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Exploring possibilities for reducing woodland deforestation and degradation at village level in Sub-Saharan Africa

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Abstract

Avoided deforestation may be financed through a multilateral fund for climate change in the future. There is a concern that payments for REDD should benefit the poor, and that it is necessary to design incentives that make sustainable forestry more profitable than deforestation or degradation. By applying a dynamic and non-linear programming model we tested a number of interventions and development trends to see how they affected deforestation and forest degradation in villages in Senegal, Tanzania and Uganda over the next 20 years. Cultivable land has already been cleared in most of the investigated villages. Thus deforestation is likely to occur only in villages with a substantial remaining woodland area. In villages with little remaining woodland harvesting of wood-fuel leads to serious degradation in a few years. Reduced growth of population is likely to reduce deforestation in most cases. Higher producer price of charcoal leads to less deforestation and more degradation. Policies that make crop production relatively more profitable normally lead to more deforestation and less forest degradation. Production quotas may be an effective measure to reduce forest degradation, but when charcoaling gets less profitable villagers will allocate more labour to land clearing and crop production, thus increasing deforestation. These results may be useful both in setting the REDD baseline, and in the design of measures to achieve REDD effectively.

Keywords: Bio-economic model, land use, REDD, Senegal, Tanzania, Uganda.

1. Introduction

Deforestation and degradation of forests may contribute 12 to 17 % of global anthropogenic emissions of greenhouse gases (IPCC, 2007; van der Werf *et al.*, 2009). Today deforestation is primarily a tropical phenomenon and, therefore, financing avoided deforestation through a future multilateral fund for climate change may be a justified action (Creighton, 2007). Carbon storage in forests may become an environmental service that the tropical countries could sell to such a fund.

If we assume that an international regime is established whereby states in the North pay states in the South for reduced emissions of greenhouse gases (GHG) from deforestation and forest degradation (REDD) (Meridian Institute, 2009), the states in the South should design efficient national policies and incentives to generate maximum reductions within a given budget (or a given reduction at minimum cost). National policies and incentives may include a multitude of policy measures affecting large portions of the population. Undoubtedly, rural people living in or next to the forest will be the target of several measures since they are often the direct agents clearing or degrading the forest (Geist and Lambin, 2002).

More than half of deforestation in Africa between 1980 and 2000 was caused by direct conversion of forest area to small-scale permanent agriculture (FAO, 2001). FAO (2006) estimated that 88 % of wood removals in Africa in 2005 were fuel wood. Biomass represents more than 80 % of energy consumption in sub-Saharan Africa (Karakesi, 2004), and supply of wood-fuels is a major cause of forest degradation in many of these countries. Apart from the Sahara and Kalahari deserts and the Central-African rainforests, Africa is primarily a continent of open forests, or woodlands.

We have studied 16 villages in Eastern Tanzania, Central Uganda, and Southern Senegal – all in the woodland zone of sub-Saharan Africa – to see how economic activities affect deforestation and forest degradation over a 20 year period. We simulated the effects of economic changes that may be the result of policies to reduce emissions of GHG in these countries. The results reflect established knowledge about the causes of deforestation and forest degradation, but they may also inform the search for efficient REDD measures that has just started. There is a growing concern that such measures should benefit poor farmers and other local people who live in and around the forest (Peskett *et al.*, 2006; Griffiths, 2007). Similarly, economists recognise the need to design incentives that will alter the decisions of direct deforesting agents from forest clearing to sustainable forest management (Pagiola *et al.*, 2002), namely making sustainable forestry more profitable than alternative land uses.

2. Methods

We shall investigate the degradation process by applying a dynamic, stochastic, and non-linear programming model (Sankhayan and Hofstad, 2001; Namaalwa *et al.*, 2007) to each of the 16 villages in Senegal, Tanzania and Uganda where detailed studies were undertaken. By incorporating the biological processes and socio-economic relations characteristic of the region, the model is specially designed for application in the context of sub-Saharan African countries. The model approximates the complex biological and economic relations by incorporating feedback, non-linear and time-delayed equations.

The basic assumption is that the villagers are the subjects who make decisions on how to use available resources and how to manipulate the environment. The model includes the most important resources available to the village, the decisions/activities undertaken by the village community and the most important relations between the prices of factors and products. Our intention is to represent most realistically the actual real world situation confronting the villagers.

