and (6.4) into equalities and solving for the farm price (p_F) and number of farms (n) that satisfy both equations (6.5).

For any set of values in the argument list (the variables in brackets in equation (6.5)), these equations indicate the point at which the project becomes viable. Solving this system with respect to (p_F, n), we obtain the break-even point for both buyer and seller. This is the point at which the carbon margins just cover the transaction costs for both parties. The break-even value of n is then converted to CER units with the formula:

$$\text{project CERs} = n \times a\ (\text{ha}) \times 89.3\ (\text{tC/ha}) \times 3.67\ (tCO_2/\text{tC}).$$

$$\begin{aligned} &v_C(a, p_F, C(t), \delta_S) - v_A(a, p_L, R(t), \delta_S) = v_T(p_L, q(t), \delta_S) \\ &V_C(a, n, p_{CER}, C(t), \delta_B) - V_A(a, n, p_F, C(t), \delta_B) = V_T(a, n, p_{CER}, C(t), Q(t), \delta_B) \end{aligned} \tag{6.5}$$

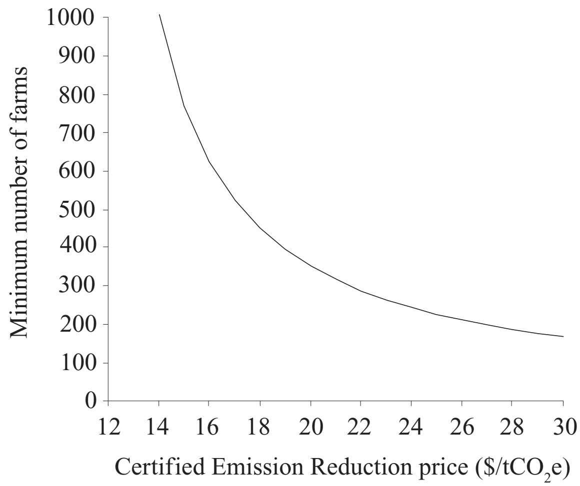


Figure 15. The break-even number of farms as a function of Certified Emission Reduction price for the base case

The PFF is plotted by solving equations (6.5) for different values of p_{CER}. The PFF is a convenient way to explore the influence of land productivity, individual transaction costs, or any other exogenous variable on the viability of a project. A new PFF can be derived by changing any exogenous variable and repeating the process, thus providing a useful tool for sensitivity analysis.

Effect of carbon-sequestration potential

The damar system in our project is assumed to increase average carbon stock by 89.3 t/ha over the life of the project (25 years) but, as shown in Appendix 1, there can be considerable variability in the productivity of farms within the same region. It is therefore important to determine the influence of carbon-sequestration potential on project viability. This can be done by modifying the carbon trajectory *C*(*t*) and solving equations (6.5). Figure 17 presents PFFs for three levels of carbon-sequestration potential: the base case, a low potential (0.75 *C*(*t*)) and a high potential (1.25 *C*(*t*)).

A change in carbon-sequestration potential causes the PFF to shift in the opposite direction. When *C*(*t*) increases by 25%, the PFF shifts left, so that, compared to the base case, smaller projects are viable at a given CER price, or lower CER prices are required to make a given project size viable. A decrease in *C*(*t*) has the opposite effect, and the effect is more pronounced. For an increase in carbon-sequestration potential, the elasticity of project size with respect to sequestration potential (Figure 18) ranges from –3.7 at a CER price of $11 to –1.1 at a CER price of $30. For a price decrease, the elasticity ranges from –5.4 at a CER price of $19 to –2.6 at a CER price of $30. These results indicate that a reduction in actual carbon sequestered relative to expectations can have a major influence on the success of the project.

Effect of transaction costs

The transaction costs assumed for this analysis were presented in Table 11. These values are arbitrary but plausible. They are based on our review of existing projects in Appendix 2 and cost estimates from the literature reviewed in Chapter 5. There is high uncertainty about some of these costs and thus it is important to evaluate their effect on project viability. This can be done by modifying the seller's transaction costs, *q*(*t*), and/or the buyer's transaction costs, *Q*(*t*), and solving equations (6.5). Figure 19 presents PFFs for three transaction-cost scenarios: the base case, low buyer cost (0.75 *Q*(*t*)) and low seller cost (0.75 *q*(*t*)).

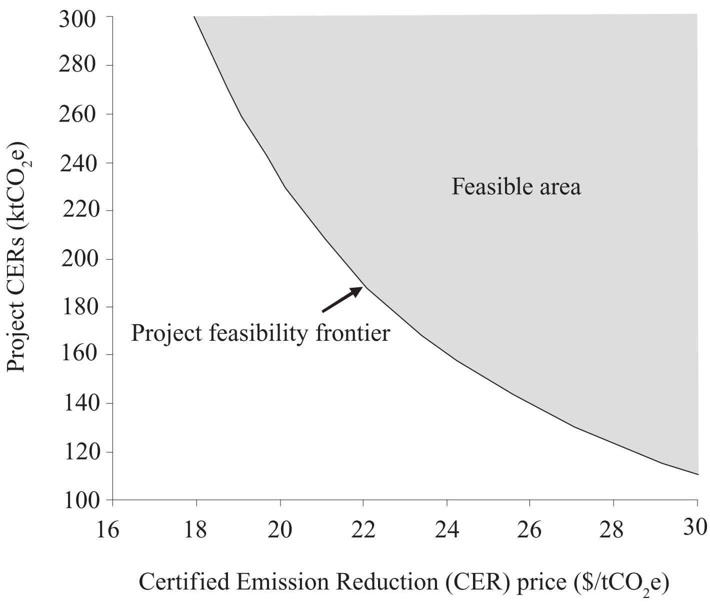


Figure 16. The project feasibility frontier

Decreases in transaction costs cause the PFF to shift left, making smaller projects viable at a given CER price, or lowering the CER price required to make a given project size viable. Buyer's transaction costs have a more pronounced influence than seller's transaction costs. The elasticity of project size with respect to buyer's transaction costs (Figure 20) ranges from 3.7 at a CER price of $11 to 1.4 at a CER price of $30. The elasticity of project size with respect to seller's transaction costs ranges from 3.3 at a CER price of

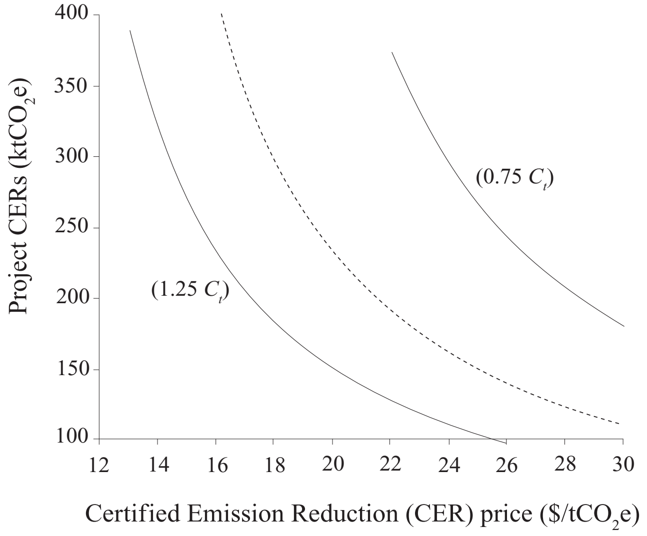


Figure 17. The effect of carbon-sequestration potential on the position of the project feasibility frontier. The dotted line is the base case, and the solid lines an increase (to 1.25 × base) or decrease (to 0.75 × base) in the carbon-stock trajectory.

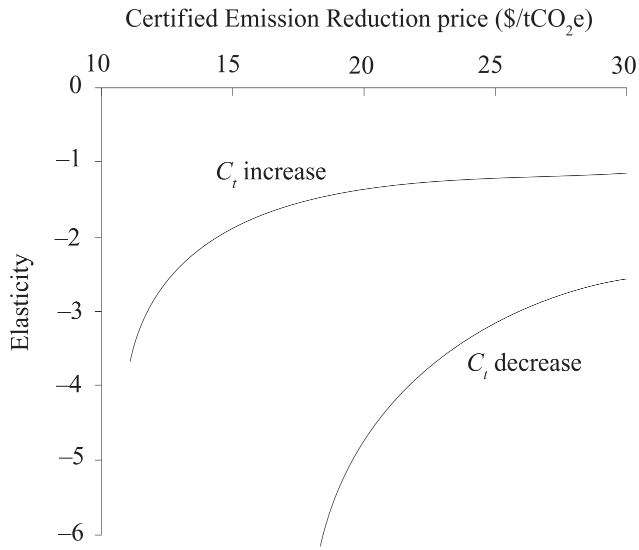


Figure 18. Elasticity of minimum project size with respect to changes in the carbon-sequestration potential of agroforestry

\$11 to 0.2 at a CER price of \$30. A value of 1.0 for the seller's elasticity is obtained at a CER price of \$14. Therefore, at high CER prices there is less pressure to reduce the seller's transaction costs than the buyer's. So reducing the transaction costs of buyers should be a priority when designing projects.

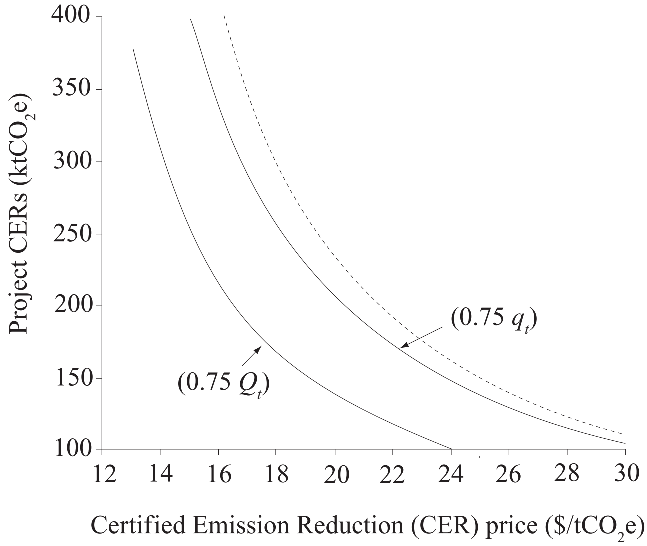


Figure 19. The effect of transaction costs on the position of the project feasibility frontier. The dotted line represents the base case, and the solid lines a 25% decrease in the transaction costs of the buyer (Q_t) or seller (q_t).

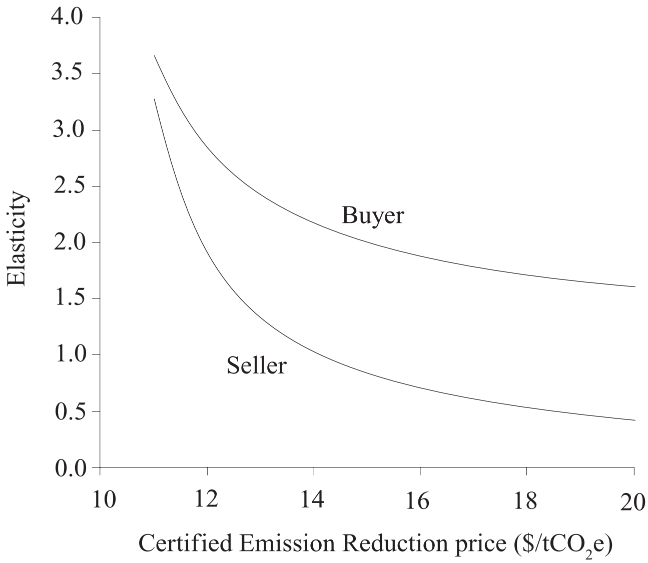


Figure 20. Elasticity of minimum project size with respect to reductions in transaction costs for the buyer and seller

7. Farm heterogeneity and other issues affecting project feasibility

Thus far we have assumed that farms participating in a project are homogeneous. This simplifies the analysis by allowing us to calculate transaction costs, abatements costs and carbon payments for the average farm, and then multiply the results by the number of farms to obtain project-level results. This simplification also makes it computationally feasible to derive the PFF for a large number of scenarios, thus helping us understand the influence of different types of transaction costs and other assumptions on the feasibility of a project. In deriving the PFF we implicitly assume that there are as many farms of a given area as needed by the project to cover transaction costs. In reality, a limited number of farms is available in a region, and expanding the project to other regions in an attempt to gain economies of scale may also increase transaction costs. Furthermore, there is considerable variability between farms in terms of size and productive capacity, as evidenced by the field results reported in Appendix 1. Antle and Valdivia (2006) observed this variability in US agriculture and pointed out that it may have important implications for policy analysis of payments for environmental services.

In this chapter we consider the role of farm heterogeneity, and derive supply curves based on the data for West Java and East Nusa Tenggara reported in Appendix 1. This allows us to evaluate whether it is realistic to expect these regions of Indonesia to contribute to AR CDM projects and, if so, under what conditions this participation is feasible.

Deriving probability functions of farm productivity

In Appendix 1, farm-level data on carbon mean annual increment (CMAI) are presented for two regions of Indonesia. Not surprisingly, we found that West Java (WJ) is more productive than East Nusa Tenggara (ENT), with CMAI values that were almost twice as large (7 kg/tree/year compared with 3.8 kg/tree/year). We converted those results to a per-hectare basis and fitted a cumulative distribution function to the data for each region. Figure 21 presents the farm data along with (a) the curves of best fit and (b) the corresponding probability density functions. It is obvious from these plots that the

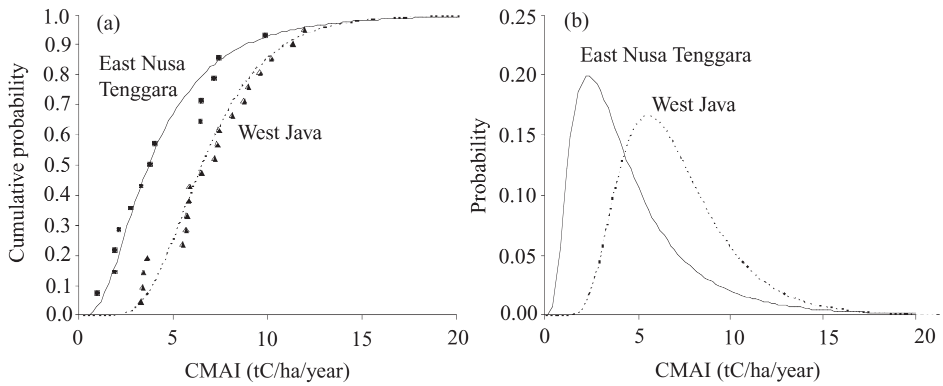


Figure 21. Lognormal probability functions for carbon mean annual increment (CMAI) and observed farm data for two regions: West Java and East Nusa Tenggara. Each point in the left panel represents a farm.

expected CMAI is higher in WJ than in ENT, and that there is considerable variability in both regions.

The curves presented in Figure 21 are lognormal distributions. Several distribution functions were considered but the lognormal provided the best fit (Table 14). The mean CMAI was 7.03 tC/ha/year for WJ and 4.66 tC/ha/year for ENT. The parameters of the distribution (μ and σ) are related to the mean and the variance of the underlying data. Both parameters are statistically significant for both regions, based on their standard errors. The lognormal distribution is restricted to values > 0; it has a long right tail, with the main body of the distribution located towards the left. These characteristics represent the farm data well because there are only a few highly productive farms. Most farms are concentrated towards moderate and low productivity. Differences in productivity between farms may be caused by differences in soil nutrients, inputs used, water availability, mix of tree species used and manager's ability.

Table 14. Results of fitting lognormal distributions to carbon mean annual increment (CMAI) results for two regions in Indonesia

	West Java	East Nusa Tenggara
Mean CMAI (tC/ha/year)	7.03	4.66
Standard deviation	2.93	3.56
Coefficients:		
μ	1.871	1.315
	(0.090)	(0.188)
σ	0.401	0.677
	(0.066)	(0.141)
Log-likelihood	–46.99	–34.91
Number of farms in sample	20	13

Assumptions for further analysis

Farms differ not only in terms of carbon-sequestration potential as observed above, but also in terms of size and profitability. Regarding farm size, results reported in Appendix 1 indicate that the average farm size is smaller in WJ (0.52 ha) than in ENT (1.4 ha). These differences are explained by the higher population density and land productivity of WJ. To simulate the observed variation in farm size, size distributions for the two regions were created based on the observed data (Figure 22).

Regarding farm profitability, we have no information on the variability of agroforestry NPV across farms, but we can make some plausible assumptions about the NPV of the project relative to the baseline. We will assume that the baseline is an *Imperata* grassland with an NPV of zero and a relatively constant stock of soil carbon. We will further assume that the grassland burns every year, releasing the accumulated biomass as CO_2. Therefore, the baseline carbon stock is zero (recall that we are considering only biomass, not soil carbon). Our brief review of the *Imperata* problem in Indonesia (see Appendix 1) indicates that it may take up to 200 person days of labour to clear a hectare of land and remove rhizomes to prevent reinvasion. Assuming the cost of this labour (plus associated materials) is Rp25,000/day, the total cost of preparing the land for tree planting would be \$575/ha (calculated as 200 × 25,000 / 8,700).

To concentrate the analysis within an interesting neighbourhood, assume that the NPV of agroforestry is the same as the cost of clearing the land of *Imperata* (\$575/ha). This means that the expected opportunity cost of land-use change is zero, and the average farmer is indifferent between doing nothing and clearing

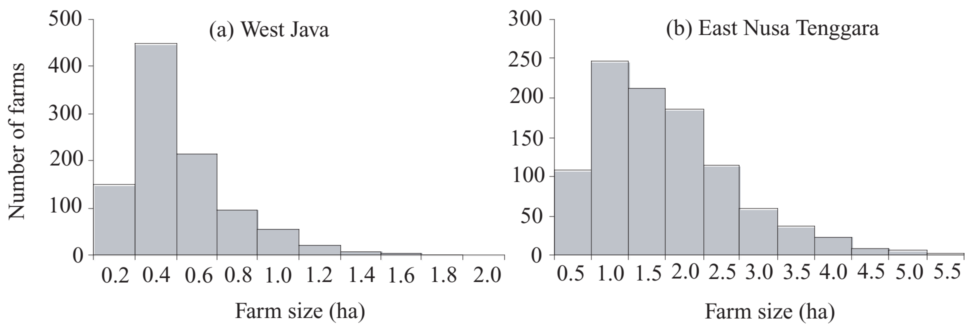


Figure 22. Assumed farm size distribution in (a) West Java and (b) East Nusa Tenggara, Indonesia

grassland to plant trees. Farmers who are below the average NPV will face a positive opportunity cost and those above the average will face a negative opportunity cost. In theory, the farmers in the latter group will not require an incentive to change land use, because a negative opportunity cost means that the land-use change is profitable. However, as discussed earlier, there may be other barriers to adoption, such as lack of access to credit and seedlings. If the mean NPV of agroforestry is \$575/ha and the standard deviation is \$230/ha, then the 95% confidence interval is –\$377 ≤ NPV ≤ \$1,525, which is a plausible range for the ENT region. West Java is more productive and would be expected to be less variable than ENT because of higher and more reliable rainfall. Based on the data reported in Table A6, we assume that the NPV of agroforestry in WJ is \$843/ha with a standard deviation of \$150/ha, then the 95% confidence interval for WJ is –\$246 ≤ NPV ≤ \$1,938.

Deriving the supply curve

We derive the carbon supply equation through simulation by the following steps:

1. Assign values to driving variables: total number of farms (n), NPV of agroforestry (mean and standard deviation), cost of clearing *Imperata* land, seller's transaction costs.
2. Draw a set of n random numbers and apply them to the lognormal distribution illustrated in Figure 21. The resulting set contains the carbon-sequestration potential of the farm population.
3. Draw a set of n random numbers and apply them to the farm-size distributions presented in Figure 22. The resulting set contains the area of the individual farms in the population.
4. Draw a set of n random numbers from a normal distribution with the mean and standard deviation of the agroforestry NPV defined in step 1. The resulting set contains the NPV values of individual farms.
5. For each element in the sets created in steps 2, 3 and 4, solve the project-participation model for the seller (see Chapter 6) and calculate the minimum farm price each seller is willing to accept (p_S).
6. Sort the set of p_S values in ascending order, along with the amount of carbon sequestered by the corresponding farm. Plot the cumulative carbon values against their corresponding prices (p_S). This is the supply curve derived for the heterogeneous farm population.

