## [Charles Palmer](#) and Tilmann Silber

## Trade-offs between carbon sequestration and poverty alleviation: preliminary evidence from the N'Hambita Community Carbon Project in Mozambique

## Discussion paper

# Research Papers in Environmental and Spatial Analysis No. 130

## TRADE-OFFS BETWEEN CARBON SEQUESTRATION AND POVERTY ALLEVIATION: PRELIMINARY EVIDENCE FROM THE N'HAMBITA COMMUNITY CARBON PROJECT IN MOZAMBIQUE

CHARLES PALMER[*] and TILMANN SILBER[#]

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[*]Corresponding author: Department of Geography and Environment, London School of Economics, Houghton Street, London WC2A 2AE, United Kingdom. Tel: 0041 765776974. Email: c.palmer1@lse.ac.uk

[#]Professorship of Environmental Policy and Economics, Institute of Environmental Decisions (IED), Department of Environmental Sciences, ETH Zurich, Switzerland

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# TRADE-OFFS BETWEEN CARBON SEQUESTRATION AND POVERTY ALLEVIATION: PRELIMINARY EVIDENCE FROM THE N'HAMBITA COMMUNITY CARBON PROJECT IN MOZAMBIQUE

## ABSTRACT

This paper assesses trade-offs between carbon sequestration and farmers' incomes from land-use systems implemented in a community-based project, in Mozambique. Systems either focus on carbon sequestration or combine sequestration with cash crop cultivation. The latter provide carbon payments with potential income from cash crop sales. Compared with sequestration-only systems those that combine sequestration and cash crop production have higher net benefits, although they are less cost-effective and have less carbon-sequestration potential. Interplanting with *faidherbia albidia* provides the most attractive balance among competing policy goals. Carbon payments contribute to cash income and may enable smallholders to overcome initial project investment costs.

**KEYWORDS:** Africa, Mozambique, carbon, trade-offs, land-use, cost-benefit

# 1. INTRODUCTION

Anthropogenic global warming due to increasing concentrations of greenhouse gases in the atmosphere is a growing threat to the world's environment, economies and human societies (Stern, 2007). Changes in land use and management of agricultural and forest lands could potentially lead to substantial carbon sequestration benefits (Niles et al., 2002). Under the Kyoto Protocol established in 1997, Annex I countries are allowed to meet emissions reductions targets during the first commitment period (2008-2012) using flexible mechanisms such as the Clean Development Mechanism (CDM). The CDM includes carbon-sequestering afforestation/reforestation (AR) projects that can be implemented by low-income communities in developing countries. To date very few CDM projects are engaged in AR activities. Meanwhile outside the CDM, a parallel market for voluntary $CO_2$ emission reductions has grown rapidly in recent years. The traded volume of so-called Voluntary Emission Reductions (VER) was 23.7 $MtCO_2e$ (million tonnes of carbon dioxide equivalent) in 2006, of which around a third were forestry-related (Hamilton et al., 2007). A number of VER-producing projects have been established in developing countries, sequestering carbon by putting in place incentives for afforestation, reforestation and agroforestry activities in rural communities (e.g., Nelson and de Jong, 2003; Chomitz et al., 1999; Asquith et al., 2002). While VERs are not eligible for the CDM, this is not necessarily a barrier to future inclusion should projects fulfil CDM criteria.

It has been argued that AR projects, whether participating in the CDM or not, can potentially combine cost-effective carbon sequestration with a significant contribution to sustainable development (Pearce, 2000; Landell-Mills and Porras, 2002).[1] Although the potential of such projects to serve as important carbon sinks has been demonstrated (Montagnini and Nair, 2004; De Jong et al., 2005, Olschewski and Benitez, 2005), there remain doubts about their economic viability and potential to deliver sustainable development benefits to local communities

(Minang et al., 2007; Perez et al., 2007; Pfaff et al., 2007). In particular, there are concerns about possible trade-offs between sequestration and developmental objectives.[2]

Smith and Scherr (2003) assessed trade-offs between the social benefits of a project and its attractiveness to potential investors. While large-scale plantations and protected areas are economically the most viable projects, they pose risks for the local population, such as the risk of losing access to land. Community-based projects, on the other hand, provide potentially the highest benefits and the lowest risks to the local population, but have higher transaction costs and are therefore less attractive to investors (see also, Cacho et al., 2005). Yet, as our paper demonstrates, trade-offs also exist among different types of community-based projects. We present preliminary evidence for possible trade-offs between the carbon sequestration potential, cost-effectiveness and income generation for a local community participating in the N'hambita Community Carbon Project located in central Mozambique. Implemented in 2003 by the University of Edinburgh, Envirotrade and the Edinburgh Centre for Carbon Management (ECCM), this pilot project follows Plan Vivo[3] management guidelines for the production of VERs.

To date relatively few studies have attempted to quantify the possible trade-offs in carbon sequestration, specifically AR, projects in low-income communities. De Jong et al. (2000) investigated the potential of an incentive-based programme to stimulate farmers to adopt various carbon sequestration activities with a modelling approach applied to farmers participating in the Scolel Té project in Mexico. Although this study did not focus on trade-offs per se, it was found that the most cost-effective method (using Net Present Value, NPV) for sequestering carbon was improved management of natural forest. In a related study of the same project, discounted benefits for most participants ranged between -US$ 110 to US$ 1,700 per hectare (DTZ Pieda Consulting, 2000). Aune et al. (2005) assessed the carbon sequestration potential of agroforestry and forestry projects in Nepal, Uganda and Tanzania. Also using NPV, these projects were found

to be economically unviable. Coomes et al. (2008) presented the NPV from an AR project implemented in a rural community in eastern Panama. These show that substantial carbon sequestration gains need to set off against the high economic costs and risks from participation, namely those resulting from the need for up-front project financing before carbon benefits are realised. Similar to De Jong et al. (2000), the Panamanian study found natural forest maintenance provided more opportunities for both carbon sequestration and poverty alleviation compared with AR schemes.

In this paper, we focus on trade-offs in AR schemes and the role of carbon payments in encouraging farmers to switch land use. In particular, the NPV of seven different land-use systems are calculated for the N'hambita Community Carbon Project using project data. Some systems focus on carbon sequestration, while others combine sequestration with the cultivation of cash crops. The latter provide carbon payments in the early years of the project with the prospect of income from cash crop sales in later years thus allowing for a differentiation in benefits received by farmers over time. We find that systems combining sequestration and cash crop production have higher NPV, although these not only have slightly less carbon-sequestration potential but also tend to be less cost-effective from the perspective of a carbon investor compared with land-use systems based on carbon sequestration alone. One system, interplanting with *faidherbia albidia*, appears to provide the most attractive balance among competing policy goals. Carbon payments, however, can contribute significantly to cash income and may enable smallholders to overcome initial project investment costs. Moreover, with increasing discount rates, farmers value these short-term benefits over those that might be realised after seven to 10 years.