By considering the entire village, rather than the individual household as the welfare optimising entity, the model assumes the existence of social control mechanisms and a central authority at village level. Each village coordinates land use to ensure that it is economically optimal at any time. Collective time preferences, e.g., exceeding sustainable use levels, are modelled by using alternative discount rates. Fuel wood for external sale is assumed to be cut only by the villagers, and not by outsiders. If nomadic herders or others use the village grazing land, this is taken account of by the villagers in their planning of animal production. The model, however, does not take account of other competition with neighbouring villages over land use.

Land use during a given year is determined by the optimum allocation of village labour force (net of hired in and hired out) among a variety of competing uses, and the production of consumption requirements and income generation by supplying products to markets outside the village. While cropland is treated as a private property, more peripheral grazing land/open woodland is considered a common property.

The model incorporates four sets of activities, namely, crops, livestock, forest products like fuel wood and charcoal, and miscellaneous products, e.g., beer and bricks. Each set of activities was further divided into sub-sets, namely, production, trading (sale and purchase of products and inputs), labour employment, and consumption. Demand and supply relationships for these sectors are linked through behavioural, structural and accounting equations.

Each village is portrayed using a modified von-Thünen model. Land use is determined by distance and transport cost from the centre of the village. The land use sites proceed outwards from the centre of the village in the following order: settlement, intensive cropping, rangeland, and open woodland. Each site is further divided into cropland and woodland. Suitability of each site for different activities is known. The sites are discrete and assume homogeneous land suitability/productivity. The model does not indicate the precise location where degradation will occur within each land site. Thus, each site is a “black box” with a total stock of biomass accumulated/degraded as the net result of regeneration and exploitation.

Woodland degradation is assumed to occur when removals exceed net sustainable yield of vegetation and is measured as a reduction of vegetative biomass density. The model incorporates three major processes responsible for woodland clearing or degradation: (a) the expansion of cropping, which may reduce woodland area or tree density directly or displace grazing from former grazing land, (b) the level of animal grazing, and (c) the quantity of wood removal. Conversion of woodlands into cropland is assumed to reduce the vegetative biomass to the level found in the existing fields. Thus, the model accounts for partial removal of vegetation rather than its total loss. Grazing losses are assumed to be proportional to the stock of vegetative biomass available in each site and land category. Fuel wood extraction is a function of distance required for travelling to the site and the stock of tree vegetation there.

We shall analyse the likely land use changes over the period 1999 to 2020, assuming that the framework conditions remain more or less constant during that period, and that the villages behave as if they are decision-making units maximising the welfare of their population.

3. The villages

Since the objective is to study land use problems in sub-Saharan villages with access to forest resources, all 16 villages are located in woodland zones of semi dry Africa; southern Senegal, eastern Tanzania and central Uganda. Probably, the productivity of the arboreal vegetation is not very different between these countries and their woodland types. Although the 16 villages do not constitute a statistically representative sample of rural sub-Saharan Africa, we think that by studying optimal land allocation in these cases a broad direction of change in land use may be revealed for the future. Some important information on the sample villages are given in Table 1.

Table 1. Some salient characteristics of 16 study villages in Senegal, Tanzania and Uganda

Country	Village	Population 1999*	Population growth (% p.a.)	Distance from town** (km)	Distance from road head (km)	Main economic activity
Senegal	Afia Mbemba	712	4.0	67	25	Cropping/Grazing
	Boulimbou	298	4.0	32	7	Cropping/Grazing
	Lambatara	781	1.5	20	20	Cropping
	Medina Pakane	156	8.3	45	10	Cropping
	Sare Birou	149	8	10	7	Cropping/Grazing
	Sare Coly Sal	497	4	9	1	Cropping/Grazing
Tanzania	Kanga	2914	2.5	140	0	Cropping
	Kilimanjaro†	4700	2.6	100	1	Cropping
	K-Madesa	1890	3.3	72	6	Cropping/Grazing /Fuelwood
	Kwadudu	2460	2.7	64	5	Cropping
	Muungano	3110	2.7	43	0	Cropping
	Mazizi	4340	2.4	68	0	Cropping
Uganda	Kyankonwa	700	1.82	100	0	Cropping/Grazing
	Namusala	1200	2.13	80	0	Cropping/Grazing
	Kabutuukuru & Kinuuma††	1710	2.1	na	0	Cropping/Grazing / Fuelwood

* Population for Tanzanian villages refers to 1998 ** town = provincial capital
† The village Kilimanjaro is not located particularly close to the mountain Kilimanjaro
†† Data collected in 2003.