This procedure assumes that farm size, carbon-sequestration potential and agroforestry NPV are not correlated, because the random numbers in steps 2, 3 and 4 are drawn independently of each other. Carbon-sequestration potential and agroforestry NPV may be positively correlated. If this is the case, the supply curve will be flatter than in the no-correlation case. It is also possible that farm size and carbon-sequestration potential are negatively correlated, because smaller farms would tend to have more family labour available per hectare, allowing for better care of trees and crops. If this is the case, the supply curve would be steeper than in the no-correlation case. In the absence of data, any assumptions about the values of the correlation coefficients would be arbitrary and would complicate the analysis unnecessarily, given that the effects of the two plausible types of correlations would tend to cancel each other out. The supply curves derived for WJ and ENT by following steps 1–6 are presented in Figure 23.

Both supply curves (Figure 23) imply increasing marginal cost of carbon sequestration (i.e. the slope of the supply curve increases with carbon sequestered). This occurs because once the most efficient farms have adopted agroforestry it becomes increasingly difficult to capture additional carbon in the less efficient farms. Given our assumptions, WJ is a more efficient provider of carbon than ENT, as indicated by a lower supply curve.

The point where the supply curve crosses the horizontal axis indicates the amount of carbon that would be sequestered in the absence of an incentive. Up to this point, capturing carbon would be more profitable than the alternative (i.e. the abatement cost is negative). This 'critical' point is labelled *a* for WJ and *b* for ENT in Figure 23. Under a strict interpretation of the additionality requirement, farmers located to the left of their respective critical point (*a* or *b*) would not be eligible to participate in a CDM project unless it could be shown that they face constraints, other than opportunity cost, to adopt agroforestry.

The fact that point *a* is to the right of point *b* in Figure 23 confirms that farmers in WJ are more efficient providers of carbon credits and suggests, in addition, that farmers in WJ have the capacity to provide more total carbon than farmers in ENT. This latter result must be viewed with caution because it was generated by assuming that the same total area of land is available for conversion to agroforestry in both regions. This would require over three times as many farms in WJ than in ENT because farms in the former region are considerably smaller. If we keep the total number of farms constant between regions (rather than the total area), the WJ supply curve would become steeper than the ENT curve.

Project feasibility revisited

Now that we have derived supply curves for two regions, we can study the conditions under which a project would be feasible when the farm population is heterogeneous. We do this by solving the project participation model for the buyer, but we now use the farm population generated in steps 1–6 above instead of assuming all farms are identical. We then plot the minimum price farmers are willing to accept (p_S) and the maximum price the buyer is willing to pay (p_B) as functions of project size measured in terms of CERs. Recall that the project is feasible only if $p_B \geq p_S$.

We found that, with transaction costs assumed for the base case in Chapter 6 and with a CER price of \$20/tCO_2e, a project would not be feasible in either region. Furthermore, we found that p_B was negative in WJ, meaning that the project was not feasible even with very large project sizes. In comparison, p_B was positive for large project sizes in ENT but, because it was below p_S, the project would be infeasible because it could not provide the incentives required by farmers. This result is interesting in that it shows that WJ, although it can provide carbon more efficiently in terms of abatement costs, underperforms ENT in terms of transaction costs. This difference in transaction costs is caused by the smaller farm sizes in WJ. In light of these results we will concentrate further analysis on the ENT case (Figure 24).

Figure 24 illustrates that a project in the simulated ENT scenario would not be feasible at current CER prices. The project is infeasible at prices as high as \$25/tCO_2e (Figure 24a) but becomes feasible at a price of \$35/tCO_2e (Figure 24b). At the higher price, p_B is above p_S over a small interval, indicating that there is a limited range of feasible project sizes. This feasible range is illustrated in Figure 25, which indicates that the hypothetical project must have between 150 and 250 participating farms to be feasible. The village sampled in ENT is associated with 221 households (most of them farmers). The results thus suggest that the required project size would be feasible in this area, provided the CER price is \$35.

Recent CER prices have ranged between \$3 and \$12/tCO_2e, well below the \$35 that would make our hypothetical ENT smallholder project feasible. In the European Union, carbon market prices have exceeded \$30 in the past, but they have fallen recently and the EU-ETS system does not accept biomass carbon. The evidence therefore suggests it is unlikely CERs will reach a price high enough to shift the p_B curve up into the feasible area (see Figures 23a and b).

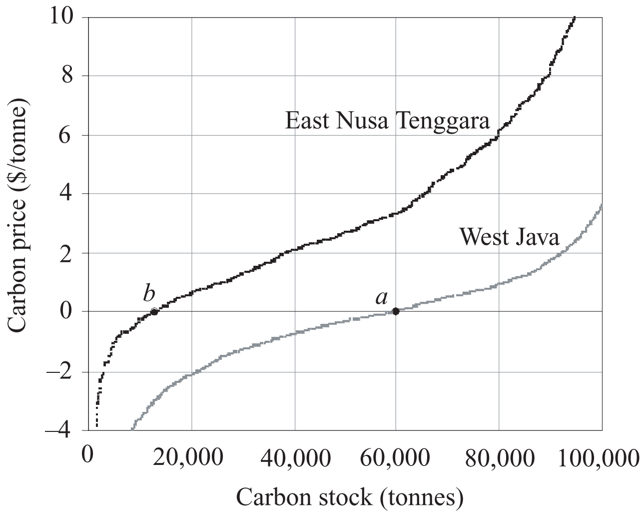


Figure 23. Estimated carbon supply functions for West Java and East Nusa Tenggara (ENT), Indonesia

The remaining question is whether enough of an upward shift in p_B can be obtained by reducing transaction costs, thus making the project feasible. Haites (2004) states:

> The simplified methodologies adopted by the Executive Board for small-scale CDM projects appear to reduce the transaction costs for those projects enough to make such projects economically viable. Evidence as to whether the transaction cost per CER is higher or lower than for a regular CDM project is mixed. But indications of a supply of potential small-scale CDM projects suggest that the transaction costs for the simplified methodologies are sufficiently low to make some small projects economically viable at the current market price for Kyoto units.

This statement refers to projects in the energy sector, which tend to be easier to monitor. It is not clear whether the same applies to LUCF projects. For our hypothetical ENT project, we may ask: by how much would transaction costs have to be reduced in order to make the project feasible at current CER prices?

Figure 26 shows that decreasing transaction costs to 50% of the base value can produce enough of a shift in p_B to make the project feasible at a CER price of \$15. It remains to be seen whether the simplified rules of CDM for small-scale projects could reduce transaction costs by this much.

Other project design issues

The analytical tools developed in this study can be applied to address a rich variety of questions with relevance to policymakers and project developers. Some interesting questions that are not answered here, but that could be tackled by applying our model, are discussed in this section.

We have assumed that carbon stocks are measured, verified and certified, and the new batch of CERs is submitted every year, thus supplying the carbon project with an annual income stream. Similarly, participating farmers receive annual payments in proportion to the stock of carbon they maintained during the year. Variations on these schedules are possible. For example, the project may certify and sell temporary CERs every 5 years, thus reducing monitoring and certification costs, but also delaying the receipt of payments and therefore increasing the need for credit.

Variations in the schedule of payments to farmers are also possible. For example, the project could provide a larger initial payment, to help farmers cover the expense of establishing agroforestry in their land, followed by smaller future payments. The payment schedule would be designed so that the present value of the total payment is the same as it would have been with annual payments. The Fondo Bioclimatico carbon project in Mexico offers an example of this approach. In their first year of participation, farmers receive an up-front payment equivalent to 20% of the total amount to be accrued over 20–30 years. Three more payments of 20% are made in years 2, 3 and 5, and the final payment is made in year 10 (Corbera 2005). This strategy requires the project developer to take on more risk, because initial payments exceed the value of the carbon already sequestered, and this money would be lost should farmers abandon the project. However, the strategy also raises interesting possibilities. Since the seller's dis-

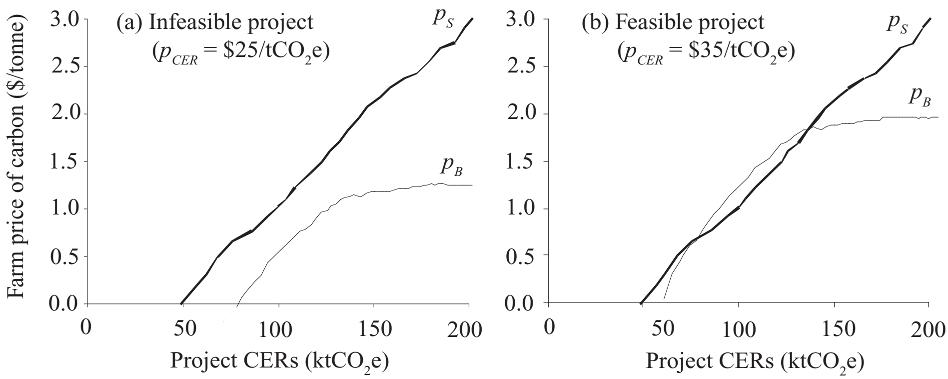


Figure 24. Minimum seller carbon price (p_S) and maximum buyer carbon price (p_B) as functions of project size for two different Certified Emission Reduction prices (p_{CER})

count rate is higher than the buyer's, the project developer can increase the present value of payments to farmers while keeping the present value of his own cost constant, thus providing higher incentives with no additional cost (although with some additional risk).

We assume in our analysis that all participating farmers join the project in its first year, and that the number of participants remains constant throughout the project. In reality, the project may start with a few farmers and, if it is successful, grow as other farmers apply to join once they observe the advantages of participation. The Fondo Bioclimatico provides an example of this evolution (Corbera 2005). The project started in 1997 with 6 communities, 43 contracts and covering 77.5 ha. By 2004 the project had 33 communities, 650 contracts and covered 845 ha. As the project has grown and fixed costs have been absorbed, it has become feasible to allow smaller farms to participate.

Good project design

The poor in any country have limited opportunities to adopt technologies, particularly when they are not part of the cash economy. Also, environmentally sound technologies with relatively small project sizes and long repayment periods deter banks because of high transaction costs. IPCC (2001) reviews a number of innovative approaches to overcome these problems, including leasing, environmental and ethical banks, micro credit, small grant facilities tar-

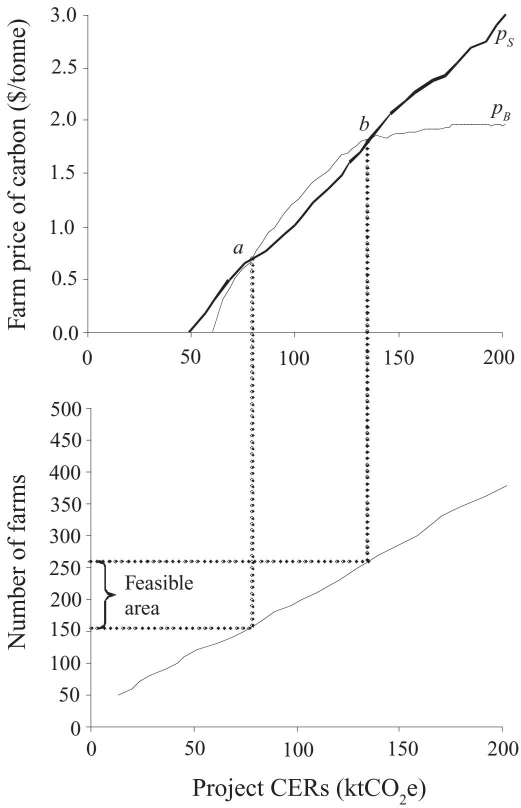


Figure 25. Certified Emission Reductions (CERs) supply (p_S), maximum buyer price (p_B) and feasible number of farms with a CER price of $35/$tCO_2e$

geted at low-income households, environmental funds, energy service companies and green venture capital. In this section we discuss other ideas about the design of projects to encourage participation by smallholders.

Authors such as Smith (2002), IPCC (2001) and Baumert et al. (2000) have recommended strategies to reduce the transaction costs of making the CDM operational in smallholder contexts and thereby contribute to sustainable development. Cacho et al. (2003b) reviewed these and added some ideas of their own. These strategies can be classified into six major categories:

- generate and disseminate information
- teach smallholders to measure carbon
- select areas where community cohesion is strong and encourage community self-regulation
- bundle projects and payments for other environmental services
- promote secure land tenure
- develop smallholder contracts.

Each of these strategies is briefly discussed.

Generate and disseminate information

This includes the sort of research that is undertaken by CGIAR centres and national research agencies. It is also illustrated by the examples presented in Appendix 1 for Indonesia. By producing information on suitable production systems and their profitability, we can decrease the search costs of starting a new carbon project. Generating information on projects where smallholders are likely to be competitive suppliers (e.g. low opportunity costs) is also needed.

Establishment of baselines can be expensive, particularly in areas subject to rapid changes in population and government policies. Under the CDM, small projects (less than 15,000 tCO_2/year) are allowed to use simplified methods to estimate baselines and monitor emissions. Moura-Costa et al. (2000) suggest that generic baselines based on sector, region or country can be developed and integrated in a system of 'technology matrices' similar to those used in the energy sector. These methods need to be developed and may represent efficient use of development research assistance.

Perhaps more work is required in developing efficient ways of storing information and making it available to potential market participants. The Profafor project and the FACE Foundation have made some progress on this front. In all FACE projects, a monitoring and information system is used to determine the amount of carbon sequestered. The system stores administrative, financial and technical information for each forestation plan. It also keeps track of technical assistance and production of seedlings (FACE 2000).

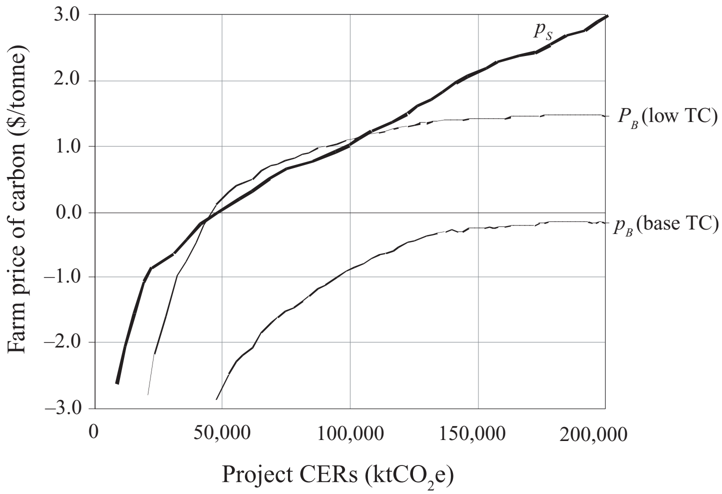


Figure 26. The effect of a decrease of 50% in transaction costs (low TC) on the feasibility of the East Nusa Tenggara project compared with the base values (base TC) at a Certified Emission Reduction (CER) price of $15/tCO_2e$

Dissemination of information among smallholders and farmer groups can reduce transaction and abatement costs. This can be done by host-country extension services as well as by NGOs and international research centres. Once a few examples of successful systems are established, word of mouth may work well. This has been the case in the Profafor project in Ecuador and *Scolel Te* in Mexico, where farmers have approached the investor after learning about the project from other farmers in the area. It is also necessary to disseminate information about the potential of the smallholder sector to supply carbon credits to potential buyers.

Train smallholders

According to ASB (Hairiah et al. 2001), farmers in Sumatra have shown that they are used to assessing the volume of wood in their trees.[9] This suggests that, if farmers learn the value of carbon biomass, they can monitor their plots at low cost. Delaney and Roshetko (1999) state that it took only 2 days for a crew to learn inventory methods to measure carbon in agroforestry gardens in Java. This provides further evidence that it may be possible to train smallholders to identify and measure their own trees and complete a sample sheet. The sample sheet could then be delivered to the project office in order to receive payment for the carbon sequestered. The project office would enter the data into a database and estimate carbon stocks using allometric equations.

There is an agency problem inherent in expecting smallholders to undertake these tasks, to the extent that scope exists for them to misreport carbon sequestration in their trees in order to reduce their costs of project compliance. However, practical ways to limit this scope may exist. For instance, a system of randomly checking reports from smallholders may, if combined with substantial penalties for misreporting, make opportunism in this area too costly for them to contemplate. Also, if the project benefits the community as a whole, and if rewards from the whole project depend on all smallholders doing the right thing, an incentive exists for community members to monitor and police one another.

The advantage of involving smallholders is apparent when it is considered that the accuracy of carbon measurements depends on sampling intensity. A large group of smallholders could achieve high measurement accuracy by allowing intensive sampling at a fairly low cost. This idea is illustrated in Figure 27, which was produced with the model of Cacho et al. (2004) for *Acacia mangium*. Carbon stocks are normally estimated based on sampling of a limited number of plots because it is not practical to measure every single tree in a project. When there is high variability between trees, the number of plots required to achieve a given level of confidence is also high.

Figure 27c presents results from Cacho et al. (2004) for the amount of CERs that can be obtained by a reforestation project based on the reliable minimum estimate (the lower 95% confidence limit) when the coefficient of variation is 0.8. The project is able to obtain a larger number of CERs per ha by increasing sampling intensity (the number of sample plots). Figure 27a shows two marginal cost (MC) curves. MC_1 assumes it costs \$10 to measure each sampling plot and MC_2 assumes \$50 per plot. The optimal sampling intensity occurs where marginal revenue (MR) equals MC. The intersection of MR and MC is indicated by dotted lines for both MC curves. Figure 27b simply translates the horizontal CER axis into a vertical axis to enable mapping between Figure 27a and Figure 27c. In this case the high marginal cost curve (MC_2) results in an optimal number of 24 sampling plots (n_2) and carbon credits of 91 tCO_2/ha, whereas the low marginal cost curve (MC_1) results in an optimal number of 70 sampling plots (n_1) and carbon credits of 101 tCO_2/ha. MC_1 could represent the cost of smallholders sampling each other's plots, and MC_2 may represent the cost of technicians travelling to the area to undertake monitoring. In this example the former strategy results in a 10% increase in carbon credited.

Select cohesive communities and encourage community self-regulation

One way to reduce the costs of smallholder involvement in carbon-sequestration projects may be to develop projects on a community basis rather than with individual smallholders. In Chapter 6 we showed that increasing the average area of the participating farms makes the project more viable by decreasing V_T and therefore increasing the difference between carbon margins and transaction costs. The ultimate effect of an increase in farm area is a shift in the PFF (Figure 28).

Figure 28 suggests that contracting with communities or farmer groups is more likely to bring success

[9] Interestingly, in farmers' minds, trees without wood value have no volume.

than contracting with individual farmers, simply because there are fewer contracts to negotiate, monitor and enforce. To put these results into context, consider that the average size of projects that had been registered with the CDM by May 2006 was about 300 ktCO_2e (indicated by the horizontal dotted line in Figure 28). A project of this size would be feasible only at a CER price of $18 for the base case (with a farm area of 2 ha). If, however, the project were to contract with groups of farmers supplying an average of 20 ha per contract, it would become feasible at a CER price of $10.

This example illustrates only one aspect of contracting with farmer groups. Another benefit of a community-based strategy is that it may encourage informal regulation within farmer groups, which could substitute for formal regulation imposed from the outside. Nevertheless, realising the potential of a community-based strategy to promote informal regulation could be expected to depend on community members perceiving the project to be fair. Participatory approaches can promote informal project compliance mechanisms, thus reducing the ex-post transaction costs of projects at the expense of increases in the ex-ante transaction costs caused by a more inclusive decision process during project design.

