Past and present profitability of deforestation of miombo woodlands considering CO2 emissions in Maseyu village Tanzania

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Abstract

The miombo woodlands of Tanzania have been subjected to continuous deforestation due to mainly agricultural expansion. Understanding the linkage between deforestation and economic efficiency of the subsequent land use is important for better land use planning and management. *Ex-post* cost-benefit analysis (CBA) was used to examine the profitability of conversion of unmanaged miombo woodlands into cropland considering the environmental cost of the activity in terms of emissions of CO_2. *Ex-ante* CBA was also used to compare profitability of keeping currently managed miombo woodland for the purpose of carbon sequestration with profitability of converting it into crop land. Net benefit (NB) of deforestation was calculated as the sum of agricultural rent and forest revenue during land conversion, minus cost of deforestation in terms of CO_2 emissions. NB of maintaining the managed woodland was based on returns from carbon sequestration. The NBs were discounted to provide an estimate of the net present value (NPV) of clearing and cropping, and maintaining the managed woodland. The value of CO_2 emissions and carbon sequestration was estimated by assuming different prices of CO_2 (USD ton^{-1}). Data collected from 54 randomly selected households were used for estimation of current maize and charcoal production in the area. Data required for the estimation of profitability of historic deforestation and carbon densities of the current land uses in the area were gathered from various secondary sources. Deforestation history was obtained from land use and cover change since 1964 reported from the area. A simple growth model was also developed to describe the biomass development of the woodlands and thus to estimate the carbon sequestration rate. We found that deforestation of miombo woodlands in Maseyu village has been, and still is, profitable if environmental costs of deforestation are not accounted for. However, fairly low prices of CO_2 emissions would make deforestation unprofitable in the social analysis. At 10 % discount rate, the break-even price was USD 11 tCO_2e^{-1} for the historic deforestation that took place since 1964 in the common land. At the same discount rate, CO_2 prices higher than USD 6 tCO_2e^{-1}would turn future deforestation of the managed woodland in Kitulangalo Forest reserve (KFR) unprofitable. Incorporating other environmental costs of deforestation such as loss of biodiversity and emissions of other GHGs could potentially reduce the profitability of deforestation further, particularly deforestation of the woodlands in the forest reserve.

Keywords: Deforestation; Maize production; Charcoal production; CO_2 emissions; Carbon sequestration; CBA; Profitability

Introduction

Small holder farmers in Sub-Saharan Africa clear woodland and forest for agriculture because it is profitable to them (Namaalwa et al. 2001). In spite of low crop prices, such deforestation is profitable because better paid employment opportunities are scarce. The opportunity cost of labor in the African countryside is very low. Deforestation has a number of environmental consequences that affect the welfare of many people negatively, most prominently loss of biodiversity and emissions of greenhouse gases (GHG), particularly CO_2. The effects are of marginal interest to the farmers, however. Thus, deforestation that is profitable to individual agents has negative externalities that should be counted in the social analysis. GHG emission has a homogenous effect on climate (Vatn 2005), and has been traded (Linacre et al. 2011). Therefore, valuing the externality is possible.

Valuing loss of biodiversity is more difficult since it depends on the specific biological loss and the effects it may have on various groups of people. Biodiversity protection has also been traded to a lesser extent (Walker et al. 2009). We analyzed social profitability of deforestation of miombo woodlands in Tanzania considering CO_2 emissions but not biodiversity loss. Understanding the linkage between deforestation and economic efficiency of the subsequent land use is important for better land use planning and management.

Miombo woodland, a collective name for woodlands dominated by species of the genera *Brachystegia*, *Julbernardia*, and *Isoberlinia*, is a common vegetation type in large parts of sub-Saharan Africa (Campbell 1996). The miombo region covers an estimated 2.4 million km^2 and supports the livelihoods of about 100 million rural and urban dwellers (Dewees et al. 2010). These woodlands cover about 36% of the total land area and about 90% of the forest and woodland ecosystems of Tanzania (Malimbwi et al. 2005). They have been declining at an average rate of about 1.06 % per year since the 1990s (FAO 2010), mainly due to agricultural expansion.