Our study contributes to the existing literature in two ways. First, this is the first in-depth study of a land-use project located in Africa that incorporates cash crops into the carbon sequestration strategy in addition to the usual forestry options. It also uses data for payments

received by farmers unlike Aune et al. (2005) who used hypothetical price data in their calculations. Given that many African countries are among the poorest in the world, the benefits from such projects could have a relatively greater economic impact than in other developing regions. However, fewer carbon sequestration projects have been located in Africa than in other developing regions of the world (Nanasta, 2007). As the international community moves towards a post-Kyoto agreement on climate change, the UNFCCC has expressed concern at the lack of carbon projects and is keen to explore ways of enhancing the continent's role in climate change mitigation (Jindal et al., 2008). Mozambique, a country with a Human Development Index (HDI) of 0.384, the sixth lowest in the world (UNDP, 2007)[4] is keen to scale-up carbon offset schemes. Hence, our results have direct policy relevance in terms of identifying those land-use activities that not only sequester carbon cost-effectively but also enhance incomes in a particularly poor part of the world. Second, our study is the first to our knowledge that assesses the temporal sequence of benefits received by farmers, i.e. from carbon payments and potential revenues from cash crops. Such a strategy to some extent deals with the issue highlighted by Coomes et al. (2008) for project participants to receive carbon benefits or subsidies from third parties such as NGOs to help offset project establishment costs. In turn, this may help encourage farmer participation through the reduction of risk.[5]

In section 2, we present the background to the project followed by sections 3 and 4, focusing on methods and results, respectively. In section 5, we discuss our results and conclude with some policy implications in section 6.


## 2. BACKGROUND TO THE N'HAMBITA COMMUNITY CARBON PROJECT

N'hambita community is located in the province of Sofala in central Mozambique within miombo woodlands in the buffer zone of the Gorongosa National Park.[6] In 2004, the community consisted of over 1000 people (Hegde and Bull, 2008) with annual cash income of approximately US$ 9

per household (Kooistra and Wolf, 2006). As is common in much of Mozambique, the local economy is dominated by traditional, subsistence agriculture, which includes crop rotation and slash-and-burn. Two different types of agricultural fields dominate, *dimbas* and *machambas*. *Dimbas* are located in flood plains while *machambas* are established around homesteads. Both are typically planted with multiple crop plants including maize, sorghum, pigeon pea and cassava with little or no use of manure or fertilizer.

The N'hambita Community Carbon Project[7] is a pilot project of five years duration organised by Envirotrade, an Edinburgh-based company, which is assisted by the University of Edinburgh and the ECCM. Core funding was partially provided by the European Union and there is a close cooperation with NGOs such as the World Wildlife Fund and the German aid organisation *Gesellschaft für Technische Zusammenarbeit* (GTZ). Project aims include the implementation of sustainable land-use practices to promote sustainable development and diversify farmers' income sources.

Land-use activities were set up in 2001 with an official project launch in 2003. The project includes the production of VERs under Plan Vivo, a management plan originally developed for a similar project in Mexico and also used in Uganda and Mozambique (see Orrego, 2005). VERs are produced via the establishment of seven land-use systems, which were sold, e.g., to the MAN Group and the International Institute for Environment and Development (IIED), between 2005 and 2007. Seedlings were provided by a local, project-built nursery. The expected amount of sequestered carbon is modelled and, on the basis of these results, carbon payments are paid out to the farmers via a carbon trust set up in 2007. These payments are the farmers' only direct cash income source related to the project. Some land use systems also encourage the development of cash crops (see below). Other products from the plots can be consumed by households, such as sustainably-produced timber and fuel wood, fruits and fodder. Additionally, the project attempts to implement new income sources for the community by promoting activities

such as beekeeping and crafting, and other associated enterprises. To improve local education, GTZ has supported the construction of a school in N'hambita. The pilot project is intended to be spread nationally and even globally later on; the project may later be nominated as a CDM measure if the requirements are fulfilled (Sambane, 2005).

Of the seven different land-use systems, six (homestead planting, two types of fruit orchard, woodlot and two types of dispersed interplanting) involve the establishment of new plots on existing land while one, boundary planting involves the planting of trees around the boundaries of existing *machambas*. The latter system provides timber, fruit, shade and nitrogen fixation, and should not affect crop yields significantly. In utilizing the otherwise less productive edge of the *machambas*, this option is ideal if little space is available. In theory, the boundary option can be established around a plot adapted for use under another system altogether.

With the homestead planting option, trees are planted around the house, providing shade, fruits and timber. Major species include mango and cashew, alongside lemon, orange and avocado, ziziphus and tamarind. By including mango and cashew trees, the homestead planting system could potentially provide cash income from the sale of fruits. Under the fruit orchard system, the area under contract is planted with trees of mango or cashew. Trees can be planted on existing *machambas*. Produced fruits are to be sold commercially but can also be consumed directly. After 50 years, the harvest will decline, and the plot is supposed to be re-established sequentially. The two systems are listed as distinct land use options called 'fruit orchard (mango)' and 'fruit orchard (cashew)', respectively.

On old *machambas* which have not been used for several years, miombo woodland is re-established under the woodlot system. In the agroforestry system, dispersed interplanting, nitrogen-fixing trees are planted throughout existing *machambas*. One of two species, *faidherbia albidia* or *gliricidia sepium* can be chosen. Dispersed interplanting removes the need to change the *machamba* via slash-and-burn agriculture and enables farmers to grow on the same plot for a

longer period. G*liricidia sepium* is harvested every 30 years, while *faidherbia albidia* is only thinned once after about 20 years and then grown to full maturity, which can take more than 100 years. The two agroforestry systems are classified as distinct options in the following analysis, 'dispersed interplanting (*gliricidia*)' and 'dispersed interplanting (*faidherbia*)', respectively.

As of 2007, over 70 percent of the community was involved in project activities (University of Edinburgh, 2007a), with 8000 hectares (ha) of land under contract. Households were allowed to enroll for multiple contracts at the same time, with each contract typically covering 0.25-1.50 ha of *machamba* land for duration of 100 years (Jindal, 2008). While data on the amount of land enrolled in each land use system are currently unavailable, 1,073 contracts were negotiated by 852 households as of 2008. The dominant land uses contracted are boundary planting (56.3 percent of all contracts), homestead planting (15.4 percent), and fruit orchards (13.8 percent) (University of Edinburgh, 2008).

## 3. METHODS AND DATA

Data provided by the ECCM, consists of 'technical specifications' of the different land-use systems, which were collected during project implementation. These include technical details (e.g. tree species and number, sequestered carbon, expected harvest etc.) as well as values for the investments required for plot establishment. The analysis only includes financial incentives implemented in the project. Non-financial benefits produced from the plots but consumed domestically such as fuel wood, timber and fruit are excluded from the analysis due to a lack of data. Before describing the data, the cost-benefit framework used in this paper is described.