A possible implication of selecting cohesive communities already organised into farmer groups may be that cost-effectiveness concerns will lead to attention being directed mostly at communities that already possess much of the capacity required to manage projects. The concern is that the CDM may tend to neglect the communities least able to organise themselves and that presumably are most in need of outside help to alleviate their problems of poverty. However, the primary goal of the CDM is climate mitigation, and poverty alleviation is a welcome bonus. A good example of this is provided by the PDDs that are being drafted with funding from ADB (see Appendix 2). In this project, district representatives were invited to submit proposals largely based on their capacity to design and implement reforestation projects. This selection process is justified, particularly during the learning phase of the CDM, where it would be wasteful to attempt to establish

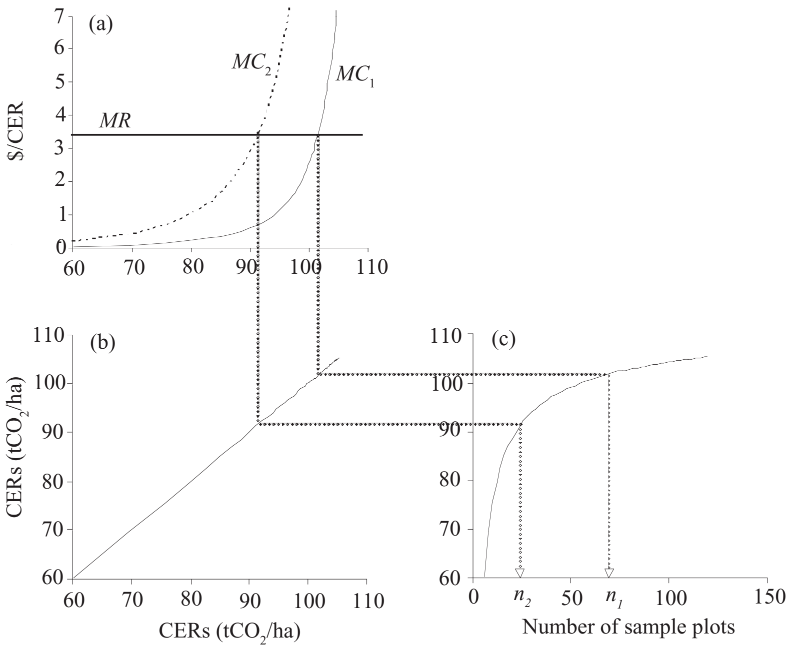


Figure 27. The effect of the marginal cost of sampling carbon ($/Certified Emission Reduction (CER)) on the optimal monitoring intensity (number of sample plots)

projects with communities that do not have the appropriate social infrastructure. Arguably, capacity building of disadvantaged communities should be funded by development aid rather than by the CDM.

Project and payment bundling

The creation of institutions and financial intermediaries to bundle carbon-sequestration projects into a portfolio, such that investors would not be tied to a particular project, is desirable (Michaelowa and Dutschke 2000). Such an approach is likely to increase the attractiveness of investing in small-scale projects to a wider set of investors who are either risk averse or financially constrained by the high pre-implementation costs. It is also likely to provide potential project hosts with access to a broader capital base and thus access to more diverse projects than available under a bilateral system (Wexler et al. 1994). Another advantage of this approach is that transaction costs can be reduced by pooling technical skills for developing baselines and monitoring plans (Baumert et al. 2000).

The potential for project bundling is illustrated by the FACE Foundation in the Netherlands, which has several projects in Latin America, Europe, Asia and Africa, and has developed infrastructure including geographical information systems, database and modelling tools, and protocols for monitoring and certifying carbon stocks. This means that project design and baseline estimation costs should be lower for new projects.

There is also scope for exploiting synergies between the UNFCCC and other international agreements such as the Convention on Biological Diversity (CBD). Where projects provide services relevant to both conventions, it may be possible to bundle payments to smallholders and communities. This may be through co-financing project design and implementation, or by providing payments to bridge the gap required to effect land-use change.

Land tenure

In reporting on a study of agroforestry management in Sumatra, Suyanto et al. (2001, p. 140) state: 'The expansion of formal credit institutions into these relatively remote areas and the establishment of official land title will become increasingly important as further intensification of the land use is required'.

In a large study in Uganda, Ghana and Sumatra, Otsuka and Place (2001b) found that commercial trees have been planted on communal land as much as on private land. They went on to observe (Otsuka and Place 2001b, p. 368):

> It is widely believed ... that because of weak individual rights or tenure insecurity, trees are not planted and well managed under communal ownership … If the com-

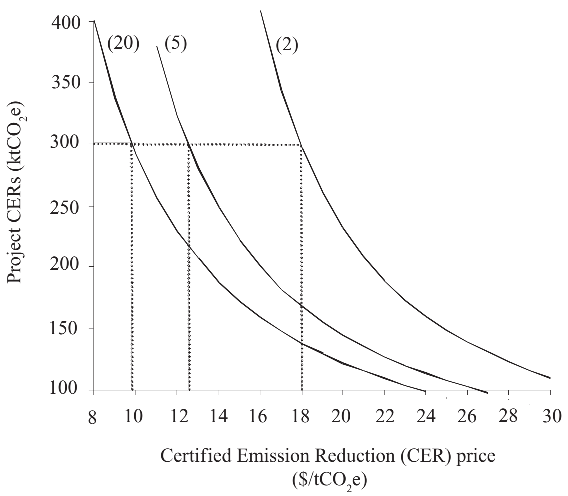


Figure 28. The effect of average farm size (2, 5 and 20 ha) on the project feasibility frontier

munal tenure institutions provide sufficient incentives to plant and manage trees, however, the enhanced efficiency of land use can reduce the incidence of poverty in marginal areas. Furthermore, the establishment of agroforestry in sloping land will help reduce soil erosion and contribute to the partial restoration of tree biomass and biodiversity.

Tomich et al. (1997) suggest that, where *Imperata* grasslands are a problem, smallholders could be granted tenure of land that they convert to forest, to provide an incentive to undertake an activity that is expensive and labour intensive.

Outgrower schemes

Outgrower schemes can inject capital, technical knowledge and access to inputs. Typical outgrower schemes consist of contracts between smallholders and agribusiness companies to produce high-value foods. Although these schemes are often associated with lower output prices and are viewed negatively by NGOs (Smith 2002), there are examples of successful contracts (Glover and Kusterer 1990). Smallholders may wish to participate in contracts based on revenue implications, cost implications and exposure to risk. They may receive advantages such as access to product markets and credit, and more stable prices (Simmons 2003).

Although smallholder contracts may be subject to high ex-ante transaction costs, these may be ameliorated by farm groups or other community organisations playing a part in negotiations. A contract is more likely to be successful if it provides benefits to the community as a whole. If it creates inequalities, it may be possible to compensate the losers in some way. There is evidence that interaction between farm groups and NGOs can increase the chances of success of a contract (Simmons 2003).

8. Conclusions

This study was motivated by the possibility that markets for greenhouse gas emissions may benefit smallholders in developing countries, by compensating them for adopting agroforestry systems that capture more CO_2 from the atmosphere than traditional cropping systems. The research project was based in Indonesia but the principles identified and the techniques developed have application to other countries and, indeed, to environmental services other than carbon sequestration. Furthermore, although the analysis of transaction costs has focused on the Clean Development Mechanism (CDM) of the Kyoto Protocol, the analytical techniques can be applied to other project-based mechanisms, such as the Prototype Carbon Fund of the World Bank.

We emphasised the need to consider both abatement and transaction costs when assessing the viability of landholders undertaking agroforestry projects to supply carbon-sequestration services. Abatement costs are the costs of producing one unit of (uncertified) carbon-sequestration services. In any given location, abatement costs can be estimated as the opportunity cost of undertaking a carbon-sequestration activity rather than the most profitable alternative activity, or the cost of switching from the previous land use to the proposed land use. In order to participate in the carbon market, it is not enough for projects to cover their abatement costs; they also incur transaction costs to certify the abatement services they provide. We outlined a typology of transaction costs in the context of landholders supplying carbon to the market. Five types of transaction costs were identified: search and negotiation, approval, project management, monitoring, and enforcement and insurance. Such a typology helped us to identify the institutional arrangements most likely to promote the competitiveness of projects in specific circumstances.

We posed three questions: (i) how do smallholders compare with other landholders in terms of efficiency in sequestering carbon? (ii) how likely is it that smallholders will want to adopt carbon sequestering activities? (iii) what sorts of policies and projects will make this more likely?

To answer the first two questions, we studied several agroforestry systems that have been adopted by smallholders in three regions of Indonesia. These systems were evaluated in terms of their economic performance, labour requirements and carbon-sequestration potential. It was found that some of these systems are competitive with other climate-mitigation measures in terms of abatement costs per tonne of CO_2 emissions reduced. It was argued that carbon sequestration may be a desirable activity for smallholders in remote areas because they do not need to transport their product to markets and they do not face the quality differences that may affect other, especially perishable, products. Obviously, smallholders cannot participate directly in the international carbon market, but they could participate in carbon-sequestration projects designed by intermediaries. A possible obstacle to the participation of smallholders in carbon markets is the need for monitoring, verification and enforcement of project activities, and their associated transaction costs. Hence the importance of the third question.

To answer the third question, we obtained evidence on the transaction costs that may be faced by projects involving smallholders. Costs of the projects studied ranged from \$477/ha to \$2,066/ha. Depending on the carbon-sequestration potential of these projects, these costs would be equivalent to between \$2.17/tCO_2 and \$18.76/tCO_2. The highest cost corresponds to a proposed project in West Nusa Tenggara and is based on an average carbon stock of 30 t/ha. This project is being designed for submission to the CDM and is expected to experience higher transaction costs than reforestation projects that do not require certification of carbon stocks. These cost estimates include some abatement costs in addition to transaction costs, and it was not possible to disaggregate them in order to evaluate the effect of project design.

Project-based carbon-sequestration projects were analysed based on a model of project participation. The conditions for a buyer (project developer) and a group of sellers (farmers) to participate in an agroforestry project were identified. The model accounts for abatement costs, transaction costs and carbon payments as functions of a set of variables that include discount rates, the price of carbon, and the number and size of participating farms. Three important project-design variables were identified: the farm price of carbon, the number of participating farmers, and the area of their farms. These variables are under the control of the project developer, subject to constraints imposed by international carbon prices and the availability of enough farmers in an area who are able and willing to change land use from the baseline to the project activity. The model allows us to estimate the conditions under which a project will be feasible. Economies of scale were shown to be an important factor, with costs per tonne of carbon sequestered dropping considerably as the area covered by the project increased.

We derived a project feasibility frontier (PFF) that shows the minimum project size that is viable for a given carbon price. We found the PFF to be a useful tool for project evaluation and to perform sensitivity analysis. Project viability is highly sensitive to not only transaction costs and carbon-sequestration potential, but also the size of participating farms. Project viability is particularly hampered when participating farms are smaller than 1 ha.

The importance of heterogeneity among farms in terms of size and productivity was studied through simulation. We estimated probability functions and generated supply curves for West Java and East Nusa Tenggara based on the farm data collected. The project-participation model was modified to include the supply curves instead of a fixed farmer price. Whereas in the fixed-price case the project size was only bound from below and could become as large as desired, in the supply-curve case the viable project size was bound on both sides. The lower bound was caused by the need to cover fixed transaction costs, and the upper bound by increasing marginal cost of carbon sequestration.

Our results indicated that a project involving smallholders with individual contracts required CER prices ranging between $12/tCO_2$ and $18/tCO_2$. These prices exceed the average market price experienced in 2005 ($7.22/tCO_2e$). Although recent prices have been higher ($11.45/tCO_2e$), there is no certainty that they will remain high in the future.

Our results need to be qualified in two respects. They are contingent on the level of transaction costs assumed, and they are based on modest estimates of carbon-sequestration potential. We were intentionally conservative to avoid painting an overly optimistic picture, and did not include carbon stored in soil and roots in our calculations.

Model results indicated that project viability can be increased significantly by contracting with communities or farmer groups rather than individuals. For example, when the participating farms have an average area of 2 ha, a project sequestering 300,000 tonnes of CO_2 over 25 years would require a CER price of $18 to become feasible. In contrast, when contracts are based on farms with an average area of 20 ha, the project would be feasible at a CER price of $10. This means that pooling their land would make farmers more competitive in the CER market.

It was also found that project viability is significantly enhanced by selecting fast-growing tree species. The elasticity of minimum project size with respect to carbon-sequestration potential was below –3.0 at CER prices of $12 or less. This means that a 1% increase in carbon captured decreases the minimum size required for a viable project by 3% or more. Similarly, minimum project size was found to be elastic with respect to transaction costs, with elasticities > 3.0 at CER prices of $12 or less. This means that a 1% decrease in transaction costs decreases the minimum size required for a viable project by 3% or more.

The baseline is another factor that can have significant influence on project viability, in terms of both opportunity cost and expected carbon stocks in the absence of the project. Our results suggest that the best strategy for achieving success is to concentrate on degraded lands that have low opportunity cost and low carbon stocks. There are millions of hectares of *Imperata* grasslands in Indonesia that may be ideal candidates for CDM projects. It is expensive (in terms of labour and materials) to clear these lands and establish trees. Carbon credits could provide funding to allow this to happen. The incentives to participate would be enhanced if communities and individuals were offered tenure of the degraded land they restore.

Based on the evidence gathered and the modelling undertaken, we answered the first two questions in the positive: (i) some smallholder systems are competitive in terms of abatement costs; and (ii) some smallholders view agroforestry as a desirable activity and have adopted it even in the absence of incentives. The role of a carbon-sequestration project would therefore be to stimulate adoption by those smallholders who may need only a small incentive to switch land use. The answer to question (iii) is more complex. Suitable policies coupled with projects that target land of low opportunity cost may produce the incentives required to enhance the adoption of agroforestry systems while contributing to greenhouse gas abatement. The most desirable policies would be those that reduce transaction costs while ensuring that carbon changes are real, directly attributable to a given project and additional to any changes that would have occurred in the absence of the project.

References

Antle J.M. and Valdivia R.O. 2006. Modelling the supply of ecosystem services from agriculture: a minimum-data approach. Australian Journal of Agricultural and Resource Economics 50, 1–15.

Arifin B. 2005. Institutional perspectives of lifescape co-management: lessons learned from RUPES sites in Sumatra, Indonesia. Pp. 156–176 in 'Carbon forestry: who will benefit?', ed. by D. Murdiyarso and H. Herawati. Workshop on carbon sequestration and sustainable livelihoods, CIFOR, Bogor, Indonesia.

ASB (Alternatives to Slash-and-Burn) 2001. The Krui agroforests: a model of sustainable community-based management. ASB Policy Briefs, July 2001. At: <http://www.asb.cgiar.org>.

Baumert K.A., Kete N. and Fueres C. 2000. Designing the Clean Development Mechanism to meet the needs of a broad range of interests. World Resources Institute, Climate Energy and Pollution Program, August 2000, Washington DC.

Betz R. 2006. Emissions trading to combat climate change: the impact of scheme design on transaction costs. Contributed paper, conference of the Australian Agricultural and Resource Economics Society, Manley.

Blanco J. and Forner C. 2000. Special considerations regarding the "expiring CERs" proposal. International forum on enhancement of Japan's private sector overseas re-afforestation cooperation, fall 2000. Ministry of the Environment, Colombia, 17 pp.

BRLKT (Balai Rehabilitasi Lahan dan Konservasi Tanah) 2000. Rencana Kerja Pembangunan Hutan Rakyat Desa Cirumput, Kecamatan Cugenang, Kabupaten Cianjut (Bantuan JIFRO). BRLKT Citarum–Ciliwung: Bogor.

— 2001. Rancangan Model Hutan Rakyat Bantuan JIFRO Tahun 2000/2001. BRLKT Citarum–Ciliwung: Bogor.

— 2002a. Rancangan Dam Penahan Bantuan JIFRO Tahun 2002/2003. BRLKT Citarum–Ciliwung: Bogor.

— 2002b. Rancangan Gully Plug Bantuan JIFRO Tahun 2002/2003. BRLKT Citarum–Ciliwung: Bogor.

— 2002c. Rancangan Model Hutan Rakyat Bantuan JIFRO Tahun 2002/2003. BRLKT Citarum–Ciliwung: Bogor.

Brown I.F., Martinelli L.A., Thomas W.W., Moreira M.Z., Ferreira C.A.C. and Victoria R.A. 1995. Uncertainty in the biomass of Amazonian forests: an example from Rondonia, Brazil. Forest Ecology and Management 75, 175–189.

Brown S. 1997. Estimating biomass and biomass change in tropical forests: a primer. Forestry Paper 134, Food and Agriculture Organization, Rome.

— 2001. Measuring and monitoring carbon benefits for forest-based projects: experience from pilot projects. In: 'Can carbon sinks be operational?' Resources for the Future workshop proceedings, 30 April 2001.

— 2002. Measuring carbon in forests: current status and future challenges. Environmental Pollution 116, 363–372.

Budidarsono S., Arifatmi B., de Foresta H. and Tomich T.P. 2001a. Damar agroforest establishment and sources of livelihood: a profitability assessment of damar agroforest system in Krui, Lampung, Sumatra, Indonesia, 5 pp.

Budidarsono S., de los Angeles M.S. and Wibawa G. 2001b. A profitability assessment of smallholder rubber agroforest systems in Jambi, Sumatra, Indonesia. Manuscript prepared for the workshop: 'Complex agroforests: farmer knowledge, management, profitability and conservation', Jambi, 3–6 September 2001.

Cacho O.J., Hean R.L. and Wise R. 2003a. Carbon-accounting methods and reforestation incentives. Australian Journal of Agricultural and Resource Economics 47, 153–179.

Cacho O.J., Marshall G.R. and Milne M. 2003b. Smallholder agroforestry projects: potential for carbon sequestration and poverty alleviation. Food and Agriculture Organization of the United Nations, ESA Working Paper 03–06.

Cacho O.J. Marshall G.R. and Milne M. 2005. Transaction and abatement costs of carbon-sink projects in developing countries. Environment and Development Economics 10(5), 1–18.

Cacho O.J., Wise R. and MacDicken K. 2004 Carbon monitoring costs and their effect on incentives to sequester carbon through forestry. Mitigation and Adaptation Strategies for Global Change 9(3), 273–293.

Cairns M.A., Brown S., Helmer E.H. and Baumgardner G.A. 1997. Root biomass allocation in the world's upland forests. Oecologia 111, 1–11.

Capoor K. and Ambrosi P. 2006. State and trends of the carbon market 2006. The World Bank, Washington DC.

Challen R. 2000. Institutions, transaction costs and environmental policy: institutional reform for water resources. Edward Elgar: Cheltenham, UK.

Corbera E. 2005. Bringing development into carbon forestry markets: challenges and outcomes of small-scale carbon forestry activities in Mexico. Pp. 42–56 in ‘Carbon forestry: who will benefit?’, ed. by D. Murdiyarso and H. Herawati. Workshop on carbon sequestration and sustainable livelihoods, CIFOR, Bogor, Indonesia.

de Foresta H., Kusworo A., Michon G. and Djatmiko,W.A. (eds). 2000. Ketika kebun berupa hutan agroforest khas Indonesia sebuah sumbangan masyarakat. International Center for Research in Agroforestry, SEA Regional Research Programme, Bogor, Indonesia.

de Jong B.H.J., Gaona S.O., Montalvo S.Q., Bazan E.E. and Hernandez N.P. 2004. Economics of Agroforestry carbon sequestration. Pp. 123–138 in ‘Valuing agroforestry systems: methods and applications’, ed. by J.R.R. Alavalapati and D.E. Mercer. Kluwer Academic Publishers: Dordrecht.

de Jong B.H.J., Tipper R. and Montoya-Gomez G. 2000. An economic analysis of the potential for carbon sequestration by forests: evidence from southern Mexico. Ecological Economics 33, 313–327.

de Gouvello C. and Coto O. 2003. Transaction costs and carbon finance impact on small-scale CDM projects. PCF Plus: Washington, DC.