As an example of deforestation and agricultural expansion, we studied land-use of unmanaged woodland in the public land and managed woodland in Kitulangalo Forest Reserve (KFR) in Maseyu village in Morogoro region, eastern Tanzania. We undertook two investigations of social profitability of deforestation in this area – one *ex-post* cost-benefit analysis (CBA) of the deforestation that has actually taken place in the common land outside the forest reserve since 1964, and one *ex-ante* CBA of possible future deforestation within the reserve. The latter is motivated by the idea that some forest reserves might be degazetted in case crop production is highly profitable even when environmental costs of deforestation, in our case CO_2 emissions, are included in the analysis.

Materials and Methods

Study site

The study site, Maseyu village is located about 50 km east of Morogoro town along the Dar es Salaam-Morogoro highway (Figure 1). The village covers approximately 36,000 ha with about 2000 inhabitants. It comprises settlements (170 ha), crop lands (215 ha), open miombo woodlands (woodland with scattered cultivation) (7000 ha), village reserve (150 ha), a part of (about 70%) the KFR (1700 ha) and a part of the Wami-Mbiki wild animals management area (WMA) (27000 ha). The woodlands on public land are openly accessible to the surrounding community. WMA is a community-based conservation area that was established in 1999. The WMA covers an area of approximately 4,200 km^2 and is surrounded by 24 villages including Maseyu (Madulu 2005). The woodlands inside the WMA have been subjected to extensive tree cutting for charcoal production and agricultural expansion. The KFR was gazetted in 1955 (GN198 of 3/6/1955) (Malimbwi and Mugasha 2001) and covers an area of about 2,452 ha, including the semi-evergreen forests in the Kitulangalo hills (Luoga et al. 2004). The part of the reserve located in Maseyu is managed jointly by the central government and the village. The current management system has been practiced since 2000. Cultivation and wood harvesting is prohibited within the reserve, but limited crop production, charcoal production and timber harvesting takes place illegally. The climate of the area is sub-humid tropical, with mean annual rainfall of 900 mm. The mean annual temperature is 24°C (Luoga et al. 2000). The vegetation is generally characterized as open dry miombo woodland, with some semi-evergreen forest (Luoga et al. 2000). The dominant tree species of the woodland are mainly used for charcoal making. As in other parts of the country, agriculture is the major occupation of the inhabitants. About 80 % of the households depend on small scale crop production, about 10% depend on charcoal production and 5% depend on livestock keeping. The rest are engaged in other activities such as petty business and casual employment (Nduwamungu et al. 2008). Maize (*Zea mays* L.) is the most important crop in the village, accounting for about 85% of all the crops cultivated.

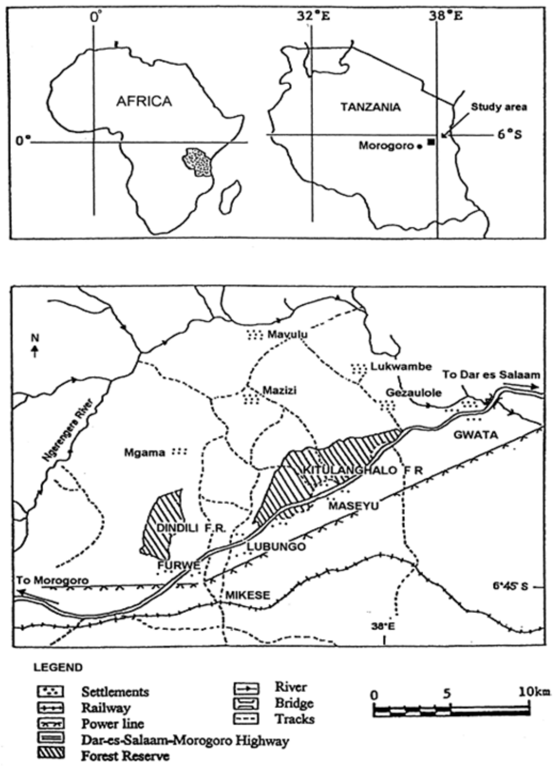

Figure 1. Location of the study site, source: Luoga et al. (2000)

Data

Data on costs and revenues related to crop and charcoal production were collected from 54 randomly selected households using structured questionnaires. Additional information on prices of inputs, crop produce and charcoal were obtained from the local markets. Data on statistics of current (nominal) local (farm-gate) and global (US) price of maize, local price of charcoal, exchange rates and consumer price index (CPI) were gathered from secondary sources and are shown in Figures 2 and 3. Data on carbon densities in different pools of both the protected and unprotected woodlands, and the surrounding cultivated lands were also obtained from different published sources. Deforestation history was obtained from land use and cover change since 1964 reported from the area (Luoga et al. 2005).