In order to compare the costs and benefits of the seven land-use systems, we adapt a formula used by De Jong et al. (2000) to estimate the costs of carbon sequestration in another Plan Vivo project established in Chiapas, Mexico. In our formulation these costs are equivalent to the revenues received by farmers in year *t* from the sale of VERs on the world market, and are

denoted $B_C(t)$. Thus, the net benefits from land use for an individual farmer per ha in year $t$ are given as:

$$NB(t) = B_C(t) + B_P(t) - C_E(t) - C_M(t) - C_O(t) \qquad (1)$$

Where: $B_P(t)$ denotes revenues from the sale of agricultural products; $C_E(t)$, costs of establishment of land-use activities; $C_M(t)$, costs of maintenance, i.e. labour and other inputs, of the plot; and, $C_O(t)$, opportunity costs. De Jong et al. (ibid) include project monitoring in the implementation and management costs, which we exclude since these are not considered by farmers. Similarly, other transaction costs such as certifying carbon sequestration rates are also excluded from our analysis, although these will also impact on overall system cost-effectiveness as discussed in section 5 (see also van Kooten et al., 2002; Cacho et al., 2005).

The opportunity cost is the net benefit that is expected from an alternative land use, which in the case of all seven land-use systems in the N'hambita community is assumed to be a *machamba* commonly cultivated with maize intercropped with sorghum (see Jindal, 2004). This can be calculated as the annual revenues from a hectare of crop production net of labour and other input costs (e.g. seeds, tools, etc.). Due to a lack of data for the alternative land-use costs, we assume that labour and other input costs in a given year are equivalent to land-use maintenance costs under the project activity in the same year.[8] As a result, (1) is reduced to:

$$NB(t) = B_C(t) + B_P(t) - C_E(t) - B_O(t) \qquad (2)$$

Where $B_O(t)$ are simply the revenues from the alternative land use. Data for the various components in (2), which are used to estimate the net benefits of adopting each land use system, are described in the following subsections.

In order to estimate the net benefits of each land-use system, we calculate their NPV over a 20 year time period, a time-frame also used, for example, by Aune et al. (2005). Calculation of NPV is a particularly useful tool for comparing activities that include benefits and costs at different points in time (Graves, 2007), which is certainly the case for the N'hambita project as

benefits from the sale of carbon certificates and from cash crop do not occur synchronously. To make them comparable over time, the costs and benefits are discounted into a present value according to the following formula:

$$NPV = \sum \frac{B(t)}{(1+i)^t} - \sum \frac{C(t)}{(1+i)^t} = \sum \frac{NB(t)}{(1+i)^t}$$

where the summations $\sum$ run from $t = 0$ to $t = T$, and $i$ is the discount rate. If the sum of discounted benefits, $\sum B(t)/(1+i)^t$, exceeds the discounted losses, $\sum C(t)/(1+i)^t$ then the system represents an efficient shift in resource allocation (see Hanley et al., 2001).

The discount rate represents the opportunity costs of the investment made (Niles *et al*, 2002), which is closely related to the local rate of interest. Regarding individual decision-making, the discount rate can also be interpreted as the individual's intertemporal preferences. These tend to be lower for Least Developed Countries (LDC) than for industrialised ones (Poulos & Whittington, 1999). In addition, they vary more widely, due to market imperfections. Niles et al. (2002) chose a discount rate of three percent in the context of carbon mitigation through land use change in developing countries. We consider private discount rates since these are used to calculate the incentives for smallholders. In the literature, comparable studies show a wide range of discount rates, ranging from five percent (DTZ Pieda Consulting, 2000), over 10 percent (de Jong et al., 2000), 15 percent (Tomich et al., 2002; Aune at al., 2005) to 20 percent (Cacho et al., 2003). In our analysis, we use a moderate discount rate of 10 percent. We test for the sensitivity of our results using a range of discount rates at the end of the following section.

**Benefits from the sale of carbon certificates ($B_c$)**

The ECCM provided data on carbon storage in biomass and products based on a model called CO2Fix-V3.1. This model was originally developed in the Netherlands by the Modelling Carbon Sequestration in Forested Landscapes (CASFOR) project (see Schelhaas et al., 2004). Important

parameters in the model include wood carbon content, timber production, product allocation for thinnings and expected lifetime of products. The average storage over 100 years serves as the baseline used by the project developers for the calculation of the carbon payments to farmers. This implies in turn, that buyers of VERs pay for carbon sequestration over a period of 100 years, an assumption we return to in section 5.

The baseline of a plot is the amount of carbon stored in biomass at the time the project activity begins, excluding carbon stored in crop plants (ECCM, 2007). The longer a plot has been fallow, the higher the baseline. Data for the accumulation of carbon in fallow plots is provided by Sambane (2005), who measured carbon sequestration on 28 sample plots within the N'hambita community. While measures on agricultural land such as boundary planting and interplanting have a baseline of zero, the ECCM assumes that fruit orchards are established on land that has been fallow for between one and 10 years. For the woodlot system, the land is assumed fallow for 11 to 30 years.

In order to be able to react to unforeseen damages to the plots, which could reduce their ability to store carbon (e.g. fire) a risk buffer of 15 percent is subtracted from the calculated amounts of stored carbon. In case of no damages, this money is to be paid out to the farmers at a later point. Within our framework, potential later payments are excluded for two reasons. Firstly, it is not clear when these additional payments would be made, and secondly, it is not straight-forward to estimate to what extent the risk buffer will be used to compensate any potential damages (e.g. fire-induced ones).

The tradable amount of carbon per ha is calculated as the sequestered amount of carbon due to project activity subtracted by buffer and baseline (see table 1).

**TABLE 1 HERE**

Carbon payments received by individual farmers are dependent on the carbon purchase price paid by carbon buyers along with the transaction costs of scheme management and the monies

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allocated to community funds. Mean carbon payments to farmers from six transactions (carbon sales) that took place from 2005 to 2007 are calculated to be US$ 6.72 per tonne $CO_2$, respectively US$ 24.63 per tonne carbon (or C) (University of Edinburgh, 2008).[9] Total carbon payments to the farmers per ha are shown in table 1. Payments are paid out by the carbon trust in annual instalments over the first seven years of land use implementation, and are supposed to reflect farmers' establishment costs.[10] In the first year, 30 percent of the total payment is made followed by 12 percent in each successive year between years two and six. In the seventh year, the final 10 percent is paid to the farmer.

**Benefits from the sale of cash crops ($B_p$)**

Three out of seven land-use systems include the cultivation of cash crops, namely mango or cashew. For the homestead planting option, the project planners suggest that 40 percent of all planted trees could be mango with another 40 percent allocated to cashew trees. The remaining 20 percent could be a mixture of other species, e.g. guava, orange, tamarind. The two fruit orchard options include either only the cultivation of mango or cashew.

Project data show cashew trees to achieve a mature yield starting from the tenth year. A different source, however, suggests an average mature yield beginning from the seventh year and an average annual yield between seven and 11 kg per tree (Azam-Ali and Judge, 2004). For this analysis, the first harvest is assumed in year seven with a linear increase to the mature yield in year 10. Project data on yield were shown to be incomplete. Instead, based on Azam-Ali and Judge (ibid), a yield of 700 kg per ha was assumed for small-scale production. The market value for cashew nuts, at US$ 0.49 per kg in 2005 is provided by the project developers. The potential income generated by sale cash crops in three of the land-use systems is shown in table 2.