It is worth mentioning that a village has a somewhat different meaning in the three countries. In Senegal this term is used for a fairly small concentration of homesteads. The houses are usually assembled in a densely built up area surrounded by cultivated fields. In Tanzania the history of villagization in the 1970s (Kjekshus, 1977) has led to the term village being used for a much larger assembly of houses and people. The built up area may stretch for quite a long distance (e.g., 1km), and the fields are not concentrated around the homesteads in the same concentric pattern normally found in Senegal. The availability of soil and water determines the land use pattern to a large degree. In Uganda the term village is used more as an administrative term than for a concentration of homesteads. Houses are often distributed fairly evenly in the terrain, surrounded by gardens and fields. It is often difficult to determine where the economic centre of the village is located, unlike in the other two countries.

Information about the villages, their people and economic activities, were collected through socio-economic surveys conducted in two stages during the years 1999 and 2000. In the socio-economic survey of the villages, detailed information about the number of households and their productive and consumptive activities were collected. A representative sample of households was asked about their production activities, input use as well as the prices of factors and products. Land available to the village for agricultural cultivation, grazing and collection of wood and other forest products was surveyed by the use of GPS equipment. Sketch maps were drawn of all the village land, with land units classified according to existing vegetation and suitability for various uses. Finally, a survey of wood and grass biomass was carried out with at least one sample plot located in each land unit of all the 16 study villages.

Table 2. Prices of key products and human labour in the sampled villages in 1999

Country	Village	Farm gate price of maize (USD/kg)	Farm gate price of beef meat (USD/kg)	Road head price of charcoal (USD/bag)	Rural labour wage (USD/man day)
Senegal	All six villages	0.12	1.31	1.85	0.31
Tanzania	Kanga	0.13	1.26	1.01	0.51
	Kilimanjaro	0.08	2.56	0.76	0.51
	K-Madesa	0.25	2.53	1.26	0.51
	Kwadudu	0.51	1.26	0.76	0.51
	Muungano	0.51	1.26	1.26	0.51
	Mazizi	0.08	2.53	1.26	0.63
Uganda	Namusala	0.17	1.33	2.67	0.27
	Kyankonwa	0.17	1.33	2.34	0.27
	Kabutuukuru & Kinuuma				0.54*

* Note: 2003

Prices of some important products and of rural labour in the surveyed villages are given in Table 2. These prices are exogenous to the model, and thus taken for given by the villagers while optimising their land use.

Table 3. Land availability in the sampled villages

Country	Village	Cultivated land (ha/head)	Total land (ha/head)	Uncultivated land (ha/TLU*)
Senegal	Afia Mbemba	0.65	0.96	0.59
	Boulimbou	1.59	10.76	10.40
	Lambatara	1.36	3.07	3.61
	Medina Pakane	1.82	17.40	18.82
	Sare Biro	1.64	3.97	0.76
	Sare Coly Sal	0.61	0.98	0.40
Tanzania	Kanga	1.34	3.34	26.01
	Kilimanjaro	0.11	0.17	9.90
	K-Madesa	0.33	3.60	1.41
	Kwadudu	1.18	3.36	181.98
	Mazizi	0.25	1.72	6.33
	Muungano	0.59	1.96	35.26
Uganda	Namusala	0.90	1.54	7.74
	Kyankonwa	0.44	0.62	0.09
	Kabutuukuru & Kinuuma	0.29	1.15	0.85

* TLU = tropical livestock unit

Land availability in the villages is presented in Table 3. Since woodland is of fundamental importance to animal husbandry in these villages, the availability of uncultivated land was also calculated per livestock unit.