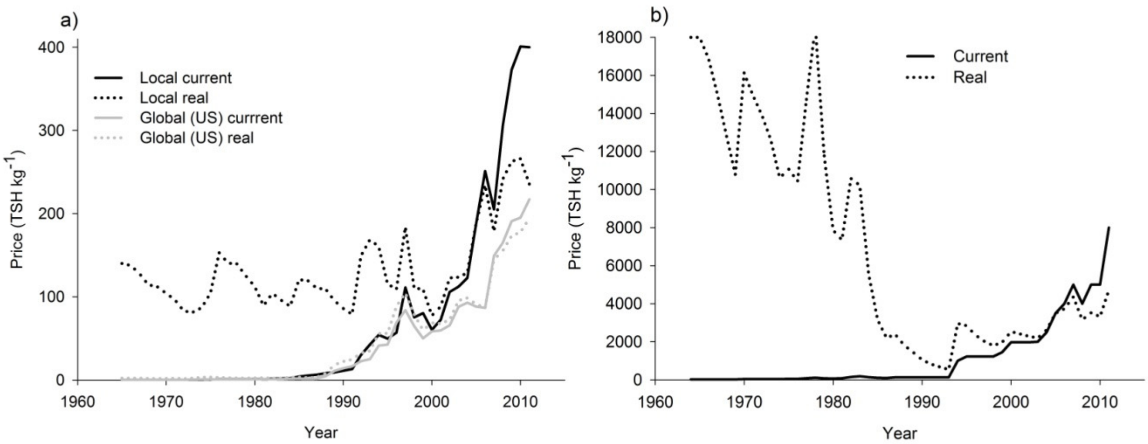

Figure 2. Current and real farm gate prices of maize in Tanzania and the USA from 1964 to 2011 (a), source: (Barreiro-Hurle 2012; Minot 2010; Morrissey & Leyaro 2007; Tapio-Biström 2001; USDA 2013) and current and real charcoal prices at the local market in Tanzania from 1964 to 2011 (b), source: (Hofstad & Sankhayan 1999; Malimbwi & Zahabu 2008)

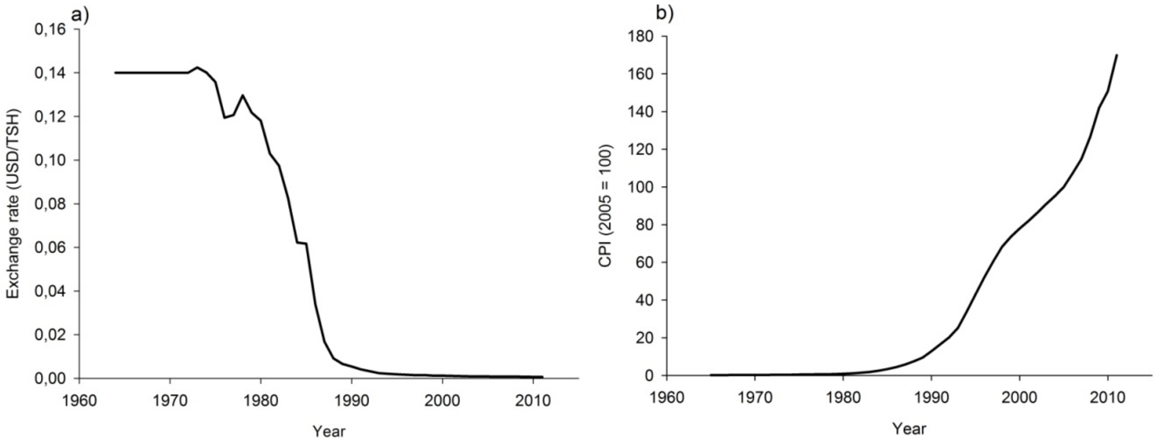

Figure 3. Tanzanian official exchange rates from 1964-2011 (a), source: (Index- Mundi 2011) and consumer price index (CPI) from 1964 to 2011 (b), source: (Index- Mundi 2011)