**TABLE 2 HERE**

Mango trees bear fruit for the first time, from four to seven years after planting (Griesbach, 2003). We assume a first harvest in year seven. Dirou (2004) reports a mature yield between eight to 10 years. Thus, similar to the cashew orchard system year 10 is taken as maturity. Further incomplete data meant that we had to use data from other sources in order to calculate yield in the study area. Coughlin (2006) reports an average mango yield of 10,000kg/ha in Mozambique, while an online agroforestry database established by the Traditional Tree Initiative[11] suggests that yield is often as small as 5,000 kg/ha. The lower-yield estimate of 5,000 kg/ha is used for this analysis. The market value of mango assumed by the project organisers is US\$ 0.21 per kg, as recorded in 2005. In the homestead land use system, 80 percent of the area is divided equally between cashew and mango trees.

**Costs of establishment $C_E$**

The costs for establishment of the plots were estimated by the ECCM. These include the time the farmers spend working on the plots[12] and the purchase of seedlings from the nursery, although these are provided for free to the farmers during the pilot phase. In addition, farmers are expected to maintain the plots on their own without the need for additional hired labour. Table 3 gives an overview of the costs for each land use activity.

TABLE 3 HERE

**Benefits from crop production under alternative land uses ($B_O$)**

An alternative land-use option for all project activities, a *machamba*, was assumed based on the description by Jindal (2004). Although maize is reportedly intercropped with sorghum as the most common cultivation, we assume for simplicity that only maize is grown on plots with an average yield of 261 kg per ha. A rotation of 6.7 years crop production followed by 15 years fallow is also assumed.[13] The value of maize was estimated using data provided by the *Sistema*

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*De Informação De Mercados Agrícolas De Moçambique* (SIMA), established by the Mozambican Ministry of Agriculture.[14] The SIMA provides data for different agricultural products at different trade levels and at different locations within Mozambique on a weekly basis. Prices for maize at the producer level in the region of Gorongosa are utilized in our analysis. Jeje et al. (1998) report huge differences in returns from the sale of maize immediately after the harvest in June and after storage from June until December. Thus, an average price of June and December prices in 2007 is calculated, which works out at US$ 0.10 per kg. The expected annual income from the production of maize on a plot (averaged over productive and fallow years) is estimated as US$ 8.05 per ha.

Table 3 shows the annual revenues received from the alternative land use for each system. For the options of homestead planting, both fruit orchard varieties and woodlot, it is assumed that these would be installed on plots that would otherwise be used as *machambas*. In the case of boundary planting, 400m surrounding one hectare are assumed to cover 20 percent of the area, in line with assumptions made by the project developers (University of Edinburgh, 2008). For the two dispersed interplanting variations, no loss in production compared to the alternative land use option is expected by the project planners. Thus, revenues from the alternative land use, $B_O$, are assumed zero.

## 4. RESULTS

**Net Present Values, carbon sequestration potential and cost-effectiveness of land-use activities**

The NPV over a 20 year horizon for the seven land-use systems are summarized along with key parameters in table 4.

**TABLE 4 HERE**

The NPV of the seven land-use systems range from a net loss of about US$ 1,500 to positive returns of about US$ 3,000 per ha, which suggests a greater range of discounted benefits compared with the Scolel Té project in Mexico (see DTZ Pieda Consulting, 2000). Those options including cash crop cultivation show the highest NPV, while only one of the other systems has a positive NPV, namely dispersed interplanting with *faidherbia albidia*. Due to high costs for establishment and no additional income from the production of cash crops, the reforestation option (woodlot) has the lowest NPV despite comprising the largest carbon payment of all systems.

Figure 1 compares the mean carbon sequestration per ha for each land-use system under the assumption that they remain undisturbed for 100 years, and NPV per ha. From the perspective of carbon sequestration efficiency, i.e. the quantities of carbon sequestered in a single ha, the most favourable option appears to be dispersed interplanting with *faidherbia albidia* and reforestation on old *machambas* (woodlot). But the most attractive options from the farmers' perspective are the systems including the production of tradable fruit, namely fruit orchards and homestead planting. These options provide the highest NPV to the farmers and hence, may contribute most effectively to improving farmers' incomes. Homestead planting appears to provide both relatively high levels of carbon sequestration per ha and high net benefits to farmers, followed by the fruit orchard and interplanting options. Nevertheless these options all seem to show varying trade-offs between carbon sequestration and incomes, similar to the systems studied by Aune et al. (2005) in Uganda and Tanzania.

**FIGURE 1 HERE**

The cost-effectiveness of each land-use system in US$ per tonne C, from the perspective of the carbon buyer, is shown in figure 2. Note this only includes costs incurred by the farmer: opportunity costs and costs for establishment and maintenance. It does not include transaction costs. While relatively high in this project (over 50 percent; see footnote 8), these are not

differentiated according to land-use system implemented. Dispersed interplanting with *faidherbia albidia* is the most cost-effective option at less than US\$ 10 per tonne C. Options producing higher direct benefits to farmers are much less cost-effective such as homestead planting and fruit orchard (mango), with carbon prices of around US\$ 30 and 50 per tonne C, respectively.

**FIGURE 2 HERE**


**Temporal distribution of costs and benefits**

Figure 3 shows the annual net benefits of the seven land-use systems over a period of 20 years. Until year five, only dispersed interplanting with *faidherbia albidia* provides an annual positive net benefit to the farmer. By years six and seven all options show positive net benefits. After year seven the three options including cash crop production show net benefits that rise until year 10, while the other four options show low net benefits of around zero.

**FIGURE 3 HERE**

Regarding the temporal distribution of costs and benefits for each land-use activity, two groups can be identified: with and without cash crop production. In order to demonstrate the main differences in the temporal distribution of costs and benefits between these groups, we first consider activities with no production of cash crops. The temporal distribution of costs and benefits for the woodlot option, for example, shows that the annual net benefit in the first five years is dominated by establishment costs as the carbon payments are not high enough to offset these. By years six and seven, there are no more establishment investments that need to be made, and the carbon payments dominate. As of year eight onwards, no more carbon payments are paid out and annual net benefits are close to zero.

The second group consists of the systems that include the production of cash crops (denoted by the dotted lines in figure 3). The temporal distribution of the costs and benefits for the homestead planting system, for instance, shows that the costs for establishment again

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dominate annual net benefits in the first five years. By year six the investments are complete and in year seven, the first cash crops can be harvested. The mature yield is reached in year 10. From year seven on, annual net benefits are dominated by the income that is generated from the sale of fruits.

**Sensitivity analysis: discount rates and carbon prices**

In this subsection, we test for the sensitivity of our NPV results by first, varying the discount rates (between three and 35 percent) while keeping the carbon price constant, and second, by eliciting the break-even carbon price in order to obtain a non-negative NPV. The latter is also undertaken at varying discount rates of between three and 35 percent. Keeping the carbon price constant at US$ 24.63 per tonne C while increasing discount rates shows NPV to be increasing for both the woodlot and dispersed interplanting (*gliricidia*) options (see table 5). NPV, however, remains negative at all rates used. As rates increase, i.e. with poorer farmers who prefer present over future consumption, NPV declines for all the other options. Fruit orchard (mango) NPV remains positive until discount rates hit around 30 percent. Dispersed interplanting (*faidherbia*) is the only option showing a positive NPV over the whole range of discount rates. The NPV for boundary planting while relatively constant remains negative at all discount rates. With increasing discount rates, farmers value short-term benefits such as the carbon payments over those that might be realised after seven to 10 years. At the same time, costs borne by farmers in the first few years are also magnified at higher discount rates. Our results show, however, that potential long-term benefits from the sale of cash crops at the prices provided by the project developers are still attractive even for quite poor farmers. The only option that would be attractive for very poor farmers, i.e. those with discount rates of 30 percent or higher, is that of dispersed interplanting (*faidherbia*), which we infer is due to the carbon payments received in the first seven years of the project.