From Table 3 one may see that land in Kilimanjaro and Mazizi villages in Tanzania is relatively scarce. It is not sufficient for the population to produce enough food and fuel wood even for own consumption. However, villagers stated that they were about self-sufficient in these products, implying thereby that additional land is probably available to them outside the area surveyed. Consequently, we have added a dummy land unit of woodland not suited for cultivation but available only to meet the wood fuel and fodder requirements of these villages. A dummy land unit has also been added to Kyankonwa and Namusala villages in Uganda. Kyankonwa is located next to Kasagala Forest Reserve, which is illegally used for collection of firewood, production of charcoal, grazing of animals, and even encroachment for crop cultivation. Also, villagers in Namusala have access to woodland for firewood collection and grazing of animals outside the surveyed village land.

Some differences in farming systems between the three countries are also worth noting. The combination of cropping and animal husbandry is more common among village households in Senegal and Uganda than in

Tanzania. This may be explained by the presence of semi-pastoral Maasai (SAAH, 1999) in most of the surveyed areas of Tanzania. These people keep large herds of domestic animals (Ndagala, 1992) and probably supply most beef and goat meat consumed by the village households. Another difference is the variety of crops cultivated among countries. While rice and cotton are important crops in Senegal, these crops are of little importance in the East-African villages. Coffee is an important cash crop in Uganda, but not in the surveyed villages in Senegal and Tanzania.

4. Deforestation and degradation under "business as usual"

Land-use development resulting from unaltered price relationships and policy regimes has been simulated. In the REDD literature this is often referred to as the baseline (Angelsen, 2008). Such baselines are often proposed to be set according to historical deforestation, but model based baselines are also suggested (Meridian Institute, 2009). Here we are more concerned with baselines in the national context rather than in international negotiations and agreements. Model based baselines are demanding in terms of data and competence, but they yield more realistic results (Brown *et al.*, 2006).

Underlying processes such as population growth and economic development have been assumed to continue at about the same pace as observed during the last couple of decades. In this section we do not attempt to simulate any policy interventions to reduce deforestation or forest degradation.

Since our main interest is to predict the degree of deforestation and woodland degradation resulting from rational land use decisions among African villagers, some measurement of these variables is required. Our model endogenously describes the development of area of cultivated fields and that of other vegetation types, mainly woodland, corresponding to the welfare maximising solution. The stock of biomass in trees and bushes is also modelled. Consequently, two indicators of deforestation and woodland degradation may be computed from the primary output of the model. The cultivated land as per cent of total land in the village is one of them. This relationship shows how woodland and other areas are cleared and converted into cultivated fields for agricultural crops. An increase in this indicator shows that villagers find it rational to reduce forest cover and expand the cropping area. This indicator is not a direct measure of deforestation (in the narrow sense of definition) since some trees are often left in fields or along the edges of fields when woodland is cleared for cultivation. Therefore, the biomass density in woodlands was used as an alternate indicator of woodland degradation. To compute this density we divide total above ground woody biomass of trees and bushes in the woodland by the total area of woodland. This indicator serves as an indicator of the state of the vegetation in the woodland. Though this measure does not capture changes in species composition, e.g., from broadleaved trees to thorny shrubs yet it can still be used as a possible indicator of woodland degradation. A reduction of biomass density may suggest that woodland resources are being depleted through grazing and/or extraction of fuel wood and thus the woodland use is not sustainable.

The development of cultivated land as a proportion of total village land over the model horizon is presented in Figs. 1 - 3.