Land use and cover change

The process of land-use change involves the expansion of crop land, extraction of wood mainly for charcoal making, and in some cases grazing of cattle. The woodlands on public land have been reduced from 13,558 ha in 1964 to 10,755 ha in 1982 and to 6,782 ha in 1996 (Luoga et al. 2005). From these figures, annual deforestation rates were estimated and the woodlands have been declining at a rate of 1.3% of the total area from 1964 to 1982 and at a rate of 3.24% of the total area from 1982 to 1996. The deforestation rate after 1996 in the public lands as well as the potential deforestation rate in the forest reserve was estimated as an average of the two rates (2.14%).

Estimating carbon storage and sequestration

Data on above-ground biomass carbon and soil carbon of the woodlands were gathered from various sources (Munishi et al. 2010; Ryan et al. 2011; Shirima et al. 2011; Zahabu 2008). The below-ground biomass (carbon) was estimated as 20 % of the above-ground biomass. The soil carbon of croplands on deforested miombo woodlands was estimated as 60 % of soil carbon in miombo woodlands (Walker & Desanker 2004). The carbon estimate was multiplied by the conversion factor of 3.67 to obtain carbon dioxide equivalents (eCO_2). The net CO_2 that will be emitted due to deforestation was calculated as the difference between the mean of the total carbon density of the woodlands and the carbon density under the cultivated land. Accordingly, the amount of carbon released into the atmosphere because of land conversion ranges from 35 t ha^{-1} (128 $teCO_2$ ha^{-1}) from the woodland on public land to 55 t ha^{-1} (202 $teCO_2$ ha^{-1}) from the woodland in the forest reserve. In the periods from 1964 to 1982, the amount of carbon stock of the woodlands on public land is assumed to be the same as the carbon stock of the woodlands in the forest reserve.

The amount of carbon sequestered by the woodland depends on the growth rate of the vegetation. Therefore, we developed a simple growth model, Verhulst (1838) equation (Figure 4a.) to describe the development of biomass of the woodland. The equation relates the stock, S, and the increment, $\dot{S}$, of biomass in the woodland: $\dot{S} = a\,S - b\,S^2$, where a and b are positive constants. The necessary data used to estimate the equation were obtained by Ek (1994) from permanent sample plots in the KFR. The constants *a* and *b* were estimated by fitting a linear regression model. Observations and the developed growth function are shown in Figure 4a. We used fitted versus residual plot (a constant variance test) to evaluate the model and it showed no bias and a constant variance with p-value of 0.469. Starting with the current average biomass density of the forest reserve, 40 t ha^{-1} (Zahabu 2008), and assuming no harvest or fire, the biomass density is predicted to grow for about 80 years until it reaches its maximum. However, Luoga et al. (2002) reported an annual wood removal of 1.12 ± 0.68 m^3ha^{-1} from the reserve. Using a 0.85 conversion factor from volume (m^3) of fresh wood to biomass (ton) (Malimbwi et al. 1994), this corresponds to 0.95 ± 0.578 $tha^{-1}yr^{-1}$. Under normal circumstances fires occur in miombo woodlands every dry season. Since observations on plots affected by fire were excluded from our material, fire was considered afterwards. Barbosa et al. (1999) found that the average probability that a plot in wetter Zambezian woodland miombo burns in a particular year is approximately 37 %. Ryan and Williams (2011) reported that 5-6 % of live trees (dbh>5cm) were killed in fires in miombo woodland. By multiplying 0.37 by 0.05 we find that predicted biomass should be reduced by 1.85% when fire is considered. In the final analysis of biomass development in KFR we considered biomass reduction due to both fire and the illegal harvest. We assumed the illegal harvest as well as fire to be constant in all future (Figure 4b.).