Delaney M. and Roshetko J. 1999. Field tests of carbon monitoring methods for home gardens in Indonesia. Pp 45–51 in ‘Field tests of carbon monitoring methods in forestry projects’. Forest Carbon Monitoring Program, Winrock International, Arlington, VA, USA.

Direktorat Jenderal Kehutanan 1976. Vademicum Kehutanan. Jakarta.

Dirjen RLPS 2005. Laporan Kegiatan Gerakan Nasional Rehabilitasi Hutan dan Lahan Tahun 2004. Direktorat Jendral Rehabilitasi Lahan dan Perhutanan Sosial, Departemen Kehutanan, Jakarta.

Dudek D.J. and Wienar J.B. 1996. Joint implementation, transaction costs, and climate change. Organisation for Economic Co-operation and Development: Paris.

Dwiprabowo H. and Wulan Y.C. 2003. A description of the Citanduy watershed, west Java and preliminary analysis of carbon-sequestration potential by smallholders. Working Paper CC09, ACIAR Project ASEM 1999/093. At: <http://www.une.edu.au/carbon/wpapers.php>.

Eaton C. and Shepherd A.W. 2001. Contract farming: partnerships for growth. Agricultural Services Bulletin 145, Food and Agricultural Organization, Rome.

EcoSecurities and United Nations Development Programme 2003. Chapter 5: Transaction costs, efficiency and supportive governance. Pp. 55–68 in ‘The Clean Development Mechanism: a user’s guide’. United Nations Development Programme: New York.

FACE (Forests Absorbing Carbon Emissions) 2001. Annual report 2000. FACE: Arnhem, The Netherlands.

Fadilasari 2000. Soal Embargo Kopi Lampung: Sonny Sarankan Cari Alternatif Lain. Tempo, 4 Agustus. At: <http://www.tempointeractif.com>.

Garrity D.P., Soekardi M., van Noordwijk M., de la Cruz R., Pathak P.S., Gunasena H.P.M., van So N., Huijun, G. and Majidm N.M. 1997. The *Imperata* grasslands of tropical Asia: area, distribution, and typology. Agroforestry Systems 36, 3–29.

Ginoga K., Cacho O., Erwidodo, Lugina M. and Djaenudin D. 2002. Economic performance of common agroforestry systems in Southern Sumatra, Indonesia: implications for carbon sequestration services. Working Paper CC03, ACIAR Project ASEM 1999/093. At: <http://www.une.edu.au/carbon/wpapers.php>.

Ginoga K., Wulan Y. and Djaenudin D. 2005. Potential of agroforestry and plantation systems in Indonesia for carbon stocks: an economic perspective. Working Paper CC14, ACIAR Project ASEM 2002/066. At: <http://www.une.edu.au/carbon/wpapers.php>.

Gintings A.N. 2005. Kajian Peraturan Perundang-undangan Gerhan dan Implikasi Teknis di Lapangan. Workshop CIFOR dan Badan Litbang Kehutanan, Bogor, 22 February 2005.

Glover D. and Kusterer,K. 1990. Small farmers, big business: contract farming and rural development. MacMillan: London.

Grist P., Menz K. and Thomas [Initial(s)?] 1998. Modified BEAM rubber agroforestry models: RRYIELD and RRECON. ACIAR Technical Report Series No. 42, Canberra.

Hairiah K., Sitompul S.M., van Noordwijk M. and Palm C. 2001. Carbon stocks of tropical land use systems as part of the global C balance: effects of forest conversion and options for ‘clean development’ activities. ASB Lecture Note 4A, ICRAF, Bogor. At: <http://www.icraf.cgiar.org/sea>.

Haites E. 2004. Estimating the market potential for the Clean Development Mechanism: review of models and lessons learned. PCFplus Report 19, Washington, DC.

Hamburg S.P. 2000. Simple rules for measuring changes in ecosystem carbon in forestry-offset projects. Mitigation and Adaptation Strategies for Global Change 5, 25–37.

Horn M.J. 1995. The political economy of public administration: institutional choice in the public sector. Cambridge University Press: Cambridge, UK.

ICRAF (International Center for Research in Agroforestry) 2000. A profitability assessment of robusta coffee systems in Sumberjaya Watershed, Lampung, Sumatra Indonesia. Southeast Asia Policy Research Working Paper No. 16.

IPCC (Intergovernmental Panel on Climate Change) 2001. Climate change 2001: mitigation, a special report of the Intergovernmental Panel on Climate Change. Cambridge University Press: New York. At: <http://www.ipcc.ch/pub/tar/wg2/index.htm>.

— 2006. Guidelines for national greenhouse gas inventories. Chapter 4: Forest land. At: <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm>.

Ketterings Q.M., Coe R., van Noordwijk M., Ambagau Y. and Palm C.A. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management 146, 199–209.

Kirschbaum M.U.F. 1999. CenW, a forest growth model with linked carbon, energy, nutrient and water cycles. Ecological Modelling 118, 17–59.

Krey M. 2004. Transaction costs of CDM projects in India—an empirical survey. HWWA Report 238, Hamburg Institute of International Economics.

Kyoto Protocol 1997. Kyoto Protocol to the Convention on Climate Change. The Climate Change Secretariat: Bonn, Germany.

Lecocq F. 2004. State and trends of the carbon market 2004. Prototype Carbon Fund: Washington, D.C.

Lecocq F. and Capoor K. 2003. State and trends in the carbon market. World Bank: Washington, DC.

Lecocq F. and Chomitz K. 2001. Optimal use of carbon sequestration in a global climate strategy: is there a wooden bridge to a clean energy future? World Bank Policy Research Working Paper 2635. World Bank Development Research Group, Washington D.C., 27 pp.

Lemmens R.H.M.J., Soerianegar, I. and Wong W.C. (eds) 1995. Plant resources of South-East Asia (PROSEA) No. 5(2), Timber trees: minor commercial timbers. Backhuys Publishers: Leiden, The Netherlands.

McCarthy J.J., Canziani O.F., Leary N.A., Dokken D.J. and White K.S. 2001. Climate change 2001: impacts, adaptation and vulnerability, a special report of the Inter-governmental Panel on Climate Change. Cambridge University Press: New York. At: <http://www.ipcc.ch/pub/tar/wg3/index.htm>.

MacDicken K.G. 1997. A guide to measuring carbon storage in forestry and agroforestry projects. Forest Carbon Monitoring Program, Winrock International, Arlington, VA, USA.

Marland G., Fruit K. and Sedjo R. 2001. Accounting for sequestered carbon: the question of permanence. Environmental Science and Policy 4, 259–268.

Michaelowa A. and Dutschke M. 2000. Climate policy and development—flexible instruments and developing countries. Edward Elgar: Cheltenham, UK.

Michaelowa A., Stronzik M., Eckermann F. and Hunt A. 2003. Transaction costs of the Kyoto mechanisms. Climate Policy 3, 261–278.

Milne M. 2002. Transaction costs of forest carbon projects. Working Paper CC05, ACIAR Project ASEM 1999/093. At: <http:/www.une.edu.au/febl/Econ/carbon/wpapers.htm>.

Milne M., Arroyo P. and Peacock H. 2001. Assessing the livelihood benefits to local communities from forest carbon projects: case study analysis. In 'Forest carbon, livelihoods and biodiversity'. Report submitted to the European Union.

Ministry of Agriculture 1999. Productivity of agricultural products. Department Pertanian, Indonesia.

Moura Costa P., Stuart M, Pinard M. and Phillips G. 2000. Elements of a certification system for forestry-based carbon offset projects. Mitigation and Adaptation Strategies for Global Change 5, 39–50.

Murdiyarso D., Puntodewo A., Widayati A. and van Noordwijk M. 2006. Determination of eligible lands for A/R CDM project activities and of priority districts for project development support in Indonesia. CIFOR: Bogor.

Nabuurs G.J., Garza-Caligaris J.F., Kanninen M., Karjalainen T., Lapvetelainen T., Liski J., Masera O., Mohren G.M.J., Pussinen A. and Schelhaas M.J. 2001. CO2FIX V2.0—manual of a model for quantifying carbon sequestration in forest ecosystems and wood products. ALTERRA Report, Wageningen, The Netherlands.

Otsuka K. and Place F. 2001a. Issues and theoretical framework. Pp. 3–33 in 'Land tenure and natural resource management: a comparative study of agrarian communities in Asia and Africa', ed. by K. Otsuka and F. Place. The Johns Hopkins University Press: Baltimore and London.

— 2001b. Toward new paradigms of land and tree resource management. Pp. 359–378 in 'Land tenure and natural resource management: a comparative study of agrarian communities in Asia and Africa', ed. by K. Otsuka and F. Place. The Johns Hopkins University Press: Baltimore and London.

Palm C.A., Woomer P.L., Alegre J., Arevalo L., Castilla C., Cordeiro, D.G., Feigl B., Hairiah K., Kotto-Same J., Mendes A., Moukam A., Murdiyarso D., Njomgang R., Parton W.J., Ricse A., Rodrigues V., Sitompul S.M. and van Noordwijk M. 1999. Carbon sequestration and trace gas emissions in slash-and-burn and alternative land-uses in the humid tropics. ASB Climate Change Working Group Final Report, Phase II. Nairobi, Kenya.

Sedjo R.A. 2001. Forest carbon sequestration: some issues for forest investments. Discussion Paper 01-34. Resources for the Future, Washington, D.C.

Sedjo R.A. and Toman M. 2001. Can carbon sinks be operational? RFF Workshop Proceedings. Discussion Paper 01-26, Resources for the Future, Washington, DC.

Simmons, P. 2003. Overview of smallholder contract farming in developing countries. Food and Agriculture Organization Working Paper, ESA/FAO WP#01-2003. FAO: Rome.

Smith J. 2002. Afforestation and reforestation in the Clean Development Mechanism of the Kyoto protocol:

implications for forests and forest people. International Journal of Global Environmental Issues 2, 322–343.

Smith J., Mulongoy K., Persson R. and Sayer J. 2000. Harnessing carbon markets for tropical forest conservation: towards a more realistic assessment. Environmental Conservation 27(3), 300–311.

Smith J. and Scherr S.J. 2002. Forest carbon and local livelihoods: assessment of opportunities and policy recommendations. CIFOR Occasional Paper No. 37.

Stavins J. 1995. Transaction costs and tradeable permits. Journal of Environmental Economics and Management 29, 133–148.

Subarudi, Dwiprabowo H., Ginoga H., Djaenudin D. and Lugina L. 2004. Cost analysis for a CDM-like project established in Cianjur, West Java, Indonesia. Working Paper CC13, ACIAR Project ASEM 1999/093. At: <http://www.une.edu.au/carbon/wpapers.php>.

Suyanto S., Tomich T.P. and Otsuka K. 2001. Agroforestry management in Sumatra. Pp. 97–143 in 'Land tenure and natural resource management', ed. by K. Otsuka and F. Place. Johns Hopkins University Press: Baltimore.

The MathWorks 2002. Using Matlab. The MathWorks Inc.: Natick, Massachusetts.

Thompson D.B. 1999. Beyond benefit–cost analysis: institutional transaction costs and regulation of water quality. Natural Resources Journal 39(3), 517–541.

Tomich, T.P., Kuusipalo, J., Menz, K. and Byron, N. 1997. *Imperata* economics and policy. *Agroforestry Systems*. 36:233–261.

Tomich T.P., van Noordwijk M, Budidarsono S., Gillison A., Kusumanto T., Murdiyarso D., Stolle F. and Fagi A.M. 1998. Alternatives to slash-and-burn in Indonesia: summary report and synthesis of Phase II. ASB Indonesia Report Number 8, Bogor, Indonesia.

Tomich T.P., de Foresta H., Dennis R., Ketterings Q., Murdiyarso D., Palm C., Stolle F., Suyanto and van Noordwijk M. 2002. Carbon offsets for conservation and development in Indonesia? American Journal of Alternative Agriculture 17(3), 125–137.

UNFCCC (United Nations Framework Convention on Climate Change) 1997. Scolel Té: carbon sequestration and sustainable forest management in Chiapas. USIJI uniform reporting document for Activities Implemented Jointly under the pilot phase. Accessed on DATE at: <http://unfccc.int/program/aij/aijact/mexusa02.html>.

—1998. Klinki Forestry Project. USIJI uniform reporting document for Activities Implemented Jointly under the pilot phase. At: <http://unfccc.int/program/aij/aijact/criusa07.html>.

—2000. Costa Rica/Norway reforestation and forest conservation AIJ pilot project. USIJI uniform reporting document for Activities Implemented Jointly under the pilot phase. At: <http://unfccc.int/program/aij/aijact01/crinor01-00.html>.

— 2001. SIF carbon sequestration project. USIJI uniform reporting document for Activities Implemented Jointly under the pilot phase. At: <http://unfccc.int/program/aij/aijact01/chlusa-01-01.html>.

van Noordwijk M., Hairiah K., Partoharjono S., Labios R.V. and Garrity D.P., 1997. Food-crop-based production systems as sustainable alternatives to *Imperata* grasslands?. Agroforestry Systems 36, 55–82.

van Noordwijk M. and Lusiana B. 2001. Water, nutrient and light capture in agroforestry systems—WaNuLCAS V2.1 (Biophysical process model run in the Stella V7 and Microsoft Excel software environments). International Center for Research in Agroforestry (ICRAF): Bogor.

Verweij H. and Emmer I.M. 1998. Implementing carbon sequestration projects in two contrasting areas: the Czech Republic and Uganda. The Commonwealth Forestry Review 77(3), 203–208.

Vincent G., de Foresta H. and Mulia R. 2002. Predictors of tree growth in a dipterocarp-based agroforest: a critical assessment. Forest Ecology and Management 161, 39–52.

Vine E., Sathaye J. and Makundi W. 1999. Guidelines for the monitoring, evaluation, reporting, verification and certification of forestry projects for climate change mitigation. Prepared for the US Environmental Protection Agency by Lawrence Berkeley National Laboratory.

Warta Gerhan 2006. Tanaman Pertama GN-RHL: Tidak Ada Alasan Untuk Mengatakan Pembuatan GN_RHL Gagal. Warta Gerhan Volume I, No. 01, 20 Maret–1 April 2006. Direktorat Jenderal Rehabilitasi Lahan dan Perhutanan Sosial: Jakarta.

Watson R.T., Noble I.R., Bolin B., Ravindranath N.H., Verardo D.J. and Dokken D.J. (eds) 2000. Land use, land-use change, and forestry, a special report of the Intergovernmental Panel on Climate Change. Cambridge University Press: New York.

Wexler P., Mintzer I., Miller A. and Eoff D. 1994. Joint Implementation: institutional options and implications. Prepared for US Environmental Protection Agency, Office of Policy, Planning and Evaluation.

Whitmore A.P., Cadisch G., Toomsan B., Limpinuntana V., van Noordwijk M. and Purnomosidhi P. 2000. An analysis of the economic values of novel cropping systems in North East Thailand and S. Sumatra. Netherlands Journal of Agricultural Science 48, 105–114.

Wibowo D.H. 1999. An economic analysis of deforestation mechanisms in Indonesia: empirics and theory based on stochastic differential and Fokker-Planck equations. PhD thesis, The University of Queensland, Brisbane, Australia.

Williamson O.E. 1985. The economic institutions of capitalism. Free Press: New York.

Winrock/IPB (Winrock International and Institut Pertanian Bogor) 2005. Forms and procedures for Indonesian institutions involved in AR-CDM activities. Working paper. Ministry of Environment, Republic of Indonesia; Asian Development Bank.

Wise R.M. and Cacho O.J. 2003. Tree-crop interactions and their environmental and economic implications in the presence of carbon-sequestration payments. Contributed paper to the 47th Annual Conference of the Australian Agricultural and Resource Economics Society, Fremantle, Western Australia, 12–14 February 2003.

— 2004. Managing Indonesian agroforests in the presence of carbon credits. Contributed paper to the 48th Annual Conference of the Australian Agricultural and Resource Economics Society, Melbourne, Victoria, 12–14 February 2004.

— 2005a. Bioeconomic analysis of carbon sequestration in farm forestry: a simulation study of *Gliricidia sepium*. Agroforestry Systems 64, 237–250.

— 2005b Tree-crop interactions and their environmental and economic implications in the presence of carbon-sequestration payments. Environmental Modelling and Software 20(9), 1139–1148.

— 2005c. Dynamic optimisation of land-use systems in the presence of carbon payments. Working Paper CC15, ACIAR Project ASEM 2002/063. At: <http://www.une.edu.au/carbon/wpapers.php>.

Wise R.M. Cacho O. and Hean R.L. 2007. Fertilizer effects on the sustainability and profitability of agroforestry in the presence of carbon payments. Environmental Modelling and Software 22, 1372–1381.

Wulan Y.C. 2002. Nilai Ekonomi Sistem Agroforestry Kebun Kopi Multi-stratum (Studi Kasus Kebun Kopi Multi-stratum di Kecamatan sumberjaya, Kabupaten Lampung Barat). Unpublished thesis, Bogor Agricultural University.

Young A., Menz K., Muraya P. and Smith C. 1998. SCUAF Version 4: a model to estimate soil changes under agriculture, agroforestry and forestry. ACIAR Technical Reports No. 41, Canberra.

Appendix I

Agroforestry systems studied

Overview of study sites

Three general areas in Indonesia were selected in this study: southern Sumatra, West Java and East Nusa Tenggara. The selection was based largely on the availability of data on agroforestry systems adopted by smallholders, but was also influenced by the need to find a balance between the more developed and productive areas of western Indonesia and the drier, less productive and poorer areas of eastern Indonesia. The economic analyses presented in this appendix were undertaken using spreadsheet models.

The economic performance of the different agroforestry systems was examined following the guidelines established by the Alternatives to Slash-and-Burn (ASB) group (Tomich et al. 1998; Budidarsono et al. 2001b). The net present value (NPV) of a land-use system with J different outputs and I inputs is calculated using equation (A1), in which $y_{j,t}$ is the yield of output j in year t and p_j is the price per unit of output; $x_{i,t}$ is the amount of input i used in year t and c_i is the cost per unit of input; and r is the discount rate. The discount rate was set at 15% for Indonesian farmers (i.e. $r = 0.15$). This value is within the range expected for farmers in developing countries who may have limited access to credit. For tree-based systems, the value of c_i in year 0 represents the cost of preparing the land and planting the trees; and generally $y_{j,0} = 0$ because there is a lag between planting and production of fruit and timber outputs. For a project lasting T years, $y_{j,t}$ values can be represented as elements in (spreadsheet) matrix **Y** of dimensions $(T+1) \times J$. Similarly, $x_{i,t}$ values can be contained in a matrix **X** of dimensions $(T+1) \times I$. These matrices have $T + 1$ rows because time is counted from year 0, when the trees are planted.

If NPV for a particular land use is > 0, then the land use is profitable. Comparing NPVs of different land uses allows the 'best' option to be determined in terms of profit, but there may be other factors, such as labour requirements and establishment costs, that are also important to farmers. Return to labour was calculated as the wage rate that makes the NPV = 0, so it provides a measure of how attractive the activity is relative to alternative employment opportunities for the farm family. Establishment costs were calculated as the present value of expenses until a positive cash flow was obtained.

Economic analysis measures profit as it 'should be' in an ideal world with no price distortions; thus, family labour is paid the going market rate and the cost of cleared land is accounted for, and NPV represents the returns to management and capital. From a social standpoint, other outputs such as biodiversity preservation should also be taken into account. While we did not attempt to do this, we comment on the biodiversity value of different agroforestry systems where appropriate.