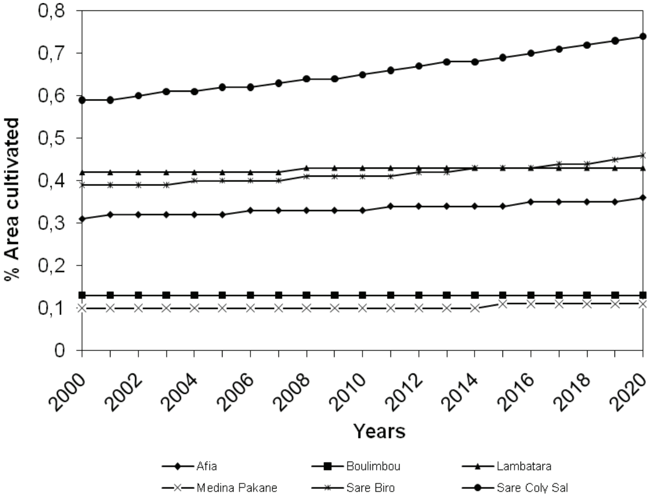

Figure 1. Proportion of cultivated land in each study village in Senegal

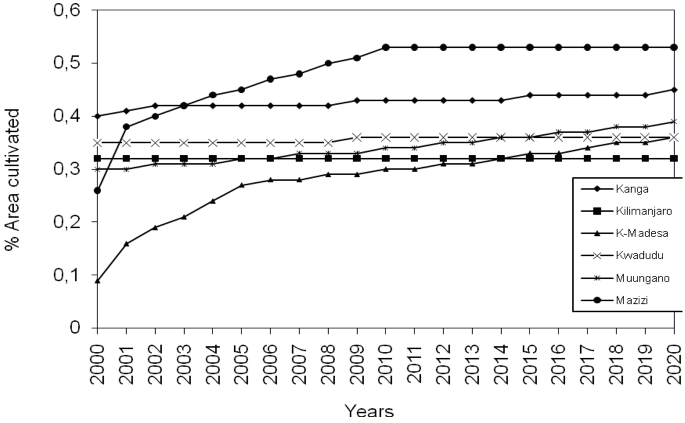

Figure 2. Proportion of cultivated land in each study village in Tanzania

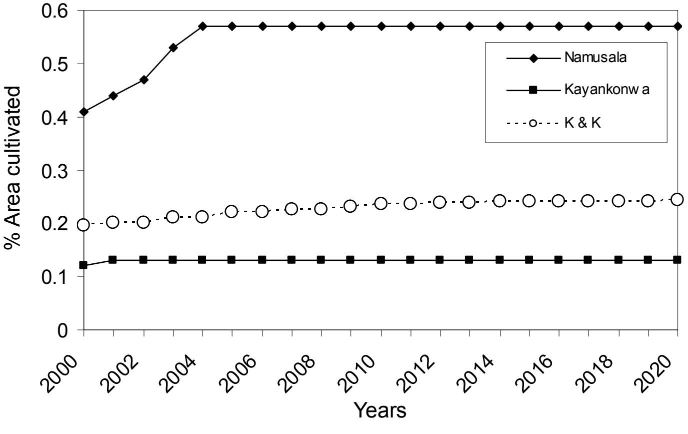

Figure 3. Proportion of cultivated land in each study village in Uganda

We note that there is very little clearing of woodland for cultivation in most villages as against quite a lot of woodland clearing in a few others. The variations in patterns of woodland clearing are primarily due to the differences in the availability of land suitable for cultivation. In many villages all, or almost all, suitable land has already been cultivated, while in other villages (Mazizi and Kihangaiko-Madesa in Tanzania, and Namusala in Uganda) there are still more remaining woodland areas suitable for cultivation. In these villages woodland clearing may still be feasible for another 10 to 15 years into the future.

The developments of biomass density in the remaining woodland pertaining to each study village are shown in Figs. 4 – 6. We note that there is a wide variation in biomass density in the Tanzanian woodlands. Per hectare densities inventoried varied between 12 and 224 tonnes in Tanzania and between 54 and 132 tonnes in southern Senegal. The corresponding figures for Uganda are 13 to 45 tonnes per ha only. The modelled scenarios indicate that most villages have difficulties to harvest sufficient wood and fodder without depleting their stock of biomass. In a few years, serious woodland degradation is likely to set in the Ugandan villages and in one of the Tanzanian villages, namely, Mazizi. A similar development may be expected somewhat later in Kilimanjaro village in Tanzania and in the Senegalese village Sare Colly Salle.