**TABLE 5**

Further policy implications can be seen with the estimation of the lowest break-even carbon prices in order for NPV to remain non-negative, in table 6. At relatively low discount rates, homestead planting, and both fruit orchard systems are all profitable even if carbon prices are zero. In other words with low levels of poverty, farmers could still opt to take up these land-use systems even if they receive no carbon payments. This implies that we might expect to observe such land-use systems to be adopted without project intervention. Hence, there are implications in terms of whether the carbon sequestered can be considered additional or not, an observation also made by Aune et al. (2005) for the agroforestry option in Uganda. However, in reality, we do not observe the spontaneous adoption of these land-use systems. One obvious reason might be that there are particularly poor farmers in the study area who strongly prefer present to future consumption. If this were the case, i.e. where discount rates might be around 20-25 percent or higher, then additionality of carbon sequestered would be less of a problem according to our results. The most expensive carbon sequestration system is the woodlot option (US$ 70-80 per tonne C) followed by the dispersed interplanting (*gliricidia*) (US$ 45-55 per tonne C), while the cheapest appears to be dispersed interplanting (*faidherbia*) (US$ 8-10 per tonne C). At higher discount rates of around 25 percent, fruit orchard (mango) is competitive with dispersed interplanting (*faidherbia*) due to the high value of mango revenues in later years, although the latter remains by far the cheapest option when rates reach 30 percent.

**TABLE 6**

## 5. DISCUSSION

Following Smith and Scherr's (2003) work on comparing the social benefits of a range of carbon sequestration projects with their attractiveness to investors, we identify and assess trade-offs in seven land-use systems that can all be described as 'community-based'. In this paper, we assess

the carbon sequestration potential, cost-effectiveness and income generation for each system along with the role of carbon payments in encouraging farmers to switch to one of the systems in the N'hambita Community Carbon Project, in central Mozambique. First, the NPV of each system is compared with its potential to sequester carbon. For the cash crop producing options, the ranking of NPV correlates with the magnitude of income generated by the sale of fruit. These systems generally have higher NPV compared with the four other options. Regarding the latter systems, the carbon payments and the costs for establishment both determine their relative attractiveness for farmers. We found that carbon payments only offset the costs in one option, namely dispersed interplanting system with *faidherbia albidia*. Our results build on earlier work undertaken by Jindal (2008) who, in a livelihood analysis of the same project, found that it was too early to judge whether or not these payments have the potential to help move households out of poverty.

In terms of the efficiency of the land-use systems to sequester carbon on a per ha basis, dispersed interplanting system with *faidherbia* is the most favourable option followed by woodlot and homestead planting. Furthermore, from the perspective of the buyer, dispersed interplanting (*faidherbia*) is the most cost-effective land use option regardless of farmers' time preferences. However, given high transaction costs of around 50 percent of revenues from the sale of VER certificates, these land-use systems will certainly be more expensive than documented in our analysis. Thus, the overall cost-effectiveness of and hence, the potential for scaling up this kind of project as a climate change mitigation tool should be considered in light of these costs.

In summary, our results show mild trade-offs between farmers' incomes, carbon sequestration potential and cost-effectiveness. Our analysis also revealed that those land-use systems that provide higher net benefits to farmers may not provide additional carbon benefits at lower discount rates. This implies that we might expect the same land uses to be adopted in the absence of the project intervention. Given we do not observe this on the ground probably reflects

the relative poverty of most of the farmers participating in the project. Those with higher discount rates of 30 percent or more may only benefit if participating in the dispersed interplanting system with *faidherbia albidia*. From year to year, interplanting with *faidherbia albidia* is the only land-use system that provides non-negative benefits to farmers. Overall, interplanting with *faidherbia albidia* provides the most attractive balance between the provision of benefits to farmers, cost-effectiveness to buyers and carbon sequestration potential. Moreover, it should be noted that *faidherbia albidia* is particularly useful in agroforestry because it is leafless during the raining season in summer and as a result, does not shade field crops (Roupsard et al., 1999).

Similar to Aune et al. (2005), one of few previous cost-benefit studies undertaken on carbon sequestration land use schemes in Africa, we found that the proportion of income due to the carbon payments is relatively small when compared with non-carbon income such as from the sale of fruit. However unlike Aune et al. who dismiss the potential of carbon payments to contribute to farmers' incomes due to their small size and high transaction costs of scheme implementation, we caution that there may be additional benefits in helping farmers overcome investment risks during the early years of scheme implementation. In N'hambita, the carbon payments are paid out over the first seven years, whereas fruit sales do not begin before year seven. The former occur within a critical phase of the land-use systems when the plots are initially established. Moreover, the size of carbon payments along with the schedule of payment is known with certainty by farmers. As there is very little cash in the community and the land is mostly used for subsistence, carbon payments might well play a key role in enabling farmers to invest in plots that could potentially generate more income later on. This supports the conclusions of Coomes et al. (2008) in their study of a rural community participating in an AR scheme in Panama.

The data used to estimate the carbon sequestration potential of each system assume a 100 year time horizon. These are the amounts of carbon that were purchased by carbon buyers whose

payments are distributed to farmers in the first seven years of the project. Given that the project is a pilot that officially finished in 2008, there are concerns about the long-run sustainability of such projects in Africa, particularly regarding the ability of communities to maintain carbon stocks over time (see Minang et al., 2007; Perez et al., 2007).

Project planners assume that the land-use systems will continue well into the future with livelihoods and incomes dependent on continued production of cash crops and the production of other commodities, both for domestic use and commercial sale (see below). However, there is of course no guarantee that farmers will continue the land-use options in a sustainable manner, with repercussions for carbon sequestration. For the calculation of carbon quantities sequestered, long-term time horizons are only credible if appropriate protocols, including monitoring and enforcement of farmers' contracts, are established to ensure that farmers do not switch land use leading to carbon reversals after the project has officially expired. We note that the 15 percent risk buffer described in section 3 may not be adequate to cover all potential risks to the carbon sequestered over such a long time period. Hence, we share the concerns of Jindal (2008) that there remain considerable risks in providing, in the first seven years of the project, the entire value of payments for carbon expected to be sequestered over a 100 year period.

There are a number of limitations in the methods used to arrive at the results in this paper. First, the database for the analysis is relatively limited and a number of assumptions have had to be made. Additionally, the value of the NPV is most likely underestimated, because some benefits from the plots were excluded. In particular, the income from other products beside mango and cashew, namely timber and non-timber-forest-products (NTFPs) has been excluded from the analysis due to missing data. Moreover, the project developers undertook efforts to foster activities such as bee-keeping and carving, and new, off-farm employment opportunities in other enterprises associated to the project. Also excluded were non-financial benefits from the participation in the carbon trading schemes. These include business training and investments such

as the newly-built school. A careful investigation of the value of non-financial benefits would allow for a more complete social cost-benefit analysis of the project.