It is important to point out that the carbon stocks reported here are conservative, as we consider only above-ground biomass. As explained earlier, below-ground biomass (roots) may represent up to one-third of total living biomass, and soil and litter may also contain considerable amounts of carbon. For example, an *Acacia mangium* plantation may contain 200 tC/ha, of which 105 tC/ha are above-ground biomass and litter and the remaining 95 tC/ha are contained in roots and soil (Tomich et al. 1997). We decided to err on the side of caution to avoid overly optimistic estimates of the potential of smallholder carbon projects, particularly considering that measuring carbon in roots and soil may be difficult and expensive.

$$NPV = \sum_t \left[\sum_j y_{j,t} p_j - \sum_i x_{i,t} c_i \right] (1 + r)^{-t} \; ; \; j \in (1,...,J); i \in (1,...,I) \qquad \text{(A1)}$$

Another important point is that carbon stocks are reported as time-averaged values rather than peak values. This is because biomass carbon accumulation is a slow process and it is not appropriate to attribute the carbon content of a forest in 25 years' time to the project today. The time-averaged carbon value can be directly calculated from a carbon growth curve, but an acceptable approximation can be obtained by averaging the initial and final carbon content of the forest. For example, considering only above-ground biomass, an *A. mangium* plantation started on bare ground (0 tC/ha) and expected to accumulate 105 tC/ha in 20 years has an average carbon stock of 52.7 tC/ha.

Southern Sumatra

The diversity of agroecological zones in the southern part of Sumatra is reflected in its agroforestry and land-use systems. The western part of the study area includes highlands, a buffer zone and piedmont, covering the Kerinci district and the upper regions of Sarolangun and Bungotebo districts in the province of Jambi. The middle part consists of a peneplain, and the eastern part includes coastal areas covering swamp and mangrove forests. To the south is the Lampung province, where Krui, on the west coast across the mountains of the Bukit Barisan range, is known for its complex agroforests. Important agroforestry systems in the highland, buffer zone and piedmont areas include damar agroforestry and multicropping, involving complex multistrata agroforestry systems such as cinnamon plantations with potatoes or coffee as secondary crops. Major land-use systems in the peneplains include rubber agroforestry with food crops such as upland rice, and simple tree-crop systems, including large-scale timber plantations, oil-palm monoculture and industrial-timber monoculture. The agroforestry systems studied in this region are described below. More details on these systems are reported by Ginoga et al. (2002, 2005). The economic analysis is then described and results are summarised in Table A1.

Rubber agroforests

Rubber agroforestry refers to land use involving rubber as a main tree, with secondary crops such as rice. It represents the most common smallholder system in the peneplain of Sumatra. Rubber plantations in Sumatra and the rest of Indonesia cover about 2,579,528 ha and 3,662,472 ha, respectively. Hence, about 70% of Indonesian rubber is grown in Sumatra (Ministry of Agriculture 1999). This production system is usually operated by smallholders on areas of between 1 and 5 ha. The type of planting material used includes cloned and traditional unselected seedlings (Tomich et al. 1998).

Rubber agroforests usually replace 'old jungle rubber' or secondary forest. The data on which our analysis is based was collected by ICRAF as part of an ongoing project in Jambi. The project is located in the Rantau Pandan and Bungo Tebo districts. Old rubber jungle was cleared and produced a negligible amount of saleable wood (Budidarsono, pers. comm.). The project experienced some problems with the supply of cloned planting materials, resulting in a much lower planting density than the traditional systems. Hence, in this paper, rubber agroforests are evaluated by modelling. The BEAM model (Grist et al. 1998) was calibrated to conditions in Jambi based on data from Tomich et al. (1998) and other sources.

Local rubber seedlings were used for the traditional system and GT1 clones were used for the clone system. Planting density was 816 seedlings/ha (with trees spaced at 3.5 m). Only the clone system received fertiliser at the time of planting, which accounts for more intensive labour use during establishment. Economic evaluation of rubber systems was based on a 40-year cycle.

Cinnamon multicropping

The area of cinnamon plantations in Indonesia is about 119,905 ha, of which around 116,761 ha (97%) are located in Sumatra, about 49% of these in Jambi. In the upper region of Kerinci, the most common farming system is multicropping involving cinnamon (*Cinnamomum burmanni*) and annual crops (Wibowo 1999). Potato is the most popular annual crop, with a relatively small amount of scallion and maize. In the lower region of Kerinci, a similar multicropping system is typical, but the most common secondary crops are coffee and chilli, with a small amount of maize.

Cinnamon trees are usually planted in rows about 4 m apart and spaced about 1–2 m apart along each row (Wibowo 1999). Multicropping is practised until cinnamon trees reach an age of about 6 years, after which the system becomes a monoculture of cinnamon, with negligible amounts of annual crops or bananas grown on the edges. Economic evaluation of cinnamon systems was based on a 12-year cycle.

Oil palm

About 8%, or 222,096 ha, of oil-palm plantations in Indonesia are located in Jambi (Ministry of Agriculture 1999). The average production between 1990 and 1998 was about 142,864 tonnes. Oil-palm plantations are usually operated by large-scale companies or state companies. Only about 23% of oil-palm plantations are operated by smallholders. ICRAF has established oil-palm plantation and industrial-timber estate projects in Jambi and Lampung, but none has reached maturity. Therefore, the project used for this analysis was taken from the nearby province of Riau, where plantations were established earlier and have reached maturity. The sample plantation consists of 10,700 ha established over a period of 10 years. The first fruit crop was harvested in year 4 and maximum production was reached in year 21. Economic evaluation of cinnamon systems was based on a 12-year cycle. Economic evaluation of the oil-palm system was based on a 25-year planning horizon.

Damar agroforests

Damar agroforests follow a multicropping scheme, in which the main trees are planted along with food crops, fruit trees and other perennials, including trees for fuelwood. The main tree species is damar (*Shorea javanica*), which produces a resin used in paints and other products, while duku, durian, pepper and coffee are planted as the secondary perennials. The most common food crops grown are rice and a negligible amount of vegetables. The damar agroforest reviewed here is located in Krui, Sumatra. It is a traditional system following forest or bush clearing, and has been developed by local people since 1927 (de Foresta et al. 2000). There are approximately 55,000 ha of damar agroforests in Krui, producing about 80% of Indonesian damar resin. There are two types of damar agroforestry, based on farming inputs used: traditional and semi-intensive. The latter includes application of chemical fertilisers and insecticides to perennial crops such as coffee and pepper, to lengthen their harvestable life (Budidarsono et al. 2001a). Economic evaluation of the damar systems was based on a 25-year planning horizon.

Coffee multi-strata agroforestry systems

Multi-strata agroforestry gardens based on coffee cover about 130,000 ha of land in Lampung (Fadilasari 2000) and produce 60% of Indonesia's coffee exports. Coffee multi-strata agroforestry systems are classified according to the tree species that dominates the system. The three common systems are timber based, fruit based and shade based. In the timber-based system the strata are dominated by timber-producing forest trees. In such cases most of the land is categorised as forest land by the government. The dominant species are sonokeling (*Dalbergia latifolia*) and sengon (*Paraserianthes falcataria*), which are species used for 'regreening' by forest officers, as well as fruit trees such as jackfruit (*Artocarpus heterophyllus)* and bananas in other strata of the systems. In the fruit-based system (Figure A1) the strata are dominated by fruit trees such as jackfruit, guava and avocado. In the shade-based system the strata are dominated by trees such as *Gliricidia sepium*, *Erythrina subumbrans* and *Leucaena leucocephala*. In such cases the system is considered a young established garden rather than a forest. Economic evaluation of coffee systems was based on a 20-year planning horizon.

Sengon plantation

Sengon is grown in both community forests and state timber plantations. In 1989 the Ministry of Forestry initiated a community-based afforestation program based primarily on sengon trees. In addition to increasing wood supply, this program also aimed to raise land productivity, provide additional wood for industry and generate employment. Sengon wood is usually used for packaging, furniture and construction. Sengon leaves are sometimes used as fodder for goats. The life cycle of this tree is usually no longer than 15 years because root rot sets in. In the system studied here, wood is harvested in year 8 and the system is managed as a monoculture timber plantation.

Acacia mangium plantation

Acacia mangium is a fast-growing nitrogen-fixing tree used for furniture, firewood and pulp. This species if very popular in Indonesia and represents one of the main plantation trees in Sumatra. Its quick growth and dense shade make it effective in reforesting *Imperata* grasslands and reducing fire risk. Its ability to grow well on infertile soils, especially those low in phosphorus, make it a favourite for rehabilitating eroded sites. The wood of *A. mangium* can be used for sawn timber, mouldings, furniture, veneer, charcoal and firewood. It is also used for particleboard, pulp and paper. Its leaves can be utilised as fodder and for medicine. The system studied is an estate managed by PT Musi Hutan Persada in South Sumatra at altitudes between 100 and 400 m above sea level. The system is intensively managed, with harvest and replanting every 8 years.

Selected fruit trees

The systems detailed here are based in Jambi, southern Sumatra, and the data were generously provided by Hendri of IPB. In this analysis all the fruit trees are planted with other food crops (rice and vegetables) for the first 3 years. Economic evaluation was based on a 40-year planning horizon.

Duku

Duku (*Lansium domesticum*) is widely distributed in Indonesia and is usually referred to as a fruit tree, although its timber is also used. The duku fruit is very popular in South Sumatra because of its sweet taste and large size. The wood of the duku tree is durable, strong, elastic and very suitable for construction (ICRAF 2000). In Indonesia, duku is grown in and around villages (*kampungs*). It does not require intensive cultivation and maintenance.

Durian

Durian (*Durio zibethinus*) is one of the most popular fruits in Indonesia. Durian trees are widely distributed and are mostly planted in drylands and gardens. Durian wood can be used for construction, furniture, cabinets, fittings, panelling, partitioning, plywood, chests, boxes, wooden slippers, low-quality coffins and ship building (Lemmens et al. 1995). Its use is generally limited to building construction and packaging.

Candlenut

Candlenut (*Aleurites moluccana*) is a fast-growing tree species that is often planted as the main tree in reforestation programs. The advantages of candlenut are that it has few input requirements, it can grow in arid land and it is a good pioneer species for reclaiming land left fallow after shifting-cultivation practices. Farmers grow candlenut for its fruit, spices and traditional medicines. The Indonesian Bio-diesel Institute is planning to use the candlenut fruit as an alternative source of biodiesel. This is because candlenut fruit yields oil that has characteristics similar to those of petroleum oil. This, and its ability to grow quickly (and hence capture and store carbon rapidly),

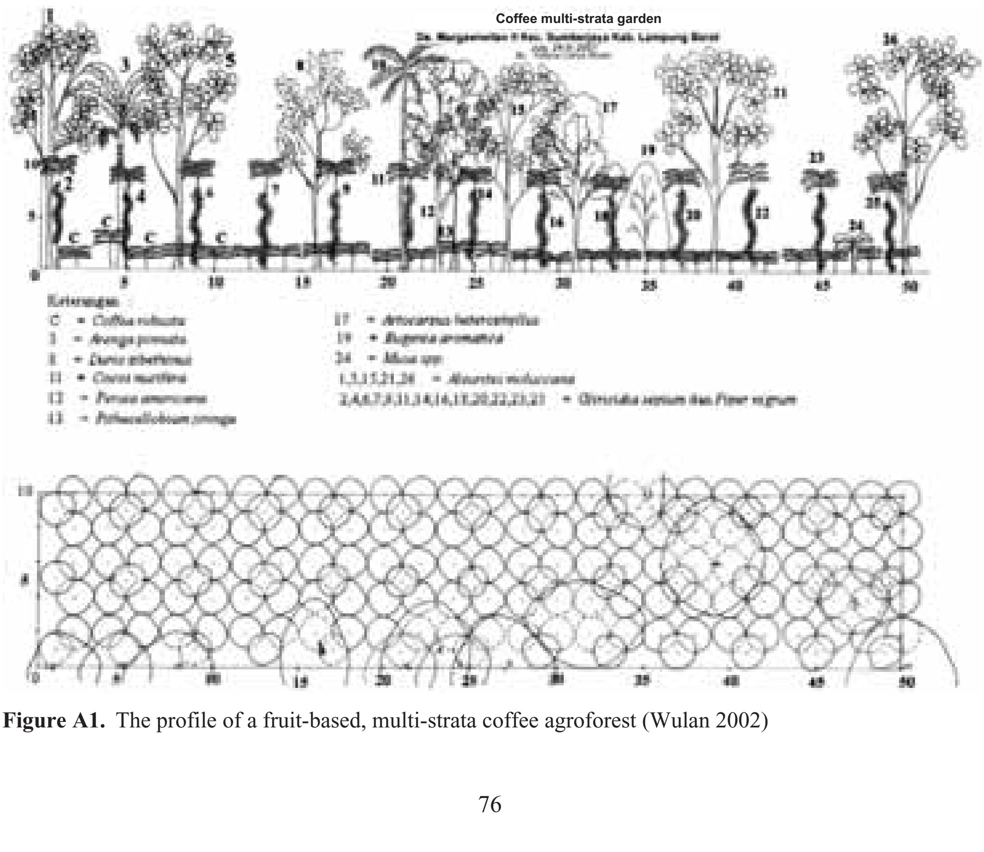


Figure A1. The profile of a fruit-based, multi-strata coffee agroforest (Wulan 2002) make candlenut a very attractive species for inclusion in carbon-sink projects.

Macang

Macang (*Mangifera* spp.) is a generic term that includes a number of different fruit trees. The wood of these trees is generally used for light construction, ceilings, door panels, interior finishing, floor boards, moulds, crates, good quality charcoal, gunstocks, veneers and plywood (Lemmens et al. 1995).

Mango

The mango tree (*Mangifera indica*) is a tall, evergreen tropical tree that typically grows between 10 and 30 m and has a dense and heavy crown. This species is very popular in Indonesia and is grown in both drylands and home gardens. People plant this species primarily for its fruit but its wood can also be used as fuel.

Pinang

The Pinang tree (*Areca catechu*) is grown for its fruit (betel nut), which is chewed as a mild stimulant. It is also used as an ornamental garden tree. Betel nut has traditionally been used by large numbers of people for cosmetic and health purposes. The nut contains large quantities of tannin together with smaller concentrations of garlic acid, fixed oil gum, volatile oil, lignin and various saline substances.

Rambutan

Rambutan (*Nephelium lappaceum*) is one of the most popular fruits in Indonesia. Rambutan is a medium-size tree that produces a red or yellow fruit, round to oval in shape, with hairs or tubercles on its skin. The flesh is translucent and sweet. Most rambutan trees that have been propagated from seed are not true-to-type and the fruits are usually sour. Rambutan produces a small crop in June and July and a large crop between November and January.

Economic evaluation

The analysis presented in this section is derived from Ginoga et al. (2002, 2005). Some results differ from those reported in the original sources because the analysis was repeated using current prices and wages. The original sources included financial as well as economic evaluation but only the economic evaluation is reported here (Table A1). The NPVs calculated with equation (A1) cannot be used to directly compare the economic performance of different agroforestry systems because they have different durations. For example, mangium and sengon systems are based on an 8-year rotation, whereas the damar system is based on the 25-year planning horizon required for a complex agroforest to develop. To make results comparable, we calculated the NPV values in perpetuity (NPV_{INF}) using the equation:

$$NPV_{INF} = NPV(T)/[1 - (1 + r)^{-T}] \qquad \text{(A2)}$$

where $NPV(T)$ is the NPV calculated over T years using equation (A1). Cacho et al. (2003a) provide more information on this equation.

The carbon stocks in above-ground biomass range between 22.7 and 91.2 tC/ha. The NPVs of the rubber systems are negative, whereas they were positive in the original analysis of Ginoga et al. (2002). This difference was largely driven by increases in wage rates. The return to labour is Rp14,900/day for the traditional rubber system and Rp17,950/day for the clone system (Table A1), and these values are below the current (2006) wage rate of Rp25,000/day. All other systems have positive NPVs, indicating that they are economically attractive. There are large variations in establishment costs, years to positive cash flows, labour requirements and return to labour. Fruit trees tend to be more profitable than timber trees because they start producing income earlier and future income is heavily discounted (at 15%). Mango, duku and durian are the most profitable trees. However, these species would not be established as monocultures in large areas, but would be part of a mix of species. Because these rankings are sensitive to changes in input and output prices, it is important to obtain local data and undertake sensitivity analysis when designing an agroforestry system for a carbon-sequestration project.

West Java

The Citanduy watershed was selected as the study site representative of West Java. This is one of 22 critical watersheds in terms of hydrology and erosion in Indonesia. Due to its critical status, the watershed has been prioritised for land rehabilitation and conservation. The Citanduy watershed lies in the south-east of West Java, encroaching on a small part of Central Java (Figure A2). The Citanduy River is the main river in the watershed. It flows to the Indian Ocean and forms an estuary called *Segara Anakan* located on the border between the West and Central Java provinces. The total watershed area is 352,080 ha. It comprises five subwatersheds, the largest of which is the Upper

Citanduy with an area of 95,500 ha, or 27% of the watershed. The Citanduy watershed, like elsewhere in West Java, is densely populated, with an average population density of approximately 833 people/km^2.

Vegetation cover in the watershed generally consists of perennial crops, horticultural crops and trees. Vegetation in state-protected forests is dominated by tree species such as rasamala (*Altingia excelsa*), puspa (*Schima noronhae*) and mahogany (*Swietenia macrophylla*), while in state-production forests dominant species are teak (*Tectona grandis*) and pine (*Pinus merkusii*). Agroforests belonging to smallholders are also present, and these are characterised by three main species: sengon (*Paraserianthes falcataria*), mahogany (*Swietenia macrophylla*) and teak (*Tectona grandis*). These are usually mixed with perennial and horticultural crops.

Land ownership in the Citanduy watershed can be divided into two categories: state land and smallholder or private land. State lands can further be

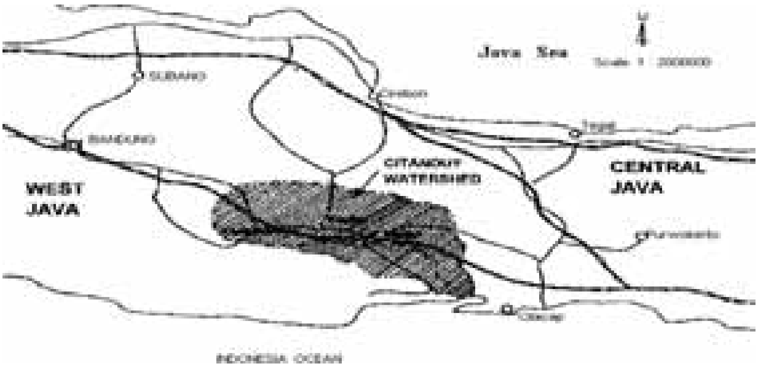


Figure A2. Location of the Citanduy watershed

Table A1. Economic evaluation of agroforestry systems in southern Sumatra

Agroforestry system	Carbon stock (tC/ha)	NPV_{INF}[a] (Rp '000/ ha)	Estimated cost (Rp '000/ ha)	Years to positive cash flow	Labour required (person days/ ha/year)	Return to labour (Rp '000/ person day)
Rubber, traditional	28.8	–4,021	16,278	–	249	14.90
Rubber, clone	48.1	–4,523	11,686	–	249	17.95
Cinnamon/coffee	27.0	13,189	6,809	13	56	77.16
Cinnamon/potato	22.7	11,965	31,987	12	157	34.58
Cinnamon /chilli	22.7	93,650	4,826	1	237	64.31
Oil palm	27.5	55,734	4,514	1	217	61.25
Damar, traditional	91.2	43,065	19,427	5	141	45.97
Damar, semi-intensive	91.2	59,470	25,230	5	190	59.40
Coffee, timber-based	39.7	65,791	88,318	13	319	29.81
Coffee, fruit-based	42.2	2,125	51,272	18	319	20.80
Coffee, shade-based	43.5	16,039	46,603	10	319	26.05
Sengon	66.4	22,133	6,966	8	59	96.87
Mangium	52.7	13,474	2,823	8	47	124.58
Duku	58.9	110,255	7,141	5	41	424.53
Durian	68.2	109,427	6,724	5	44	374.50
Candlenut	63.9	25,121	8,089	5	38	105.81
Macang	62.1	185,849	7,433	5	33	667.11
Mango	62.1	224,634	6,724	5	31	843.44
Pinang	32.1	9,885	7,563	6	31	56.91
Rambutan	60.5	7,987	6,908	6	32	54.08

[a] Net present value of an infinite series of rotations

divided into state-forest land, state land for commercial use (HGU) and other state lands. Land classified HGU provides a 30-year licence to grow commercial estate crops or plantations. Some 68.5% of land in the Upper Citanduy subwatershed is privately owned.