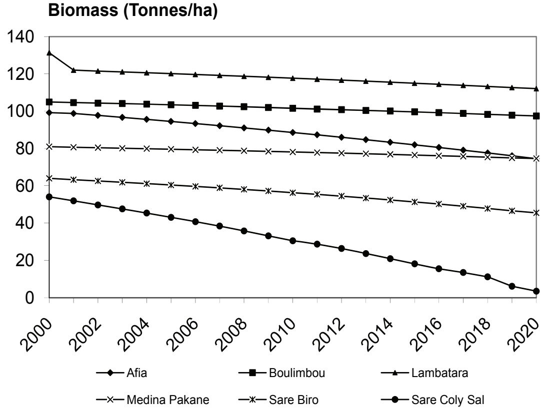

Figure 4. Biomass density in woodland area of Senegalese villages

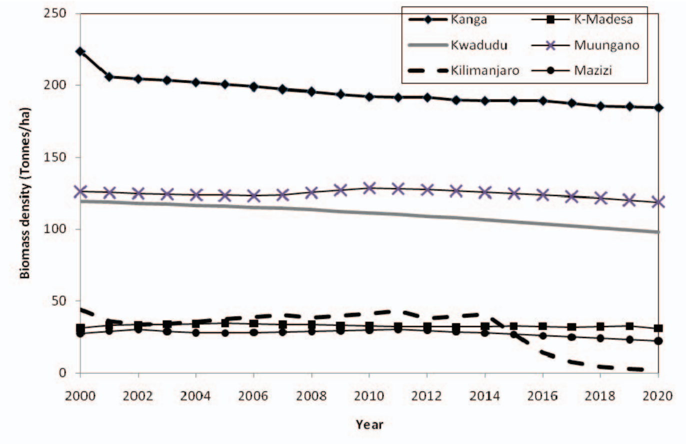

Figure 5. Biomass density in woodland area of Tanzanian villages

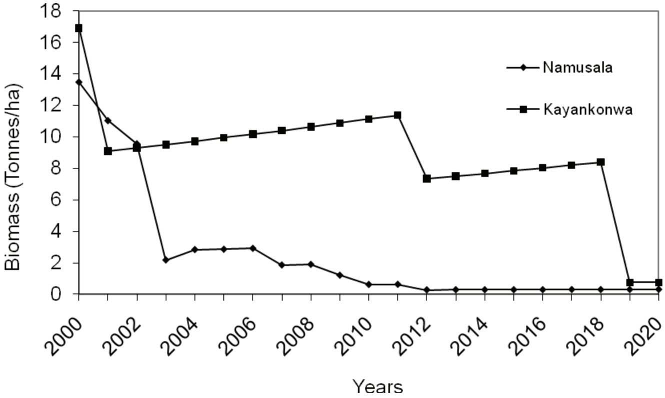

Figure 6. Biomass density in woodland area of two Ugandan villages

It should be mentioned that the results reported here for Lambatara village in Senegal are somewhat different from the results reported for the same village by Sankhayan and Hofstad (2001). This is due to improved quality of data obtained for this study during the second phase of survey of the village during the year 1999.

A summary of woodland degradation estimates for all 16 villages over a 20 year period is given in Table 4.

Table 4. Biomass density and likely biomass degradation in 20 years in 16 villages

Village	Actual (tonnes/ha)	Prediction (tonnes/ha)	Change = predicted:actual
Namusala	13.49	0.31	0.023
Kilimanjaro	44.54	1.24	0.028
Kyankonwa	16.91	0.76	0.045
Sare Coly Salle	53.99	3.47	0.064
Mazizi	12.20	1.59	0.130
Kabutuukuru & Kinuuma	29.75	17.20	0.579
Sare Biro	63.91	45.44	0.711
Afia Mbemba	99.23	74.49	0.751
Kwadudu	119.57	96.96	0.811
Kanga	223.84	183.36	0.819
Lambatara	131.32	112.07	0.853
Medina Pakane	80.92	74.57	0.922
Boulimbou	104.92	97.44	0.929
Kihangaiko-Madesa	31.43	30.12	0.958
Muungano	126.06	122.54	0.972

5. Effects of measures to reduce deforestation and degradation

Detailed analysis of some interventions to reduce deforestation or forest degradation has been undertaken for one of the Senegalese villages, Lambatara, and for the two Ugandan villages Kabutuukuru and Kinuuma.

In the Senegalese case we tested the effects of two abrupt changes, namely, introduction of fertilizer use for major crops and increase in population growth from 1.5% to 3% p.a. In addition, effect of three gradual changes, namely, decrease in charcoal prices by 3.5% p.a., increase in wage rates by 5% p.a. and increase in cotton price by 3.5% p.a.