Project activities are expected to have further impacts with respect to the provision of environmental services other than carbon, including biodiversity (University of Edinburgh, 2008). Wider biodiversity benefits may, however, largely depend on the mix of species used. Given the focus on monocultures in the fruit orchard and dispersed interplanting systems, biodiversity benefits are likely to be very limited. In seeking to re-establish the natural vegetation of miombo woodland the woodlot system, on the other hand, might provide the highest levels of biodiversity due to the planting of the highest number of tree species of all the options (University of Edinburgh, 2007b). If this is the case then a further trade-off becomes clear: the most attractive land-use system from the perspective of farmers, i.e. the fruit orchard and dispersed interplanting options, not only sequester less carbon per ha than the woodlot option but are also less likely to provide wider biodiversity benefits compared to the woodlot option.

Finally, the use of NPV assumes that farmers will respond rationally to price signals. Unlike, for example, the study of Mexican farmers by De Jong et al. (2000), it is not clear that this is the case for farmers in Mozambique. One way to investigate this is to assess participation rates of farmers in each land use activity after implementation. Such an analysis was undertaken by Jindal (2008). While still early days for the project, this study found that larger households and those with more farmland had a higher probability of participating. For a better understanding of what drives land-use behaviour, a follow-up study should be undertaken in the coming years. In addition, an econometric analysis using panel data might enable the project developers to gauge the relative environmental effectiveness of each land-use system with respect to carbon sequestration.

## 6. CONCLUSION

In this paper, we present a preliminary assessment of the N'hambita Community Carbon Project in Mozambique, which was officially launched in 2003. Since project launch, there has been high interest among farmers in participating in the project. For seven land-use systems, we have shown that trade-offs exist between raising farmers' incomes to alleviate poverty, carbon sequestration potential and cost-effectiveness. Interplanting with *faidherbia* appears to provide the most attractive balance among competing policy goals. We have also shown that carbon payments have some potential to alleviate poverty and encourage rural development. Specifically, carbon payments provide much-needed cash for investments in generating income in the long-run, e.g. from cash crops.

The danger, of course, then resides in creating a dependency on incomes derived from volatile cash crop markets. Mozambique was once a global leader in cashew production, for example, a situation that changed from the 1970s onwards due to a combination of civil war and increased global competition (for example, see Horn-Welch et al., 2003). In order to minimise the risk of exposure to these markets, the project developers have implemented a range of other income-generating opportunities, including beekeeping, carving, and limited timber production alongside investments in local infrastructure. It is still to be shown, however, whether or not these are sufficient for long-run project sustainability and permanence of the carbon sinks grown on the plots. As noted, further research on farmer participation and actual rather than potential benefits received by farmers alongside the environmental effectiveness of the project is needed in the future.

The project is being used as a template for similar projects in Mozambique and possibly other countries. Including N'hambita, Envirotrade currently has three carbon projects in Mozambique. Given that the long-term impacts of the project will not be known for some time, this paper provides only limited guidance on how other projects might be implemented. Two issues, in particular, should be considered for N'hambita and similar projects. First, given that

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carbon buyers have paid for the potential carbon sequestered over a period of 100 years, robust systems need to be in place to ensure the long-term viability of carbon sinks. New investors participating in a potential expansion of AR projects in a post-2012 climate framework may need more assurances that their investment will endure beyond a time-frame of a few years. Second, the project suffers from relatively high transaction costs, which would need to be reduced if future projects are to attract new investors and perhaps allow more carbon benefits to flow to farmers. It should also be noted that N'hambita has benefited from intense support from outside organizations such as the EU. Scaling-up thus raises the question of who should bear the cost, e.g. of 'core funding', of projects. Furthermore, the necessary institutions such as reasonably clear and enforceable property rights need be in place to support such an intense intervention on a much larger scale.

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[1] Note that the official objective of the CDM is to achieve cost-effective reductions of GHG emissions while enabling sustainable economic development in host countries. See text of the Kyoto Protocol, particularly Article 12.2 under http://unfccc.int/essential_background/kyoto_protocol/items/1678.php, retrieved on 2008-06-26.

[2] More broadly, possible trade-offs between poverty alleviation and the provision of environmental services by the poor in developing countries have been examined in numerous studies, e.g. Grieg-Gran et al., 2005; Pagiola et al., 2005; Bulte et al., 2008.

[3] See: www.planvivo.org

[4] The Human Development Index (HDI) gives a relatively complete picture of the level of development of a country. It includes live expectancy, illiteracy and Gross Domestic Income (GDI) per capita. At 0.384, Mozambique's HDI is well below the mean of Least Developed Countries (LDC), at 0.488 (UNDP, 2007).

[5] Nevertheless, it was also noted that such strategies may also lead to new problems and risks for project investors (see Coomes et al., 2008).

[6] Named after the Swahili word for the dominating genus of *Brachystegia* and spread over large parts of Southern Africa, miombo woodland consists of seasonally dry deciduous woodland (Williams et al, 2008). The canopy in the

dry Eastern Miombo woodlands in Mozambique is smaller than 15m and can be described as 'a kind of closed-canopy savanna' (Sambane, 2005).

[7] See: http://www.envirotrade.co.uk/Pages/mozambique_sustdevel.htm and www.miombo.org.uk

[8] We observe that the inputs and practices used in the land-use systems adopted in the project are designed to closely resemble those used in *machamba* cultivation. For example, fertilizers are used neither in *machamba* cultivation nor in project land-use systems.

[9] Between 2005 and 2007, 79,658 tonnes of $CO_2$ were sold in the form of VER certificates for a total of US$ 639,374 of which US$ 339,059 were recovered as costs by Envirotrade including certification costs (University of Edinburgh, 2008). Thus, transaction costs accounted for over 50 percent of carbon sale revenues.

[10] While a seven year period seems to be relatively short for carbon that is to be stored over 100 years, it is comparable to other PES schemes, such as the PSA (*pagos por servicios ambientales*) scheme in Costa Rica, where the payments are paid out over five years (Chomitz et al., 1999).

[11] See: www.agroforestry.net/tti, retrieved on 2008-05-01.

[12] Labour costs are estimated using standard day rates for 2006 (W. Garrett, personal communication, 2008-05-06).

[13] The average age of *machambas* reported by Jindal (2004) is 6.7 years, followed by a fallow time of 10–20 years.

[14] Available online at: http://www.sima.minag.org.mz/, retrieved on 2008-05-13.