The watershed covers part or most of seven administrative districts (*kabupaten*). The Ciamis and Tasikmalaya districts cover 35.5% and 59.5% of the Upper Citanduy subwatershed, respectively. In terms of strategic importance, Ciamis is the most important district in the Citanduy watershed, followed by Tasikmalaya. These districts generally have light to moderate terrain. A field survey was conducted in two subdistricts: Cisayong (in the Tasikmalaya District) and Sadananya (in the Ciamis District). The Citanduy watershed is described in some detail by Dwiprabowo and Wulan (2003). The research sites represent areas that are considered socially and economically disadvantaged due to high unemployment and low income.

Data on smallholder agroforestry systems, inputs, outputs, prices and tree biomass were collected through a field survey. Interviews with the landowners, and observation and measurement of their trees, were conducted in a sample of farms. Systematic sampling was employed to obtain estimates of tree volume and biomass of the various agroforestry systems. A sample of 20 farms was taken, consisting of 8 farms in Tasikmalaya and 12 farms in Ciamis (Table A2). The farms tend to be small, ranging between 0.25 and 1.0 ha, with a mean area of 0.5 ha.

Species identification and tree measurements were conducted in all measurement plots. Tree age was noted based on information from the farmer. Data on establishment costs were collected by interviewing each farmer using a prepared questionnaire. The total number of trees measured was 665 (221 in Tasikmalaya and 444 in Ciamis). The allometric equation of Brown et al. (1995) was used to estimate biomass carbon based on tree diameter and height (see equation (4.1)). Carbon mean annual increment (CMAI) was calculated by dividing the carbon content of a tree by its age.

A good diversity of tree species was found in both districts: 12 species were identified in Tasikmalaya (Table A3) and 29 species in Ciamis (Table A4), although most species were represented by only a few trees.

The main species planted in Tasikmalaya was *Paraserianthes falcataria* (86.9 %) followed by *Agathis dammara* (2.3 %) and *Hibiscus* sp. (2.3 %). *Paraserianthes falcataria* was chosen as a main tree in the area because of the land suitability and easier accessibility to market. Most *P. falcataria* trees were harvested in year 6, when they reached an average diameter of 20–25 cm. The average price received by farmers for wood was Rp140,535/m^3.

The main tree planted in Ciamis was *Maesopsis eminii*, representing 26.4% of trees, closely followed by *P. falcataria*, with 26.1% of trees, and *Swietenia macrophylla*, with 17.1% of trees. The two former tree species were harvested in years 5–6 at an average diameter of 20–25 cm. *Maesopsis eminii* trees were sold for about Rp66,670/m^3. The species was popular in the area because it grew better than *P. falcataria*.

Other trees planted in Ciamis include kidamar (*A. dammara*), puspa (*Schima wallichii*), pine (*P. merkusii*) and mahogany (*S. macrophylla*). These trees are planted for their wood, for shelter and for

Table A2. Characteristics of farms sampled in West Java

Location	Farm	Farm size (ha)	Farmer's age (years)	Land-use system[a]
Tasikmalaya	1	0.70	45	1
	2	0.50	50	1
	3	0.38	45	1
	4	0.50	47	1
	5	0.57	40	1
	6	0.60	35	1
	7	0.50	47	2
	8	0.50	58	1
Ciamis	1	0.42	37	2
	2	1.00	42	1
	3	0.50	47	2
	4	0.42	54	1
	5	0.50	67	1
	6	0.25	35	2
	7	0.50	35	1
	8	0.50	56	1
	9	0.47	50	2
	10	0.50	52	1
	11	0.57	38	2
	12	0.50	45	2
Mean		0.52	46.25	
Minimum		0.25	35.00	
Maximum		1.00	67.00	
Coefficient of variation		0.28	0.18	

[a] 1 = trees and crops, 2 = trees only

soil protection, while trees such as kemang (*Mangifera* spp.), durian (*D. zibethinus*), cengkeh (*Eugenia aromatica*), alpukat (*Persea americana*), limus (*Mangifera foetida*) and kelapa (*Cocos nucifera*) were planted mainly for their fruit. Most of these products were sold, but the fruit of guava (*Psidium guajava*) and cempedak (*Artocarpus integer*) were mainly used for home consumption.

Not all smallholder agroforestry systems have the same potential. On average, carbon mean annual increment (CMAI) was slightly higher in Ciamis (7.4 kg/tree/year) than in Tasikmalaya (6.7 kg/tree/year). Due to the small number of trees representing most species, it is not possible to undertake a reliable comparison for all species, but the main species exhibited similar rates of carbon accumulation, ranging between 6.5 and 8.8 kg/tree/year for *S. macrophylla*, *M. eminii* and *P. falcataria* (Tables A3 and A4). The general profiles of the smallholder agroforestry systems in the two areas are shown in Figures A3 and A4. Consistent with the previous discussion, it can be seen that systems in Ciamis have more trees and a closer cover of canopy than in Tasikmalaya. To evaluate the various agroforestry systems from an economic perspective, they were grouped into four patterns for each district (Table A5). The patterns differ in terms of diversity of species, tree density and, implicitly, management intensity.

The mean carbon stocks of representative agroforestry systems in Citanduy range between 23.21 and 85.3 tC/ha (Table A6). NPVs have a range of between –Rp6.9 million/ha and Rp20.3 million/ha. As with the Sumatra systems, there is a wide range of values for establishment costs, years to positive cash flow, labour requirements and return to labour.

East Nusa Tenggara

East Nusa Tenggara is representative of the general characteristics of eastern Indonesia. It consists of small islands with lower population density and a longer dry season than western Indonesia. East Nusa Tenggara lies between longitudes 118˚E and 125˚E and latitudes 8˚S and 12˚S. Geographically, East Nusa Tenggara is an archipelago with hilly topography and young volcanic rocks. The province comprises 566 islands. The three main islands are Flores, Sumba and Timor (only West Timor is part of Indonesia). Timor, on which Kupang, the capital, is located, is hilly and steep. Most rivers on the island are temporary, flowing only in the rainy season.

Due to the central highlands and their closeness to Australia, the seasons in East Nusa Tenggara are irregular. Generally, the islands are semi-arid, with a long dry season lasting from March to November and a wet season from December to February. Rainfall varies between 500 and 2000 mm a year. Most of this region exhibits low land fertility and, as a result of wild shepherding and fire, there is low vegetation coverage. This also lessens the capacity of rain infiltration, causing high run-off and occasional floods.

Table A3. Details of species found in Tasikmalaya smallholder agroforests

Common name	Scientific name	Outputs[a]			Trees sampled		Mean age (years)	CMAI[b] (kg/tree/year)
		L	F	W	(*n*)	(%)		
Afrika	*Maesopsis eminii*			•	1	0.5	3.0	4.4
Alpukat	*Persea americana*		•	•	3	1.4	6.7	3.6
Cengkeh	*Eugenia aromatica*		•	•	3	1.4	9.3	1.0
Huru	*Litsea monopetala*			•	1	0.5	3.0	4.1
Kidamar	*Agathis dammara*			•	5	2.3	6.2	4.2
Mahogany	*Swietenia macrophylla*			•	2	0.9	5.0	2.2
Manglid	*Manglietia glauca*			•	4	1.8	6.5	2.5
Nangka	*Artocarpus heterophyllus*		•	•	3	1.4	6.3	6.9
Petai	*Parkia speciosa*	•	•	•	1	0.5	15.0	0.6
Sengon	*Paraserianthes falcataria*			•	192	86.9	2.8	7.1
Suren	*Toona surenii*			•	1	0.5	3.0	3.5
Tisuk	*Hibiscus* sp.			•	5	2.3	3.0	6.9
				Total:	221	Weighted average:		6.7

[a] L = leaf, F = fruit, W = wood
[b] Carbon mean annual increment

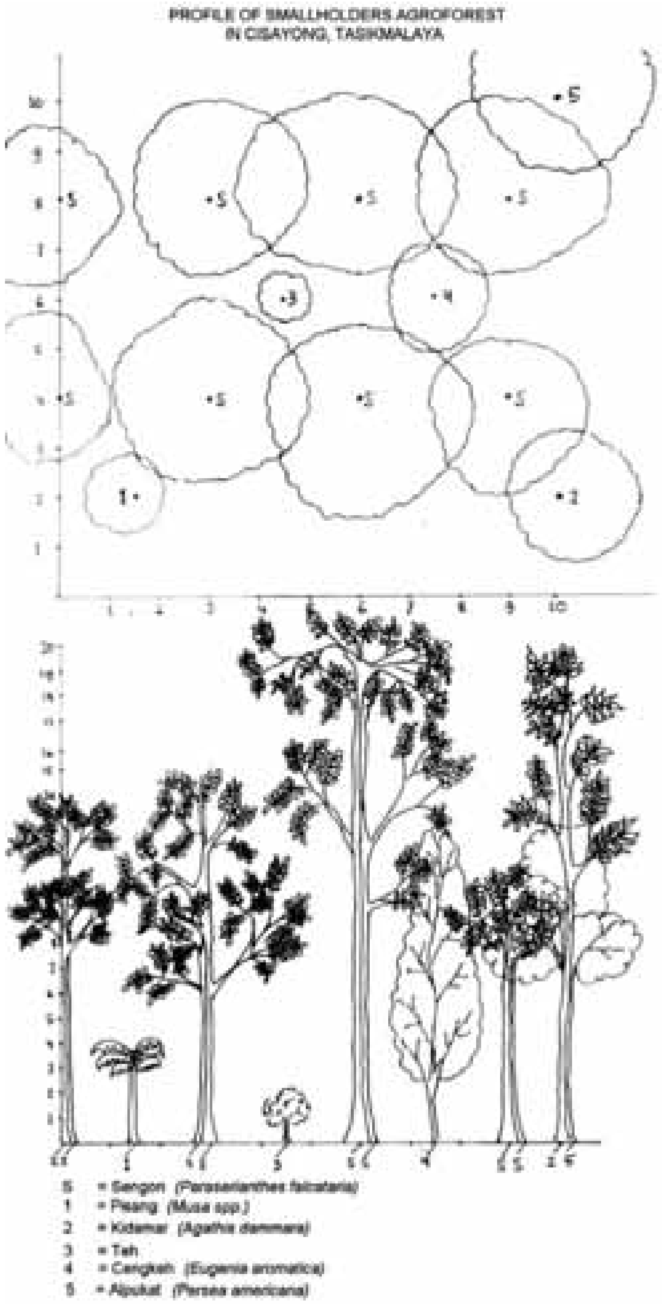
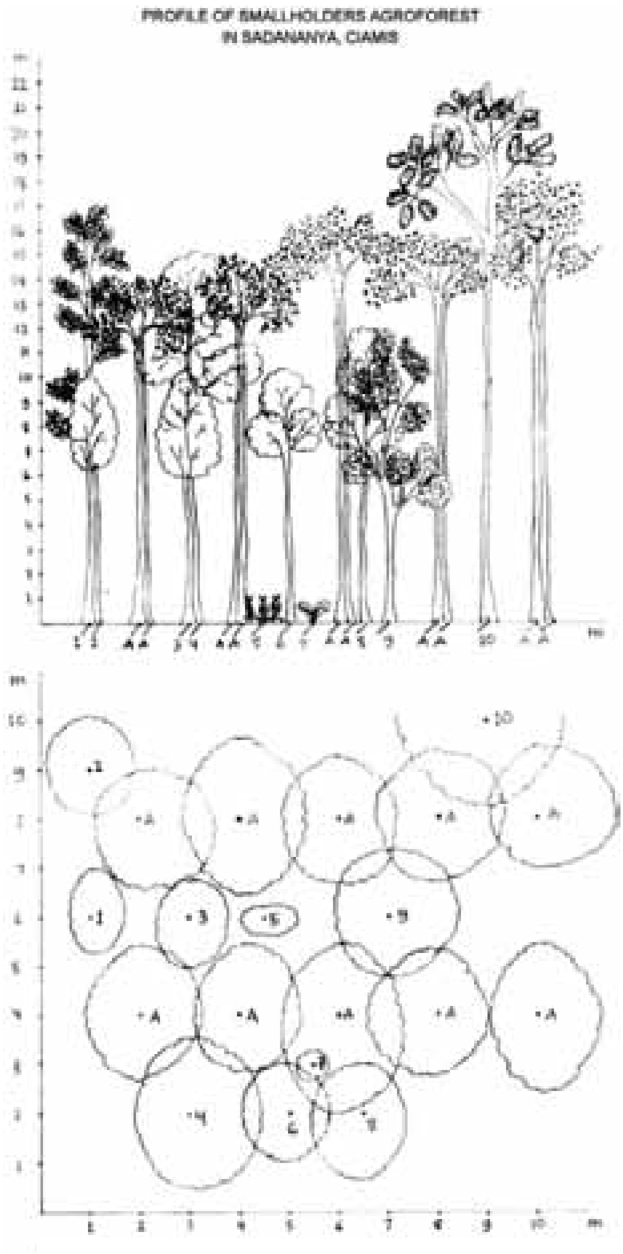


Figure A3. Agroforestry pattern in Cisayong, Tasikmalaya



A = Kayu Afrika (*Maesopsis eminii*)
1,3 = Cengkeh (*Eugenia aromatica*)
2 = Kidamar (*Agathis dammara*)
4,6,8 = Mahoni (*Swietenia macrophylla*)
5 = Nanas (*Ananas comosus*)
7 = Kapulaga (*Amomum compactum*)
9 = Tangkil (*Gnetum gnemon*)
10 = Sengon (*Paraserianthes falcataria*)

Figure A4. Agroforestry pattern in Sadananya, Ciamis

The area used in this analysis is the Manamas village, in the Timor Tengah Utara district. This is a remote village with hilly and steep land. The rainfall is limited to only 4 or 5 months of the year. Land ownership is claimed personally with unclear boundaries, and farmer incomes are relatively low. Agriculture in Manamas is for subsistence: most food crops produced are for home consumption, although farmers raise some livestock (pigs, chicken, goats and a small number of cattle) for sale. Livestock fodder depends on natural availability. This village has 291 households, and about 22% of them belong to a farmer group.

We sampled 14 farms in East Nusa Tenggara (Table A7). The average farm area is 1.4 ha, with farm sizes ranging between 0.3 and 6.0 ha. These farm sizes are larger than in West Java, reflecting the lower soil fertility and water availability, and the resulting need for larger areas to have a viable business. The average household size is 5.7 people, with a dependency ratio of 1.08 (meaning that each productive-age person has 1.08 dependants). In the Manamas village there is only one primary school building. To attend high school, children must travel to another village, which is relatively distant. As a result, the education level is low (Table A7).

Some 295 trees were measured and 14 species identified (Table A8), including two varieties of *T. grandis* (jati). The most popular species is *Gmelina arborea*, representing 59.3% of the trees sampled,

Table A4. Details of species found in Ciamis smallholder agroforests

Common name	Scientific name	Outputs[a]			Trees sampled		Mean age (years)	CMAI[b] (kg/tree/year)
		L	F	W	(*n*)	(%)		
Afrika	*Maesopsis eminii*			•	117	26.4	3.1	8.4
Alpukat	*Persea americana*		•	•	4	0.9	2.8	5.0
Cempedak	*Artocarpus integer*		•	•	1	0.2	3.0	2.3
Cengkeh	*Eugenia aromatica*		•	•	17	3.8	7.0	2.1
Durian	*Durio zibethinus*		•	•	4	0.9	3.5	3.6
Huru	*Litsea monopetala*			•	1	0.2	3.0	15.8
Jambu batu	*Psidium guajava*		•	•	2	0.5	6.0	1.6
Jengkol	*Pithecellobium jiringa*		•	•	4	0.9	4.5	6.5
Johar	*Gliricidia sepium*			•	3	0.7	4.0	1.9
Kelapa	*Cocos nucifera*	•	•	•	4	0.9	20.0	8.1
Kemang	*Mangifera* spp.	•	•	•	3	0.7	3.0	14.9
Kidamar	*Agathis dammara*			•	4	0.9	6.8	8.5
Kinyere	*Syzigium* spp.			•	1	0.2	6.0	11.6
Kiteja	*Cinnamomum* spp.			•	5	1.1	6.4	11.0
Limus	*Mangifera foetida*		•	•	4	0.9	11.3	3.1
Mahogany	*Swietenia macrophylla*			•	76	17.1	5.0	6.5
Nangka	*Artocarpus heterophyllus*		•	•	13	2.9	6.7	6.3
Petai	*Parkia speciosa*	•	•	•	12	2.7	11.6	3.4
Picung	*Hibiscus* sp.			•	2	0.5	8.0	12.9
Pinus	*Pinus merkusii*			•	1	0.2	3.0	3.1
Pisitan	*Lansium* sp.		•	•	1	0.2	6.0	2.1
Puspa	*Schima wallichii*			•	15	3.4	8.5	7.9
Putat	*Planchonia valida*			•	2	0.5	3.5	9.0
Rambutan	*Nephelium lappaceum*		•	•	1	0.2	4.0	2.7
Sengon	*Paraserianthes falcataria*			•	116	26.1	3.2	8.8
Suren	*Toona sureni*			•	3	0.7	2.7	5.4
Tangkalak	*Litsea* spp.		•	•	1	0.2	2.0	7.7
Tangkil	*Gnetum gnemon*	•	•	•	16	3.6	5.4	3.1
Tisuk	*Hibiscus* sp.			•	11	2.5	3.0	11.5
				Total:	444	Weighted average:		7.4

[a] L = leaf, F = fruit, W = wood
[b] Carbon mean annual increment

followed by the two varieties of jati making up 15.6%. The third most popular species is *S. macrophylla*, with 8.5% of trees. The carbon-sequestration potential of the East Nusa Tenggara systems is relatively low, with an average CMAI of 3.8 kg/tree/year, compared with 6.7 and 7.4 kg/tree/year in the two East Java districts described earlier. There was a wide range of CMAI values. Although the highest value was 19.1 kg/tree/year (Table A8) this represented a single tree that is an obvious outlier. The largest reliable value (with a sample size of 25 trees) was exhibited by jati lokal (7.6 kg/tree/year).

Farmers obtained an average income of Rp1.4 million from cropping (mostly maize, peanuts and vegetables) and Rp335,000 from livestock (mostly poultry). The tree systems sampled were dominated by timber species that have not been harvested, thus it was not possible to undertake the type of economic evaluation presented for other districts. However, the data obtained will later be used to study the feasibility of carbon-sequestration projects in the region.

Imperata as a baseline

Imperata cylindrica is an invasive grass that has occupied deforested areas throughout South-East Asia. Within a few years of deforestation for food production, the land becomes infested with *Imperata* as soil nutrients are exhausted. Garrity et al. (1997) estimate that *Imperata* covers 8.6 million ha in Indonesia, of which 2.1 million ha occur in Sumatra, 0.2 million ha in Java and 1.7 million ha in East Nusa Tenggara.

Imperata grasslands are prone to burning either accidentally or intentionally (van Noordwijk et al. 1997). Fires destroy naturally restored secondary forest and enhance the competitive advantage of *Imperata*. *Imperata* grasslands have low economic value and their control in much of Indonesia is mostly a problem of labour. It is possible to clear *Imperata* grasslands manually and plant crops or trees, but this may take up to 200 person days per hectare, which is more than it takes to open up new forest through slash-and-burn. There are some successful examples of communities establishing agroforests in grassland areas but this is still uncommon (van Noordwijk et al.