Most of these changes may result from modified economic development in the country. Which policies should be implemented by the government to achieve such changes is not easy to pinpoint. To make fertilizer use more common, subsidies may be required (Jepma, 1995:115), but higher product prices may also contribute. A reduction in the population growth rate normally follows from better education of girls, better health services, and economic growth in general. Increased wage rates may often result from economic improvements in agriculture and industry. The government may also increase minimum wages over time to ensure equity. Cotton prices may increase relative to other prices due to growing world market demand, or government subsidies. The government may introduce more effective taxes on traded charcoal in order to reduce the producer price. Better supply of alternative sources of energy (electricity, kerosene, gas, solar, wind, etc.) may also reduce charcoal price, and the authorities may contribute to this in various ways.

Table 5. Deforestation and degradation under various model scenarios at Lambatara village in Senegal – after 20 years

Scenario	**Deforestation***	**Degradation****
BASE (business as usual)	117 ha (2.5%)	30.9 T/ha (-12.4%)
ATECH (fertilizer introduced)	126 ha (2.7%)	31.0 T/ha (-12.2%)
GRPOP (3% population growth pa)	285 ha (6.1%)	31.1 T/ha (-11.8%)
CHARCP (charcoal price -3.5% pa)	117 ha (2.5%)	31.7 T/ha (-10.1%)
WAGER (wages +5% pa)	126 ha (2.7%)	31.5 T/ha (-10.9%)
COTP (cotton price +3.5% pa)	37 ha (0.8%)	30.7 T/ha (-13.0%)

* Ha of woodland cleared for cultivation (% of available woodland)
** Biomass density (T/ha) in remaining woodland after 20 years (% change)

The results shown in Table 5 for Lambatara village in Senegal indicate that there is a limit to woodland degradation that can occur over the model horizon irrespective of model scenario. This is explained by the fact that the village has access to a fairly large woodland area (4,678.5 ha). There are two assumptions that affect deforestation substantially; namely, population growth rate, and producer price of cotton, though in opposite directions. If population grows at 3% p.a. rather than the actual 1.5%, deforestation also proceeds at approximately double the rate of business as usual. If cotton price increases by 3.5% p.a. compared with other prices, deforestation is reduced to about a third of what is expected under business as usual.

In the Ugandan case we tested the effects of the following abrupt changes:

- Crop yields are increased by 20%
- Producer price of charcoal is increased by 20%
- Annual wood harvest is restricted to biomass increment
- Charcoal production limited to specific annual quota

These changes are more directly related to specific interventions on part of the authorities. Charcoal price may increase (in real terms) as a consequence of increased demand and reduced supply due to woodland degradation and increasing transport distances. The authorities may, however, contribute to price hikes through the introduction of various taxes, e.g., stumpage fees, transport fees, and value added tax. This may reduce the producer price of charcoal. Also the authorities may introduce production quotas, either on wood harvest or charcoal. Such quotas should ideally be related to the biological yield of woodlands in question. However, the actual basis for fixing such quotas is seldom known. Effective implementation of such control systems is often hampered not only by practical problems related to transport and communication, but also by the prevailing corruption in the society and the poor law enforcement. This means that harvest control is an expensive activity that can possibly be financed by reinvesting a proportion of payments for carbon storage in African forests and woodlands. Transaction costs related to payments for environmental services like REDD (Eliasch, 2008) in Africa are probably quite high.

The results presented in Table 6 indicate that crop yield increasing measures (improved crop varieties, fertilizers, pesticides) are likely to accelerate deforestation. On the other hand, degradation of the remaining woodland would probably be retarded. Measures affecting the producer price of charcoal also have pronounced effects on deforestation and degradation. Increasing charcoal price leads to less deforestation, but more rapid degradation. The effects of quotas on wood harvest or charcoal production obviously depend on how restrictive they are, but in our case these measures resulted in high deforestation and little or no degradation of remaining woodland. This is the result of a shift from charcoaling to cropping among villagers when the quotas are imposed. We did not find a set of measures that would stop both deforestation and woodland degradation simultaneously without reducing villagers' income and livelihoods severely.