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**FIGURES AND TABLES**

**Table 1: Average carbon storage, baseline, buffer, tradable carbon and total carbon payments of the seven land-use systems.**

| Land use system | Average carbon storage over 100 years [tC/ha] | Baseline [tC/ha] | Buffer [tC/ha] | Tradable carbon credits [tC/ha] | Total carbon payments [US $/ha] |
|---|---|---|---|---|---|
| Boundary planting | 12.92 | 0.00 | 1.94 | 10.98 | 270.53 |
| Homestead planting | 42.05 | 0.00 | 6.31 | 35.74 | 880.49 |
| Fruit orchard (cashew) | 40.14 | 2.80 | 5.60 | 31.74 | 781.87 |
| Fruit orchard (mango) | 34.00 | 2.80 | 4.68 | 26.52 | 653.30 |
| Woodlot | 61.30 | 11.30 | 7.50 | 42.50 | 1,046.95 |
| Dispersed interplanting (*gliricidia*) | 10.00 | 0.00 | 1.50 | 8.50 | 209.39 |
| Dispersed interplanting (*faidherbia*) | 58.20 | 0.00 | 8.73 | 49.47 | 1,218.65 |

Source: Authors' calculations based on information provided by the Edinburgh Centre for Carbon

Management (ECCM)

**Table 2: Potential annual yields and generated income in the three land-use systems with commercial fruit production.**

| | Year after planting | 1 to 6 | 7 | 8 | 9 | ≥ 10 |
|---|---|---|---|---|---|---|
| Fruit orchard (cashew) | Yield relative to mature yield | 0% | 25% | 50% | 75% | 100% |
| | Absolute yield [kg/ha] | 0 | 175 | 350 | 525 | 700 |
| | Income [US$/ha] | 0 | 85.75 | 171.5 | 257.25 | 343 |
| Fruit orchard (mango) | Yield relative to mature yield | 0% | 25% | 50% | 75% | 100% |
| | Absolute yield [kg/ha] | 0 | 1,250 | 2,500 | 3,750 | 5,000 |
| | Income [US$/ha] | 0 | 262.5 | 525 | 787.5 | 1,050 |
| Homestead planting | Income [US$/ha] | 0 | 139.30 | 278.60 | 417.90 | 557.20 |

Source: Azam-Ali and Judge (2004); Traditional Tree Initiative (2008); University of Edinburgh (2008); authors' calculations

**Table 3: Costs for establishment and maintenance ('Costs') and annual benefits from crop production under the alternative land use $B_O$ for the different land-use systems.**

| Land use system | Costs in year 1 [US \$/ha*yr] | Costs in years 2 to 5 [US \$/ha*yr] | $B_O$ [US\$/ha] |
|---|---|---|---|
| Boundary planting | 100 | 40 | 1.61 |
| Homestead planting | 480 | 200 | 8.05 |
| Fruit orchard (cashew) | 480 | 200 | 8.05 |
| Fruit orchard (mango) | 520 | 200 | 8.05 |
| Woodlot | 1,100 | 430 | 8.05 |
| Dispersed interplanting (*gliricidia*) | 145 | 62.5 | 0 |
| Dispersed interplanting (*faidherbia*) | 145 | 62.5 | 0 |

Source: Edinburgh Centre for Carbon Management (ECCM) and authors' calculations.

**Table 4: Key parameters of the seven land-use options: costs for establishment, total carbon payments, total revenues from the sale of cash crops and NPV over 20 years.**

| Land use system | Total costs for establishment [US$/ha] | Total carbon payments [US$/ha] | Total revenues from sale of cash crops over 20 years [US$/ha] | NPV over 20 years [US$/ha] |
|---|---|---|---|---|
| Boundary planting | 260 | 270 | 0 | -20 |
| Homestead planting | 1,280 | 880 | 6,965 | 1,482 |
| Fruit orchard (cashew) | 1,280 | 782 | 4,288 | 673 |
| Fruit orchard (mango) | 1,320 | 653 | 13,125 | 2,970 |
| Woodlot | 2,820 | 1,047 | 0 | -1,536 |
| Dispersed interplanting (*gliricidia*) | 395 | 209 | 0 | -158 |
| Dispersed interplanting (*faidherbia*) | 395 | 1,218 | 0 | 587 |

Source: Edinburgh Centre for Carbon Management (ECCM) and authors' calculations.

**Table 5: NPV at carbon price of US$ 24.63/tC at different discount rates (dr)**

| NPV over 20 years [US$/ ha] | dr: 3% | dr: 5% | dr: 10% | dr: 15 % | dr: 20% | dr: 25% | dr: 30% | dr: 35% |
|---|---|---|---|---|---|---|---|---|
| Boundary planting | -20 | -20 | -20 | -21 | -21 | -22 | -21 | -21 |
| Homestead planting | 4,095 | 3,057 | 1,482 | 698 | 289 | 69 | -53 | -121 |
| Fruit orchard (cashew) | 2,235 | 1,612 | 673 | 214 | -18 | -138 | -200 | -230 |
| Fruit orchard (mango) | 7,923 | 5,957 | 2,970 | 1481 | 701 | 278 | 40 | -95 |
| Woodlot | -1,791 | -1,709 | -1,536 | -1,396 | -1,280 | -1,181 | -1,096 | -1,022 |
| Dispersed interplanting (*gliricidia*) | -177 | -171 | -158 | -146 | -135 | -125 | -117 | -110 |
| Dispersed interplanting (*faidherbia*) | 738 | 688 | 587 | 509 | 447 | 399 | 359 | 327 |

Source: Authors

**Table 6: Break-even prices (US$) at different discount rates (dr)**

| Break-even carbon price for $NPV_{20}= 0$ [US$/tC] | dr: 3% | dr: 5% | dr: 10% | dr: 15 % | dr: 20% | dr: 25% | dr: 30% | dr: 35% |
|---|---|---|---|---|---|---|---|---|
| Boundary planting | 27 | 27 | 27 | 28 | 28 | 28 | 29 | 29 |
| Homestead planting | 0 | 0 | 0 | 0 | 11 | 21 | 28 | 32 |
| Fruit orchard (cashew) | 0 | 0 | 0 | 14 | 26 | 33 | 38 | 41 |
| Fruit orchard (mango) | 0 | 0 | 0 | 0 | 0 | 4 | 21 | 33 |
| Woodlot | 71 | 72 | 74 | 75 | 77 | 78 | 79 | 80 |
| Dispersed interplanting (*gliricidia*) | 48 | 48 | 50 | 51 | 52 | 53 | 54 | 54 |
| Dispersed interplanting (*faidherbia*) | 8 | 8 | 8 | 9 | 9 | 9 | 9 | 9 |