Table A5. Smallholder agroforestry patterns in Citanduy

Pattern	Tree species
Tasikmalaya district	
T1	Sengon
T2	Sengon, mahogany, manglid, avocado, kidamar
T3	Sengon, tisuk, suren, jackfruit, parkia, avocado
T4	Sengon, avocado, kidamar, tisuk, cengkeh
Ciamis district	
C1	Afrika, mahogany, sengon, puspa, tisuk, tangkil, nangka, cengkeh, kiteja, kidamar, coconut, avocado, parkia, durian
C2	Sengon, afrika, cengkeh, mahogany, parkia, puspa, jackfruit, tangkil, johar, limus, tisuk, kemang
C3	Kiteja, mahogany, sengon
C4	Sengon, mahogany, afrika, tangkil, jackfruit, cengkeh, kidamar

Table A6. Economic evaluation of agroforestry systems in Citanduy

Pattern	Carbon stock (tC/ha)	Net present value (Rp ’000/ ha)	Establishment cost (Rp ’000/ ha)	Years to positive cash flow	Labour required (person days/ha/year)	Return to labour (Rp ’000/person day)
T1	25.15	–6,871	10,342	–	144	6.17
T2	19.51	2,005	18,384	17	145	17.15
T3	25.30	16,329	9,149	8	66	49.51
T4	23.21	10,900	17,886	10	162	25.05
C1	48.68	–2,999	12,303	–	64	7.78
C2	85.27	11,198	437	11	62	42.89
C3	49.76	20,250	1,863	3	22	181.93
C4	41.61	7,931	11,306	12	89	28.62

1997). In vast grassland areas the cost of converting *Imperata* land is compounded by the risk of fires that move rapidly through the landscape and destroy trees. The vast areas occupied by *Imperata*, combined with its low economic value, the risk of fires and the high labour inputs required to convert the land, make it an ideal candidate for CDM projects. Not only should conversion of *Imperata* grasslands meet additionality and sustainable-development criteria, but estimation of the baseline should also be relatively simple because the carbon content of biomass and soil is fairly constant.

Table A7. Characteristics of farms sampled in East Nusa Tenggara

Farm	Area (ha)	Farmer's age	Family size	Farmer's education[a]	Land-use system[b]
1	3.0	51	5	4	3
2	0.3	37	4	2	1
3	0.5	34	8	4	1
4	0.5	42	11	2	3
5	0.5	32	7	3	3
6	1.0	56	4	1	1
7	0.4	56	9	1	1
8	0.3	38	7	2	1
9	6.0	42	5	1	3
10	2.0	48	8	4	3
11	1.5	36	3	2	2
12	0.3	36	4	4	2
13	0.3	40	3	2	1
14	3.0	32	2	4	3
Mean	1.40	41.43	5.71	2.57	
Minimum	0.30	32.00	2.00	1.00	
Maximum	6.00	56.00	11.00	4.00	
Coefficient of variation	1.17	0.20	0.46	0.48	

[a] 1 = no schooling, 2 = elementary school, 3 = junior high school, 4 = senior high school
[b] 1 = trees and crops, 2 = trees and livestock, 3 = trees, crops and livestock

Table A8. Details of species found in East Nusa Tenggara smallholder agroforests

Common name	Scientific name	Trees sampled (*n*)	Trees sampled (%)	Mean age (years)	CMAI[a] (kg/tree/year)
Ampupu	*Eucalyptus urophylla*	6	2.0	10.0	1.8
Asam	*Tamarindus indica*	1	0.3	8.0	19.1
Eucalyptus	*Eucalyptus pellita*	23	7.8	4.5	4.0
Gmelina	*Gmelina arborea*	175	59.3	7.9	3.9
Huek	*Eucalyptus alba*	5	1.7	10.0	2.7
Jati[b] lokal	*Tectona grandis*	25	8.5	9.4	7.6
Jati super	*Tectona grandis*	21	7.1	4.4	1.4
Johar	*Gliricidia sepium*	1	0.3	5.0	0.6
Kabesak	*Acacia leucophloea*	1	0.3	8.0	0.9
Kemiri	*Aleurites moluccana*	4	1.4	13.3	7.1
Mahogany	*Swietenia macrophylla*	25	8.5	6.9	1.0
Masi	*Broussonetia papyrifera*	1	0.3	8.0	7.0
Sengon	*Paraserianthes falcataria*	3	1.0	4.0	4.0
Tastasi	*Vitex trifolia*	1	0.3	1.0	0.1
Turi	*Sesbania grandiflora*	3	1.0	8.0	0.3
		Total: 295	Weighted average: 3.8		

[a] Carbon mean annual increment
[b] Jati is the local name for teak.

Appendix 2
Projects studied

Overview of projects

The analysis in Appendix 1 focused on specific agroforestry systems suitable for adoption by smallholders. The analysis was based on standard discounted cash flow techniques supplemented by measurement of trees in the field to calibrate models of carbon accumulation. Those models are implemented on spreadsheets and require information on inputs, outputs, prices and discount rates. Those data are laborious to collect but their application in estimating abatement costs is straightforward. In contrast, estimating transaction costs is not a straightforward process, as it requires assumptions about particular aspects of the project to be implemented. At the time of writing, there were no approved AR CDM projects that could be studied to estimate transaction costs. We therefore resorted to studying existing Indonesian reforestation projects as reported in this appendix. This gave us insight into the process of designing and implementing projects involving smallholders and communities, and the associated costs. Four projects were visited, one in West Java, one in West Nusa Tenggara and two in East Nusa Tenggara. Project managers were interviewed and data on costs were collected where available. These projects are described below.

Two additional Indonesian projects are briefly presented in this appendix to round out the discussion. The first is an ADB technical-assistance project that has funded the development of four AR PDDs in Indonesia for submission to the CDM. This project has not been completed, but examining its progress gives insight into the process of search for sites and selection of communities with which to collaborate. In this appendix we also present a brief description of the GERHAN project, a national movement of land and forest rehabilitation with ambitious goals.

Finally, the information obtained from the Indonesian projects was supplemented by studying several Latin American projects originally established as Activities Implemented Jointly (AIJ). The AIJ program was created by the UNFCCC to facilitate the implementation of the Kyoto flexibility mechanisms (which include the CDM).

JIFPRO project in Cianjur, West Java

This CDM-like project was initiated through an agreement between the Directorate General of Land Rehabilitation and Social Forestry and a director of JIFPRO (Japan International Forestry Promotion and Cooperation Centre). The project consists of establishing a private forest in the Cianjur District, West Java. The implementer of the project is the Citarum–Ciliwung Watershed Management Agency (BPDAS) in collaboration with the District Office of Forestry and Soil Conservation and other related institutions. The field implementers are local people belonging to farmer groups.

A model plan was produced by BPDAS to provide technical and administrative guidance for the smooth operation of the project. The plan covers infrastructure requirements, socioeconomic aspects and a schedule of main activities. The specific objectives of the plan are: (i) to guide the implementation of private forest management in accordance with local biophysical, social and economic characteristics, considering the needs of landowners for sustainable forest management and (ii) to contribute to wood supply for community needs. Before field implementation, training of farmers was conducted following participatory rural appraisal principles to enhance the probability of success of the project. The process of control, monitoring, evaluation and reporting was conducted by BPDAS through field inspections.

The total area of the project is 17.5 ha, divided into two phases. The first phase established 10 ha in 2000–01 and involved 54 farmers. The second phase established 7.5 ha in 2002–03 and involved 14 farmers. The land-use plan includes a mix of annual crops, seasonal crops and mixed cropping. Financing for the project (a total of Rp136,233,500) was provided by Home Direct Co. Ltd, Japan, through a grant distributed by JIFPRO.

We collected primary data about stakeholders' perceptions and cost structures. We also obtained secondary data from the Forestry Provincial Office, the District Office of Forestry and Soil Conservation, the Citarum–Ciliwung Watershed Management Agency, the Sub-District Office and the farmer group. Twenty-four people were interviewed.

The selection of agroforestry systems in the project was limited, consisting of suren (*Toona sureni*), coffee, mahogany (*S. macrophylla*) and crops under trees. Some farmers planted other trees in their own land such as rambutan *(N. lappaceum)*, alpukat *(P. americana),* pala *(Myristica fragrans),* pisang *(Musa* spp.*),* and jengkol *(Pithecellobium jiringa).* Most of the additional trees are multipurpose species that produce harvested outputs every year, and thus produce a stream of income while waiting to harvest the main trees.

Most of the land cultivated in the project is owned by the government and distributed by the head of the village. The average land owned by farmers in the project ranges from 0.185 ha to 0.536 ha per person. Five respondents (24%) used rented land, ranging from 300 m^2 to 1,200 m^2, with land rental payments of Rp1,500,000 per ha per year.

The costs of establishing the agroforestry systems are presented in Table A9. The total cost of establishment (materials and labour) was approximately Rp4.5 million/ha, which corresponds to about $520/ha. The 7.5-ha phase was more expensive per hectare than the 10-ha phase (Rp4,942,300 versus Rp4,143,000) because of the higher cost of seedlings in the former. The price of suren and mahogany seedlings in 2001–02 was four times higher than the price in 1999–2000. Subarudi et al. (2004) provide more details on costs.

The total cost of the project (including design and administration costs) was Rp136,233,500, or Rp7,784,770 per hectare (Table A10), which is equivalent to $895/ha at the current exchange rate of Rp8,700 per US dollar. The amount of carbon sequestered in this project is expected to be similar to the amounts in Tasikmalaya agroforestry systems reported in Appendix 1, which ranged between 19.50 and 25.15 tC/ha. This results in carbon costs of between $35.60 and $45.90 per tonne. Since 1 tonne of biomass carbon is equivalent to 3.67 tonnes of CO_2, these costs correspond to between $9.70 and $12.50 per tonne of CO_2 sequestered. These costs are high, considering that the BioCarbon Fund of the World Bank quotes prices between $3 and $5 per tonne of CO_2. However, from a development standpoint, other environmental and social benefits must be considered. In Cianjur the project is helping to prevent soil erosion, maintain water quality in the catchment, and improve farmers' skills and knowledge, in addition to increasing their incomes.

Table A9. Establishment costs of Japan International Forestry Promotion and Cooperation Center project in Cianjur

Cost description	10-ha phase 1999–2000 (Rp '000)	7.5-ha phase 2001–02 (Rp '000)
Materials		
– planting	21,610	24,987
– first-year tree maintenance	2,740	1,500
Total materials	24,350	26,488
Labour cost		
– planting	13,550	9,430
– first-year tree maintenance	3,530	1,150
Total labour	17,080	10,580
Total cost	41,430	37,068
Cost per hectare	4,143	4,942

Source: BRLKT (2001, 2002c)

JIFPRO project in Lombok, West Nusa Tenggara

In support of the Indonesian Government's reforestation and rehabilitation programs, the Japanese Government, through JIFPRO, has implemented a two-phase reforestation project in West Nusa Tenggara over the past 10 years. The first phase of the project took place between 1996 and 2001, and involved the reforestation and protection of 350 ha of land in Sekaroh, East Lombok. A further 130 ha were reforested and protected in Rembitan, Central Lombok, during the second phase of the project between 2002 and 2005. Table A11 presents information on the institutions involved in the implementation of the project. Since this project was not implemented under the CDM, the institutions involved and the roles undertaken to plan, develop and monitor the various phases may be fewer and simpler than would be required for CDM projects.

Data were collected from primary and secondary sources. Primary data were collected from the field and from several individuals and organisations, including the Provincial Forestry Office (PFO), the Office of Nature Conservation, the District Office of Forestry and Soil Conservation, the Watershed Management Agency, the University of Mataram, the Regional Environmental Office, the Regional Planning Agency and affected landholders. Activities contributing to transaction costs, and estimates of these costs, were gathered during interviews with relevant people in the institutions involved in both the development of the proposal and the implementation of the project.

Four to five sites were proposed by the Provincial Forestry Office based on general criteria set by JIFPRO:

- The land must be accessible and have enough water.
- The land must have potential to provide ecosystem functions and environmental services.
- Grazing activities in the region must be limited.
- The status of the land must be protected forest, but the land must be bare (the area was deforested in the 1970s and 1980s).
- Some kind of historical, social or environmental value must be associated with the land.

Table A10. Total costs of the Japan International Forestry Promotion and Cooperation Center project in Cianjur

Financial description	10-ha phase (Rp ’000)	7.5-ha phase (Rp ’000)	Total cost (Rp ’000)
Measurement and production of model plan	1,930	1,930	3,860
Seedling provision	9,460	17,825	27,285
Tree planting	26,140	16,592	42,732
Tree maintenance	6,710	2,650	9,360
Watershed support building	5,120	5,070	10,190
Gully plug making	1,153	5,120	6,273
Farmer training	13,150	4,383	17,533
General costs	9,500	9,500	19,000
Total cost	73,163	63,070	136,233

Source: BRLKT (2000; 2002a,b,c)

Table A11. The institutions involved and their respective roles in the development of Japan International Forestry Promotion and Cooperation Center (JIFPRO) projects in East Lombok implemented between 1996 and 2005

Steps	Institutions involved	Role
Preparation	Proponent (PFO[a]) Investor (JIFPRO) Ministry of Forestry DG of LRSF[b]	Planning (measurement and mapping) and species matching, seedlings criteria control Funding source Project liaison
Implementation	PFO Farmer group	Project manager Land preparation, seedling provider, planting, maintenance
Validation	DFO[c] NGO[d]	Land suitability Seedling provider
Monitoring	PFO, DFO Farmer group	Replanting and maintenance; community development Replanting and maintenance
Evaluation	University of Mataram	Tree maintenance; income and employment generation

[a] Provincial Forestry Officer; [b]Director General of Land Rehabilitation and Social Forestry; [c]District Forestry Office; and [d]non-government organisation

The land is moderately settled and there is temporary grazing of buffalo and cattle. However, there is limited access to safe drinking water; reforestation is expected to increase the quality of the water. In theory, the use of (currently deforested) protected forest for the development of a CDM project makes it easier to implement and manage, and increases its likelihood of success, since there are no disputes about land tenure.

The final choice of sites is presented in Table A12 and the species planted are listed in Table A13. The tree species planted in the project are a mix of timber and fruit trees.

Table A12. Japan International Forestry Promotion and Cooperation Center projects implemented in protection forests on Lombok Island, West Nusa Tenggara.

Year	Area (ha)	Location[a]
1996–97	50	Sekaroh
1997–98	150	Sekaroh
1998–99	150	Sekaroh
2001–02	20	Rembitan
2002–03	100	Sekaroh and Rembitan
2003–04	10	Rembitan

[a] Sekaroh is in East Lombok and Rembitan in Central Lombok

Deciding on the project sites took some time, requiring three visits to the sites over 4 days by three to five people from JIFPRO and a further four visits by two to three people from the Ministry of Forestry. The selection process also involved inputs of time and money from the University of Mataram. Information was exchanged between the PFO and JIFPRO mainly through email, but a JIFPRO liaison officer within the Directorate General of Land Rehabilitation, Ministry of Forestry, also aided in the exchange of information. Experience with previous JIFPRO projects indicates that it takes approximately 1–2 years for a project to be approved by JIFPRO. In the case of a CDM project this may take even longer, since approval is needed not only from JIFPRO but also from the many other stakeholders involved. Once the project has been approved the management responsibilities generally fall on the PFO. The main office normally will be located in either the Provincial or District Forestry Office building. Although a base camp will be built near or on the site it will not be fitted with computers and software. This base camp is used for shelter and administration by farmers and farmer groups, and for the training and coordination of field crews.

Table A13. Tree species planted in the Japan International Forestry Promotion and Cooperation Center project in Lombok

Site	Species
Rembitan	Coconut (*Cocos nucifera*) Jackfruit (*Artocarpus integra*) Mahogany (*Swietenia macrophylla*) Mango (*Mangifera indica*) Serikaya (*Annona squamosa*) Sonokeling (*Dalbergia latifolia*) Teak (*Tectona grandis*)
Sekaroh	Cashew nut (*Anacardium occidentale*) Johar (*Gliricidia sepium*) Leucaena (*Leucaena leucocephala*) Neem (*Azadirachta indica*) Randu (*Ceiba pentandra*) Sengon (*Paraserianthes falcataria*) Serikaya (*Anona squamosa*) Tamarind (*Tamarindus indica*) Teak (*Tectona grandis*)

Information gathered through interviews with government officials at both the district and provincial levels indicates that it does not take long to get the required letter from the head of district certifying the eligibility of the land for the development of a CDM project, provided there are no problems or conflicts over the land. Several estimates about the time taken to issue this letter have been put forward. If there is a one-stop service for CDM projects and there is no conflict over the land, it could take as little as 1–5 days. If, however, these criteria are not met, it can take up to 6 months. The amount of information already available about the various stakeholders, such as affected villages and community groups, can also influence the amount of time taken to issue this letter.

Currently, the PFO and JIFPRO are negotiating the implementation of another 150-ha AR project in East Lombok. This project is planned for the Sambelia subdistrict and is expected to qualify for CERs under the CDM. Thus far, it has taken approximately 1 year of negotiations between the government, local authorities and JIFPRO to plan the project and for JIFPRO to release the funds for implementation. The proposed budget for this project is presented in Table A14. The total cost is Rp2,696 million, equivalent to $309,917, to reforest 150 ha, resulting in a cost of $2,066/ha. Some 65% of this cost is for planting and maintenance of the trees. The baseline scenario of the proposed project is shrubs and *Imperata* grasslands.

OECF project, East Nusa Tenggara

This community forest, or hutan kemasyarakatan (HKM), project in East Nusa Tenggara (1999–2001) covered planning, planting, capacity building, community development and infrastructure building, including roads. The objective of HKM projects is to ensure forests are managed sustainably with involvement of the local community. The project was funded by the Overseas Economic Cooperation Fund (OECF). It covered four villages in three districts: Kupang, Alor and East Sumba (Table A15). The project covered a total of 2,000 ha.

The baseline was typified by bush fallow or secondary forest with *Eucalyptus* dominant. The Kupang district, because of its lower elevation and easier access, has higher population density than the Alor and East Sumba districts. The project started with a process of socialisation of farmers, with training to help them understand the roles and obligations of the community in terms of forest status and function. As most of HKM participants have only an elementary school education, field workers from NGOs were available for socialisation for about 20 months. The harvesting and use of forest is trusted to the community under guidance from the government. The farmer group organises marketing of the timber and other products of the forest.

Mixed agroforestry systems were established, comprising timber and multipurpose tree species. The wood-tree species planted are mahogany (*S. macrophylla*), teak (*T. grandis*), johar (*Cassia siamea*) and gmelina (*G. arborea*). Multipurpose tree species include candlenut (*A. moluccana*), jambu

Table A14. The proposed budget for the 150 ha Clean Development Mechanism – Japan International Forestry Promotion and Cooperation Center (JIFPRO) project

Steps	Activities	Institutions[a]	Costs (Rp '000)[b]	Percentage of costs
Preparation	Project design	PFO, DGLRSF	15,000	0.56
Implementation	Establishment: seedlings, land preparation, planting and maintenance	Farmer group, NGOs, DFO, PFO	1,761,875	65.34
Project management	Infrastructure and equipment Project administration	Project Project	344,100 200,400	12.76 7.43
Monitoring	Community development	PFO, DFO and farmer group	174,500	6.47
Evaluation	Coordination, monitoring and evaluation	University of Mataram	200,400	7.43
Total (Rp)			2,696,275	

[a] PFO = Provincial Forestry Officer; DGLRSF = Director General of Land Rehabilitation and Social Forestry; NGO = non-government organisation; DFO = District Forestry Office; PFO = Provincial Forestry Office.
[b] JIFPRO provides 78.34% of funds, PFO 13.26% and East Lombok district 8.4%.