Table 6. Deforestation and degradation under various scenarios at Kabutuukuru and Kinuuma villages in Uganda – after 20 years

Scenario	Deforestation*	Degradation**
BASE (business as usual)	112 ha (46.7%)	17.2 T/ha (- 42.1%)
YIELD (+20% crop yields)	236 ha (98.3%)	24.6 T/ha (- 17.3%)
CPRICE (+20% charcoal price)	62 ha (25.9%)	15.6 T/ha (- 47.5%)
CTAX (-10% charcoal price)	220 ha (91.7%)	20.8 T/ha (- 30.0%)
BMQUOTA (wood harvest at MAI)	236 ha (98.3%)	26.2 T/ha (- 11.9%)
CQUOTA (limited charcoal production)	236 ha (98.3%)	34.3 T/ha (+15.5%)

* Ha of woodland cleared for cultivation (% of available woodland)

** Biomass density (T/ha) in remaining woodland after 20 years (% change)

6. Conclusion

If reduced emissions from deforestation and forest degradation are included in a post-Kyoto regime to mitigate climate change, governments intending to sell this environmental service must design forest policies and Climate Action Plans that are effective, and preferably efficient. We have investigated deforestation and woodland degradation at village level in three countries of Sub-Saharan Africa, namely, Senegal, Tanzania and Uganda, outside the rainforest zone. The study has brought out that while expansion of cropland is a major driver of deforestation, wood harvesting for meeting energy requirements is the major cause of forest and woodland degradation in these regions.

We find that cultivable land has already been cleared in most of the investigated villages. Thus deforestation is likely to occur only in villages with a substantial remaining woodland area. This is in agreement with the general observation that deforestation in these parts of Africa takes place as an expansion of cropland at the fringes of woodlands and forests. Present economic and institutional conditions are likely to maintain further deforestation wherever cultivable woodlands are available. These findings are important for estimating baseline emissions from deforestation and forest degradation (Olander *et al.,* 2008).

Most observed villages have difficulties in limiting harvest of wood to sustainable rates. The villagers are either in need of fuelwood for their own consumption, or for earning income from sale of charcoal. This results into more wood harvest than the present increment. In villages with little remaining woodland this would lead to serious degradation in a few years. This behaviour is rational in spite of villagers knowing quite well that it is not sustainable. Our results raise the question whether paying compensation to such communities for reducing emissions would be a sufficient measure. Rural households would need other types of fuel. It could be purchased by part of the compensation, but the energy should not come from fossil fuels. Urban populations will also be affected by decreased supply of wood fuels. How they should be compensated is an open question. Energy supply may become a major policy challenge after REDD in countries that are now dependent on wood fuels. Also, many people who are presently employed in wood-fuel production and trade would need alternative employment (Hofstad *et al.,* 2009).

Model experiments with three of the studied villages lead to some conclusions concerning factors that may reduce deforestation or woodland degradation. Reduced growth of population, through family planning, education of women or outmigration, is likely to reduce deforestation in most cases. This is hardly a surprising result given the existing evidence of positive correlation between population growth and deforestation (Bawa and Dayanandan, 1997; Angelsen and Kaimowitz, 1999), especially in Africa.

Increasing producer price of charcoal leads to reduced deforestation and increased degradation because villagers allocate less labour to land clearing and crop production and spending more time on charcoal production.

Policies that make crop production relatively more profitable (e.g., subsidising fertilizers or improved crop varieties), have similar effects as increased producer prices of crops. Such changes normally lead to more deforestation and less forest degradation. This is exemplified by our Ugandan case where maize and other crops are grown on newly cleared land. The case of increased cotton price in Senegal, however, shows that the general pattern cannot always be expected. Cotton in Senegal is grown entirely for the market as a cash crop on particularly productive soils as against maize that is mostly grown for meeting self-sufficiency requirements in Uganda. When these are fully utilised, price increases will not necessarily lead to further deforestation.

Production quotas may be an effective measure to slow down, or even stop, forest degradation. Whether such measures are also cost effective, has not been tested here. We are afraid that effective controls may be rather expensive. Sustainable harvest quotas are likely to make charcoal production less profitable, unless they are applied without exemptions and lead to increased price. If charcoaling gets less profitable, villagers are likely to allocate more labour to land clearing and crop production, thus increasing deforestation.

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