Estimating benefits and costs of deforestation, crop cultivation and woodland preservation for carbon sequestration

The benefit items of deforestation (clearing and cropping) are crop produce and wood obtained during land conversion. Deforestation also involves cost of land clearing and environmental costs such as loss of biodiversity and emissions of GHGs. The type of environmental cost of deforestation considered in this study is only CO_2 emissions. The deforested land is assumed to be used for the production of maize, the major crop type cultivated in the village. Since application of commercial fertilizers is very limited in the study area, the only input cost considered in relation to maize production is the cost of seed. Most of the sample households depend on family members for labor and opportunity cost of labor in the area is nearly zero. Hence, the cost of labor required for different activities during the production process is not considered in the analysis. The median yield of maize estimated from the household survey data was 620 kg ha^{-1} and the average farm-gate price of maize in 2011 was 400 TSH kg^{-1}. Farm-gate price of maize in the USA were considered as an approximation of global price of maize.

Wood obtained during clearing is assumed to be used for charcoal production. The current average standing volumes of the woodlands on public land and the woodlands in the KFR are 14 m^3 ha^{-1} and 65 m^3 ha^{-1}, respectively (Zahabu 2008). Tree species used for charcoal making represent 40 % of the standing volume and one m^3 of wood yields 4.3 bags of charcoal (56 kg bag^{-1}). The labor required to produce one bag of charcoal is 2.3 man-days (Hofstad 1997). The average price of a bag of charcoal in 2011 was 8000 TSH at the kiln site and 10000 TSH at the road side.

The only benefit item of maintaining the protected woodlands is considered to be carbon sequestration. Currently, there is no cost involved related to maintaining or patrolling the forest reserve. Illegal harvest and fire are expected to continue (Figure 4b). Hence, there is no cost of management included in this study. Value of a ton of CO_2e emissions and carbon sequestration was estimated by assuming different prices of CO_2 (USD/ton).

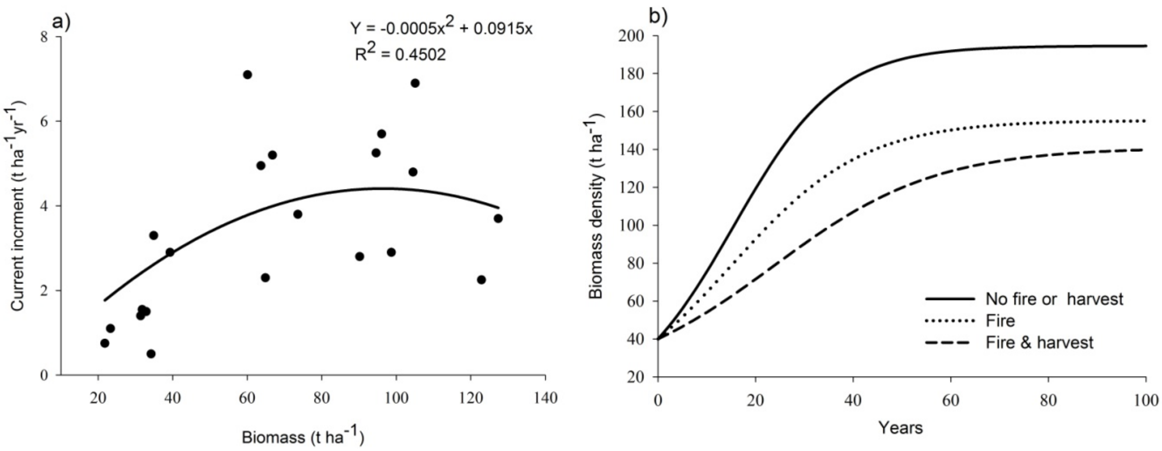

Figure 4. Observations of current increment and biomass density in KFR, with an estimated Verhulst growth function (a), and development of biomass density in KFR without fire or harvest, with fire alone, and with both fire and constant harvest of 0.95 t $ha^{-1}yr^{-1}$ (b)

Cost-Benefit Analysis (CBA)