Table A15. Overseas Economic Cooperation Fund project district characteristics

	District		
	Kupang	Alor	East Sumba
Elevation (m above sea level)	200–350	300+	600–850
Topography	Flat to steep	Very steep	Very steep
Baseline	Bushland and secondary forest	Secondary forest	Bushland/grassland
Distance to subdistrict (km)	27	90	95
Land status	Limited production forest	Unclear	Protected forest
Population density (persons/km^2)	109	36	26
Land ownership (ha/household)	2.6	2.0	4.0

mete (*Anacardium occidentale*) and other species. Other crops and trees that provide steady income flows vary between sites, but they include paddy rice, maize, peanuts, tamarind, coconut, mango, jackfruit, banana, betel nut, avocado, almond, cassava, sweet potato and a variety of vegetables.

There was no detailed cost information for this project but rough information could be gathered (Table A16). The total cost of Rp8,300 million to reforest 2,000 ha results in a cost of Rp4.15 million/ha, or $477/ha. This cost is lower than in the JIFPRO Lombok project discussed in the previous section.

Table A17 shows that there are differences between planted area and target area, with only 10–65% of the target area planted. The differences are partly influenced by site characteristics. Field observation in September 2004, 3 years after the completion of the project, revealed several problems: (i) the survival rate of the main plantation is only 50–60% in the area planted, and the area planted is only 10–55% of the target area; (ii) intercropping with trees was abandoned in some areas; and (iii) many plots are not being maintained and have been invaded by cattle. These conditions have been noticed by district officers but there is no further funding for monitoring and control. Since farmers consider the plots as government land, they are unwilling to incur maintenance costs. In addition, there is no contract or specific arrangement about how trees would be shared, so farmers are reluctant to maintain plots.

This experience indicates that the participatory approach is not sufficient to ensure sustainability in reforestation projects, as the newly planted trees had very low survival rates. It would appear that the success rate would be higher if there were security in land and tree ownership.

IFSP project, East Nusa Tenggara

The Indonesia Forest Seed Project (IFSP), funded by Danida, was launched in July 2000 with the purpose of helping smallholder farmers and NGOs strengthen their existing technical awareness and capacity and enhance their access to high-quality germplasm. This project is being implemented by ICRAF and Winrock International. Project activities include:

- surveys, meetings and participatory appraisal to identify NGO/smallholder current pathways, as well as their seed technology awareness, capacity and constraints

Table A16. Overseas Economic Cooperation Fund project costs in East Nusa Tenggara (1999–2001) for 2000 ha

Activities	Costs (Rp million)	Percentage of costs
Planning	400	4.8
Planting	6,000	72.3
Controlling	900	10.8
Co-working with non-government organisations, including training and capacity building	1,000	12.0
Total	8,300	

Table A17. Area planted and survival rate of trees in Overseas Economic Cooperation Fund project in East Nusa Tenggara

	Kupang		East Sumba	Alor
Village:	Haeknutu	Tesbatan	Probur	Meu Rumba and Kambata
Total area (ha)	600	400	500	500
Area planted to trees (ha)	331	261	50	179
Percentage area planted (%)	55	65	10	36
Survival rate (%):				
2001	83	70	91	81
2004	60	–	–	–

- participatory training activities (four types of training activities were held in the first year: (i) timber and fruit tree propagation; (ii) nursery management; (iii) seed-source management and seed collection; (iv) calliandra production and utilisation; all training involved 150 NGO staff, farmers and government field staff)
- production of technical documents in English and Indonesian (during the first year, five occasional documents were produced to support the opening seminar and training activities)
- the design and establishment of a smallholder demonstration trial (there were two types of demonstration trial: seed gardens and smallholder tree farms planted to test and show the advantages of superior quality seed)
- evaluating the suitability of guiding the formation of NGO or smallholder-based seed procurement.

The project has locations in southern Sumatra, Central Java and Nusa Tenggara. These locations were chosen because ICRAF and Winrock had productive relationships with local NGOs and farmer groups. The project studied here is located in the Manamas village, within the Timor Tengah Utara district. To improve the effectiveness of the participatory approach, IFSP adopted a full NGO partnership before, during and after the project, as reforestation occurs over a relatively long time period.

The NGO involved in this project is Yayasan Mitra Tani Mandiri (YMTM), an organisation involved in dryland agriculture. YMTM has been active in the region since 1990 and provides field assistance in every village it is associated with. The project provides improved tree seeds to farmers. The planting technique involves application of organic fertiliser, which is abundantly available from cattle and goats, in a 50 × 60 cm hole prepared 1 week before planting. In addition to the seeds provided by the project, farmers plant other trees such as banana, cashew and orange on their land, to supplement their income. To fulfil food needs, farmers in groups of two or three plant vegetables such as maize, paddy rice, tomato, eggplant, chilli and cabbage. Any surplus production is sold in the local market.

A demonstration plot was started in 2000. The tree species planted were teak (*T. grandis*), eucalyptus (*Eucalyptus* spp.), mahogany (*S. macrophylla*), and gmelina (*Gmelina arborea*). One year before planting on steep slopes, conservation activities such as terracing were undertaken. To evaluate tree growth in the demonstration plot, tree height and diameter are measured regularly using simple tools (a rope and a bamboo stick). The survival rate has been relatively high: 100% for gmelina and superior teak, 94% for eucalypts, 89% for gold teak and 88% for mahogany.

Project costs per hectare are presented in Table A18. These are estimates obtained from the NGO working for the project. Most costs (46%) are associated with monitoring, which requires technical expertise and co-working with farmers, followed by tending of trees (24%). Land preparation and planting together also represent a significant cost (25%). The total cost is equivalent to $870/ha, which is intermediate relative to other projects reviewed here.

The main problem faced by farmers in the project is dryland cultivation technology, which is a general problem in East Nusa Tenggara. All the farmers interviewed pointed out that training about the advantages of settled farming, seed handling, land cultivation, planting and stand maintenance are very useful. Once the farmers understand the benefit of settled farming, they claim that they would not undertake their previous practice of slash-and-burn. Yet, some farmers outside the group still followed their conventional system of slash-and-burn, despite the fact that it is prohibited by local government.

ADB project, carbon sequestration through CDM

This project is a technical assistance funded by the Asian Development Bank designed to help Indonesia develop four AR PDDs for the forestry sector. A national project identification workshop was held to identify possible projects. Districts were invited to participate in the workshop on the basis of four key factors:

- readiness of district stakeholders to implement AR-CDM projects
- analysis of district level conditions and availability of eligible CDM lands (Murdiyarso et al. 2006)
- a balanced geographical representation from across the country
- other factors that may indicate a particular district has high potential to implement an AR-CDM project.

Thirteen districts were invited to participate from three regions: (i) Sumatra and Java (west Indonesia), representing the most developed and densely populated area of Indonesia; (ii) Sulawesi and Irian (east Indonesia), representing the least developed, drier and poorer area of the country; and (iii) Kalimantan, representing an intermediate case. A ranking process was undertaken to select the sites that would develop PDDs. The project is still in progress, so actual costs of designing and implementing these projects are not available yet. However, a description of the selection process provides insights for further analysis.

Table A18. Indonesia Forest Seed Project (IFSP) costs

Activities	Costs (Rp '000/ ha)	Totals (Rp '000/ ha)
Preparation		
Land clearing	600	
Tree supports and digging holes	600	
Subtotal		1,200
Planting		
Gliricidia seedlings	300	
Local teak seedlings	40	
Labour	1,000	
Subtotal		1,340
Tending		
Weeding	1,200	
Pruning	1,200	
Subtotal		2,400
Administration		
Mailing, telephone and facsimile	300	
Reporting	200	
Subtotal		500
Monitoring		
Field co-worker	1,920	
Supervisor	1,440	
Coordinator	1,200	
Subtotal		4,560
Total		10,000

The screening used a scoring system based on the following criteria:

- presentations made by the district representatives at the workshop
- responses to questionnaires completed by district representatives at the workshop
- geographic characteristics and other factors that indicate high potential of success.

Eleven evaluators were involved in this process, five from Winrock International and six from the National Steering Committee (NSC) / Technical Team (TT). The presentations were scored based on the level of detail provided by district representatives and their answers to questions asked by evaluators.

The questionnaires represented an intensification of the evaluation process used to select the initial 13 candidates. Scoring of these was based on four criteria:

1. socioeconomic condition of the area and presence of conflicts
2. presence of networks
3. experience in undertaking forest-rehabilitation projects
4. readiness and commitment of local government in managing the environment.

Criterion (1) was further disaggregated into the following factors: (i) land-ownership conflicts; (ii) proportion of households under the poverty line; (iii) proportion of households whose main income comes from agriculture; and (iv) number of undeveloped villages within the district. Scoring of this criterion was designed to screen out areas with land-tenure conflicts but also to favour poorer, more agriculturally based districts. Under criterion (2), functional networks were evaluated based on the number of activities conducted by groups of stakeholders. Criterion (3) required the submission of documentation as evidence of successful participation in previous projects. Criterion (4) was scored based on the presence of environmental and forestry forums and the number of stakeholders involved.

Districts with the highest score in each region were recommended for selection to prepare a PDD. In cases where the scores were very close, additional criteria were used to select candidate sites. These included the presence of carbon investors interested in the site and the ability of the district to replicate capacity-building activities to help neighbouring districts.

The selected sites are presented in Table A19 and their locations are shown in Figure A5. Project areas range between 600 and 7,500 ha and the baselines vary, including *Imperata* grasslands and slash-and-burn agriculture. Two areas are classified as protection forest, but they have been deforested, and three sites are degraded state land. CIFOR are now using the CO2Fix model to estimate the carbon-sequestration potential of the areas selected. ICRAF is using the FALLOW model to investigate leakage and additionality associated with the possible land-use systems.

GERHAN

To overcome the problem of forest degradation, the Indonesian Government implemented a national movement of land and forest rehabilitation (*gerakan national rehabilitasi hutan dan lahan* or GERHAN). GERHAN is designed to cover 3 million ha in the period 2003–07. It is a multisectoral project involving central, provincial and district agencies. In 2004, GERHAN was covering 31 provinces, 375 districts and 141 watershed areas.

Data were collected mainly from secondary sources, but some primary data were obtained through interviews of selected respondents and a field visit. The land includes private land and conservation forest. The stakeholders are the Ministry of Forestry, BPDAS, the District Forestry Service, NGOs and communities. Funding is provided by

Table A19. Description of the five sites selected for project design document assistance in Asian Development Bank – Clean Development Mechanism project.

	Location				
	Sindenreng Rappan, South Sulawesi	Bombana, South East Sulawesi	Deli Serdang, Sumatra	West Lampung, Sumatra	Hulu Sungai Selatan, South Kalimantan
Area proposed (ha)	600	700	3,000	7,500	2,500
Original land cover (baseline)	*Imperata* grassland	Grassland	Agriculture (3-year slash-and-burn cycle)	Coffee systems	Grassland
Proposed systems	Mixed fruit and timber	Cashew and teak plantation	Rubber and mixed fruit	Multi-strata coffee with fruit trees	Mixed rubber agroforest
Land status	Degraded state land	Degraded state land	Degraded state land	Protection forest	Protection forest

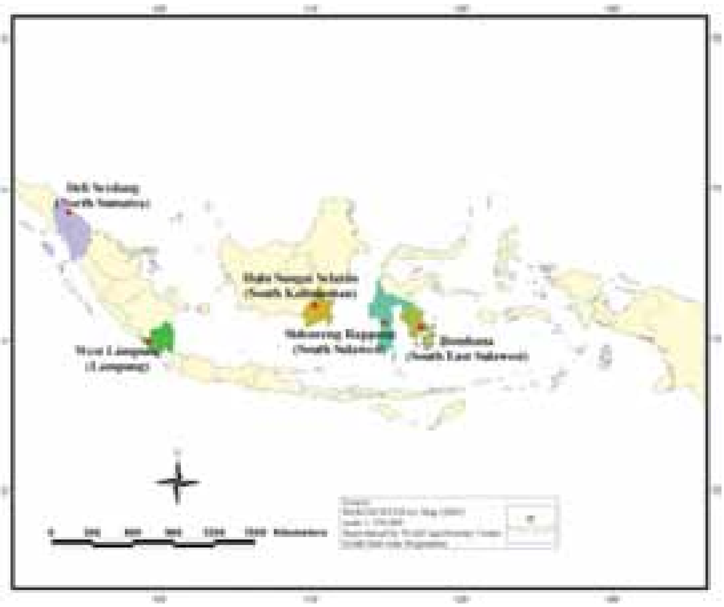


Figure A5. Location of selected sites for development of project design documents for the Asian Development Bank Clean Development Mechanism project interest paid by the reforestation fund deposit. The planting pattern is 30% timber and 70% multipurpose tree species. The costs of the GERHAN project for 2003–04 are presented in Table A20.

The average cost per hectare for 800,000 ha reforested in 2003–2004 was Rp3.13 million/ha. This is equivalent to $360/ha and would appear to compare favourably with other projects evaluated above. The average realisation of targets, accounting for area planted and tree survival, is 73% (Table A20). When the costs per hectare are adjusted by the percentage realised, the resulting cost of $493/ha still compares favourably with other projects. Thus, GERHAN could be categorised as a successful forestry program and may offer a good model for large-scale project design. However, some environmentalists have argued that the realisation data are unreliable due to the non-transparency of data analysis. Furthermore, some researchers argue that the implementation of the program needs to be improved (Gintings 2005). Perceived deficiencies include poor coordination among agencies, especially between seedling providers and plantation teams in the field, poor maintenance of trees and lack of enforcement to prevent plantation failure.

Selected AIJ projects

Activities Implemented Jointly (AIJ) were designed as pilot projects to provide lessons for future carbon projects under the Kyoto Protocol. As a result, they incurred unavoidably high transaction and learning costs for all partners, particularly as the international carbon market was not yet fully operational, and uncertainty regarding the rules of the CDM was high.

To obtain the actual and expected transaction costs of existing forest carbon projects, a written survey was sent to 11 AIJ forest-carbon project teams. Details of the survey are presented in Milne (2002). A number of the selected projects were found to be no

Table A20. Costs and performance of the GERHAN project in 2003 and 2004

	Year		Total
	2003	2004	
Target area (ha)	300,000	500,000	800,000
Costs (Rp million)			
National demonstration plot	4,500	–	4,500
Project administration	4,688	12,996	17,684
Technical planning	14,682	30,349	45,031
Seedling procurement	353,879	609,198	963,078
Tree planting	559,828	552,342	1,112,170
Land conservation buildings	15,853	42,648	58,501
Road construction (250 km)	2,500	91,690	94,190
Institutional buildings	45,271	132,733	178,003
Technical guidance and monitoring	8,128	12,645	20,773
Provincial monitoring and evaluation	19,666	18,539	38,204
Total costs	1,028,994	1,473,139	2,502,133
Cost per target area (Rp million/ha)	3.43	2.95	3.13
($/ha)	394.25	338.65	359.50
Project performance			
Area planted (ha)	295,509	428,419	723,928
(a) percentage of target	98.5	85.7	90.5
(b) survival rate of trees (%)	75.0	84.0	80.6
Percent realisation (a × b)	73.9	72.0	73.0
Soil conservation buildings			
target	1,764	6,257	8,021
realised	1,263	4,753	6,016
percentage realisation	71.6	76.0	75.0
Cost per ha realised (Rp million/ha)	4.64	4.09	4.29
($/ha)	533.66	470.52	492.75

Sources: Dirjen RLPS (2005); Warta Gerhan (2006) longer operational and, for those that were, the concept of transaction costs could not be successfully communicated by way of a written survey. As a result, a number of the project managers were interviewed by telephone and, where possible, quantitative estimates of time expended and financial costs incurred were estimated.

At the time, no small-scale forest-carbon projects had been established in Indonesia. Hence, we spoke to developers of outgrower schemes (partnerships between community and private sector) about the transaction costs in establishing and running small-scale plantation schemes, and the constraints and opportunities of these types of operations in Indonesia. An international plantation company based in Indonesia was also contacted regarding the risks and opportunities facing foreign investors interested in forestry projects in Indonesia.

Table A21. Selected Activities Implemented Jointly afforestation and reforestation projects

	Project name, country				
	Profafor, Ecuador	Scolel Té, Mexico	Klinki, Costa Rica	SIF, Chile	Virilla, Costa Rica
Land type	Andean highlands (>2,800 m)	Highland and lowland tropical communities	Pastures and marginal farmland	Pastures and marginal farmland	Pastures
Duration (year)	25	30	25	51	25
Target area (ha)	75,000	2,000	6,000	7,000	1,000
Area planted	22,500	500	48	na	131
CO_2 sequestered (kt)	35,000	1,210	7,216	1,414	847
Carbon, total (kt)	9,537	330	1,966	385	231
Carbon per year (t/ha/year)	5.09	5.50	7.12	1.08	9.23
Project cost ($1,000)	8,810	3,681	10,703	20,600	3,395
Annual cost ($/ha/year)	4.70	61.35	38.78	57.70	135.81
Carbon cost ($/tC)	0.92	11.16	5.44	53.47	14.71
Sources[a]	a, b, c	d, e	f, g	h	i

[a] Sources: (a) Verweij and Emmer (1998); (b) Milne et al. (2001); (c) FACE (2001); (d) UNFCCC (1997); (e) Hellier, pers. comm. (2002); (f) UNFCCC (1998); (g) Barres, pers. comm. (2002); (h) UNFCCC (2001); (i) UNFCCC (2000)

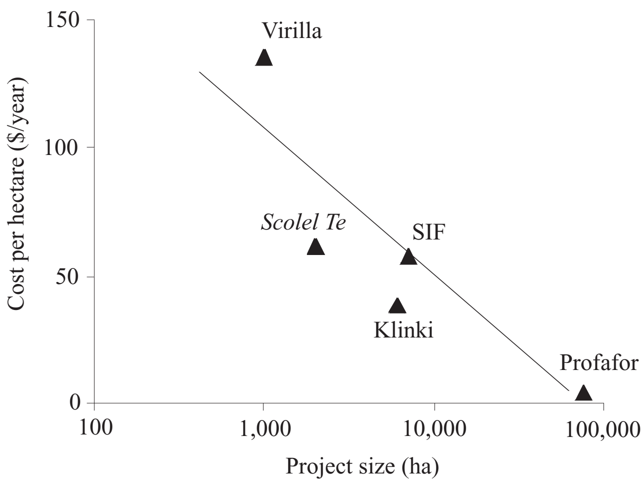


Figure A6. Annual costs per hectare of selected Activities Implemented Jointly afforestation and reforestation projects

All AIJ reforestation and afforestation projects approved by the UNFCCC were initially selected. Of the 11 projects, 8 were located in Latin America, 1 in Asia and 2 in the Russian Federation. The AIJ projects were at varying stages of the project cycle. For the case study analysis, it was decided that projects that were not yet operational would not be included [Milne (2002) presents a detailed description of these projects]. As a consequence, the sample was reduced to six projects. This analysis was later updated by Cacho et al. (2003b) and was reduced to the five projects that involved farmer participation (see Table A21). The sixth project (Rusafor) was a large reforestation project. Milne (2002) noted that, under Rusafor and the other Russian project (Virilla), about the same size area was to be planted. But the Virilla project, which involves payments to private landholders, was projected to cost 30 times more than Rusafor, which involved reforestation of state land.

Although the CDM market was not yet operational, both *Scolel Te* and Profafor were selling carbon offsets. *Scolel Te* was trading Verifiable Emission Reductions (VERs) and Profafor had its carbon offsets certified by a third party for sale to the FACE Foundation in the Netherlands. Projects in this sample (Table A21) covered areas ranging from 1,000 to 75,000 ha, with annual costs ranging between $4.70/ha and $135.81/ha. Costs of carbon sequestration ranged between $0.92/tC and $53.47/tC. Carbon-sequestration costs were estimated by dividing total project costs by projected total carbon sequestration; thus they assume that carbon will be stored in perpetuity and do not account for the timing of sequestration.

Evidence of economies of scale is presented in Figure A6. These data were from reports submitted voluntarily to UNFCCC and the numbers are not independently verified. Also, the sample is too small to draw any definite conclusions. Although the trends are interesting, as indicated by the slope of the line (Figure A6), we could not tell whether the economies of scale were in monitoring or other activities.