Source: Authors

**Figure 1: Comparison of mean carbon sequestration potential (tC/ha) vs. NPV over 20 years after the establishment of the land-use systems (US$/ha).**
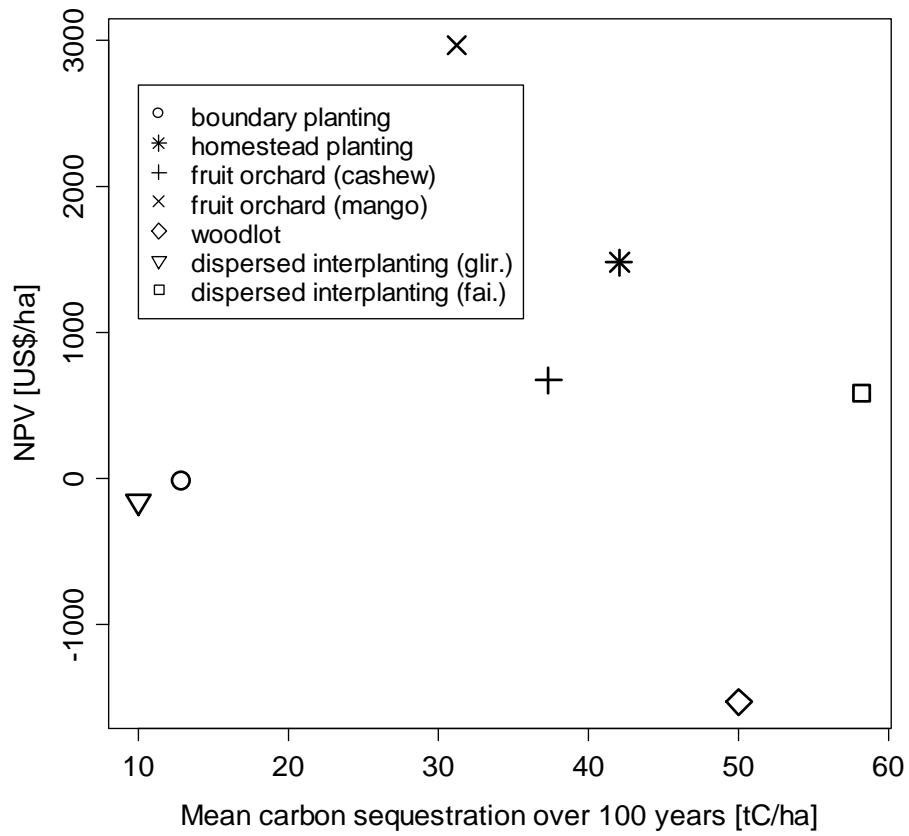
**Figure 2: Comparison of carbon cost-effectiveness (US$/tC) vs. NPV over 20 years after the establishment of land use-systems (US$/ha).**
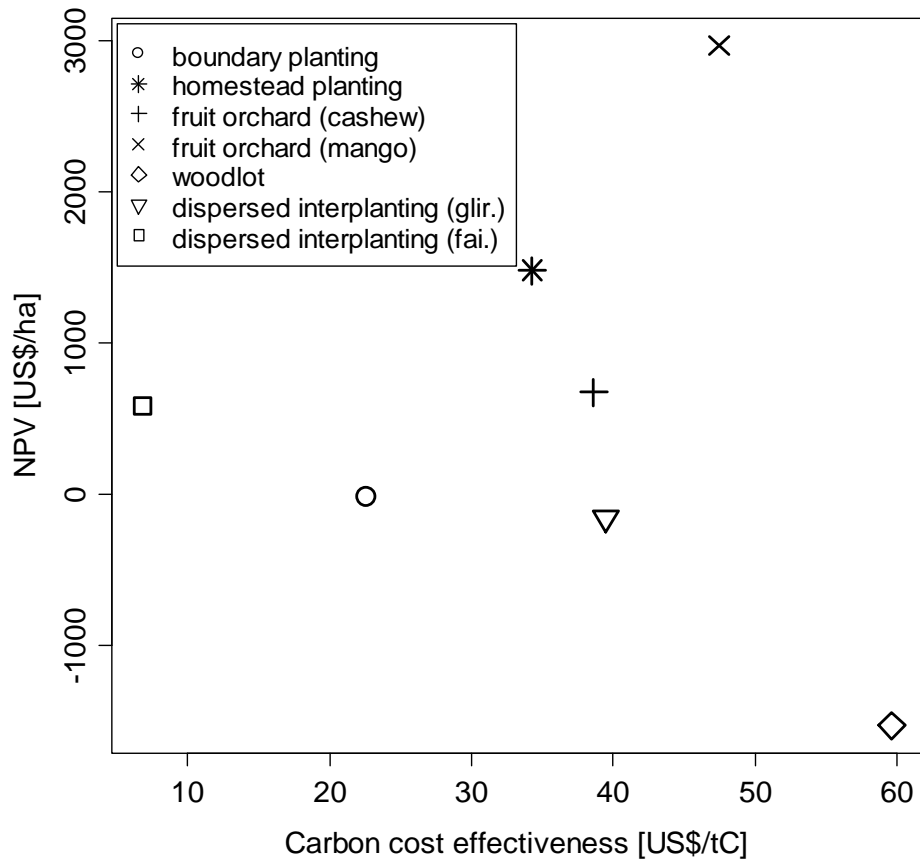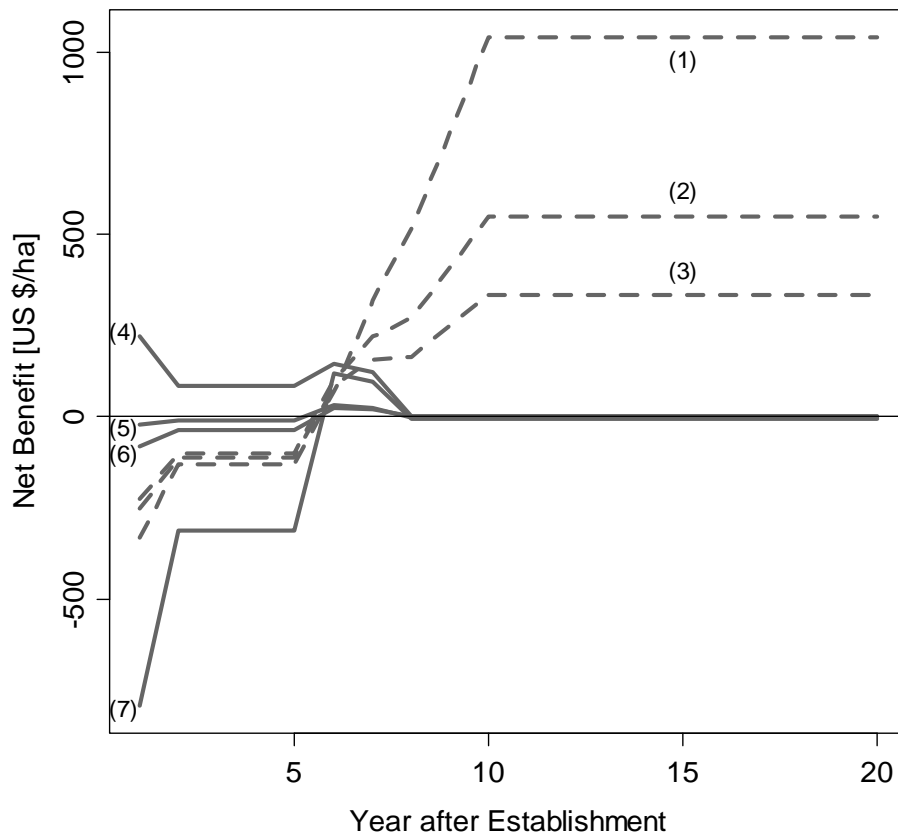
**Figure 3: Annual net benefit for farmers of the seven land-use systems in US$ per ha over the first 20 years. Legend: (1) fruit orchard (mango); (2) homestead planting; (3) fruit orchard (cashew); (4) dispersed interplanting (*faidherbia*); (5) boundary planting, (6) dispersed interplanting (*gliricidia*); (7) woodlot.**



**Note: Dotted lines represent systems including the cultivation of cash crops.**