In order to analyze the profitability of the deforestation that has actually taken place in the common land outside the forest reserve and possible future deforestation within the reserve, an *ex-post* and *ex-ante* CBA were undertaken, respectively. We estimated the financial returns to deforestation as the sum of agricultural rent and forest revenue during land conversion minus the environmental cost in terms of CO_2 emission. Net present value (NPV) of deforestation was used as a profitability criterion (Johansson & Löfgren 1985). The Cost-benefit flows were discounted to provide an estimate of the NPV of clearing and cropping, and maintaining the managed woodland, respectively. The discount rate used in this estimation is a real interest rate, estimated by adjusting the nominal discount rate (12 %) for inflation (6.4 %). The nominal discount rate is based on the rate of lending by the Bank of Tanzania as of January 2011 and the inflation rate is the inflation rate of all items for the period January 2010 to January 2011 (BOT 2011). Accordingly, we used a discount rate of 5.3%, but further investigated the effect of increasing this rate to 10% and reducing it to 2.5% through a sensitivity analysis. Other parameter considered in the sensitivity analysis was cost of labor. The opportunity cost of labor might change in the future and hence an increase in wage rate was examined in the analysis of potential deforestation. If real discount rates are to be used the prices of all inputs and outputs should also be in real terms. Hence, the real prices of maize as well as charcoal were calculated using the current (nominal prices) (Figure 2) and CPI (base year 2005) (Figure 3b). All values are equivalent to 2005's value. The global (USA) prices of maize were transformed to TSH by use of the 2005 exchange rate (Figure 3a).

Results and Discussion

Figure 5 shows that clearing the woodland on public land has been profitable when a ton of CO_2 was valued at less than TSH 14,600 and 9,800 when local and global real prices of maize were considered, respectively. The values are equivalent to USD 13 and 9 respectively (Table 1), using an exchange rate as of 2005. The results of sensitivity analysis showed that increasing the discount rate from 5.3 % to 10 % reduced the break-even price of a ton of CO_2 to TSH 12,500 (USD 11) and TSH 9,100 (USD 8), respectively. Deforestation was less profitable using the US price of maize as compared to Tanzanian price because the price in Tanzania was kept higher than world market prices early in the considered period. The high discount rate used in this study is within the range of the discount rates (8-15%) applied for agricultural projects in developing countries (Bond et al. 2010). Besides, given the level of poverty persisting in the miombo areas, a discount rate of 10 % per annum may be a reasonable assumption. Given the degraded state of woodlands in the common land in 1964 the shift from woodland to cropland could have been profitable even when we consider the social cost of CO_2 emissions. The conclusion depends on which price of CO_2 is considered realistic. The present low price in the EU market may be a result of the high volume of emission quotas distributed when the market was established (McGrath 2013; Zhang & Wei 2010). The reduction of biodiversity and other important ecosystem services following deforestation was not included in our analysis, however. This negative externality could have reduced profitability of deforestation significantly. On the study of the economics of deforestation in Ecuador, Wunder (2000) reported that the underlying cause of deforestation is that the natural forest provides less income than alternative land uses. He also suggested that considerable success in reducing deforestation can only be achieved when payments for global forest benefits are applied.

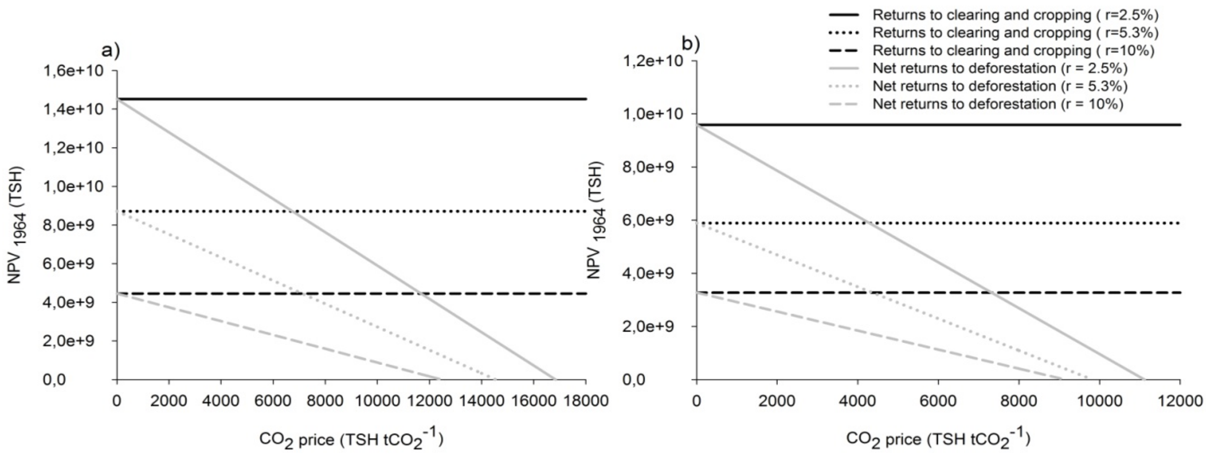

Figure 5. Social profitability of deforestation estimated using local price of maize (a) and global (USA) price of maize (b)

Table 1. Break-even prices of CO_2 emission (USD tCO_2e^{-1}) for the historic deforestation of woodlands in the common land

Price of maize	Discount rate (real)		
	2.5%	5.3 %	10 %
Local price	15	13	11
US price	10	9	8

Table 2 shows that maintaining the protected woodland can be more profitable than the potential benefits of deforestation at a price of CO_2 higher than USD 9.5. Increasing the discount rate from 5.3 % to 10 % made managing the reserve profitable at a price of CO_2 higher than USD 6. Reducing the discount rate from 5.3 % to 2.5 % on the other hand increased the price of CO_2 where managing the woodland becomes profitable into higher than 18 USD ton^{-1}. When wage rate was increased from zero to the minimum wage rate of 2,692 TSH $manday^{-1}$, keeping the forest reserve for carbon sequestration became profitable at a price of CO_2 higher than USD 11.5, 6 and 3.5 for interest rates of 2.5%, 5.3% and 10%, respectively (Table 2). This implies that better employment opportunities in the area would make deforestation of the woodland in the reserve less profitable.

The miombo ecology is still relatively well protected inside the reserve. Future deforestation of the protected forest reserve does not seem to be a profitable land-use alternative from the perspective of the global community. Emission of CO_2 and lost opportunities to sequester additional quantities of CO_2 from the atmosphere make this management option non-profitable at fairly low values per ton of CO_2 emission. However, from the perspective of the local community, conversion of the reserve into crop land is a profitable activity. The similar conclusion in the *ex-ante* analysis of the reserve and the *ex-post* analysis of the common land is explained mainly by the fact that biomass density increment in the reserve is very low if the illegal wood harvesting and fire remain.

It is not possible to generalize the results from Maseyu to all of Tanzania, much less so to the whole of Sub-Saharan Africa. However, our results support the intuitive general insight that forests with low biomass density may be allocated to crop production while forests with higher biomass density and a potential for further biomass accumulation should be protected (Kaimowitz et al. 1998). This conclusion presupposes a certain productivity of land in crop production. One should keep in mind that this study did not investigate whether restoration of degraded woodland or establishment of forest plantations on such land are profitable means of climate change mitigation.

Table 2. Break-even price of GHG emission (USD/tCO_2e) for protection of KFR

Wage rate	Discount rate (real)		
	2.5 %	5.3 %	10 %
Zero	18	9.5	6
Minimum wage	11.5	6	3.5

Conclusion

Deforestation of miombo woodlands in Maseyu village has been, and still is, profitable if environmental costs of deforestation are not accounted for. However, fairly low prices of CO_2 emissions would make deforestation unprofitable in the social analysis. At 10 % discount rate, depending on the prices of maize considered, this price ranged from USD 8-11 $tCO_2e^{-1}$for the historic deforestation that took place from 1964 in the common land. At the same discount rate, CO_2 prices higher than 3.5 - 6 USD tCO_2e^{-1}, depending on the wage rates applied, would turn future deforestation of the woodland in KFR unprofitable. The difference between the break-even price estimated using the *ex-post* analysis and *ex-ante* analysis is due to the fact that biomass density is higher inside the reserve than it was in the common land, and biomass density is likely to increase in spite of fire and illegal harvesting if the reserve is maintained. Lower discount rates would obviously lead to higher break-even prices of emissions. However, given the fact that the inhabitants in miombo areas prefer immediate consumption because of poverty, applying higher discount rate might be a reasonable assumption. Incorporating other environmental costs of deforestation such as loss of biodiversity and emissions of other GHGs could potentially reduce the profitability of deforestation further, particularly deforestation of the woodlands in the forest reserve.

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