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Bio-Energy Production and Consumption Options for Forest Conservation in Uganda

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Abstract: This study examines the effectiveness of selected policy options for increasing fuelwood supplies or decreasing fuelwood demand in Hoima district, Uganda. On the supply side, a benefit-cost analysis is done on a government sponsored tree farming project. In order to reduce the demand for fuelwood, two demand-side options are considered, namely, introduction of an improved energy-efficient woodstove and the substitution of a kerosene stove for a traditional woodstove. A non-linear dynamic programming model was used to explore the system behaviour of forest degradation. Our results show that tree-farming is one of the possible approaches to increase the supply of fuelwood (energy), while the woodstoves and kerosene substitution are policies that reduce the demand for fuelwood. This helps to alleviate the rural energy shortage and take some pressure off existing protected forest areas. This study does not attempt to analyse the wider energy planning program that would be needed to understand accurately the various alternatives available in Uganda.

Key words: Population, commercial fuels, tree farming, woodstoves

INTRODUCTION

Fuelwood occupies an enviable place for providing many people, especially the poor and rural households, with a primary source of energy (MoEMD, 2002). Fuelwood is used for both domestic and industrial purposes in rural and urban areas of most economies of the developing world (Tietema, 1993). Wood consumed annually for fuel energy in Sub-saharan Africa increased 1,500 - 3,500 million m^3 between 1950 and 2002 (Moyini and Muramira, 2002).

The energy sector is characterised by a heavy dependence on biomass resources and studies have demonstrated that woodfuel (firewood and charcoal) account for more than 90% of energy used in Uganda (MoEMD, 2002). Traditionally, the majority of Ugandans depend on fuelwood for their domestic heating, cooking and lighting purposes. Total wood production (monetary and non-monetary) has registered a steady increase over the period between 1995-2000.

The importance of wood fuel becomes clearer when for example kerosene is substituted for charcoal in urban households, which would result in an increase in the national import bill by US$180 million (Ushs. 324 billion) annually (Falkenberg and Sepp, 1999). Such strategy will in fact lead to loss of jobs by poor people who are involved in wood fuel income generating activities.

It has been argued that in southern Africa, there is a fuelwood crisis in many areas (Dovie *et al*., 2004). The crisis refers to a shortage in fuelwood supplies to meet households' requirements and is manifest as an ever increasing distance covered by rural households to obtain and harvest wood suitable for fuel energy. With increasing deforestation, the distance travelled to collect firewood increases. This affects the productivity of households, when the time spent on collecting firewood would have been used for productive activities. The average distance travelled by households to collect firewood has increased dramatically between 1992 and 2000 from 0.06-0.73 km (MoEMD, 2002). Fuelwood is one of the commodities that households sell to raise income especially in areas where free access to forestry resources is declining. Unfortunately, the income from sale of fuelwood not clearly recorded in the national accounting system as part of the forestry contribution to household income. Hence forestry remains just recognised as being of extremely high economic importance, but mainly in the informal sector (MWLE, 2002b).

Factors affecting the pressure on fuelwood use have been oversimplified as type and quality of wood, stove technology, population growth and availability of substitutes (Kalumian and Kisakye, 2001; Jacovelli and Caevalho, 1999). However, their link to supply-side approach to providing fuelwood through tree-farming projects and demand-side options aimed at reducing firewood demand by either introducing more efficient woodstoves and use of kerosene as a substitute fuel are

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still unclear and with little empirical justification. The objective of this study is therefore to examine, using revealed preference technique, the various policy options for meeting the demand for fuelwood and rural energy supplies in Hoima district, Uganda.

MATERIALS AND METHODS

Description of study area: The study site was Kigorobya sub-county, Hoima district (1°00'-2°00'N; 30°30'-31°45'E). The district covers an area of 59,327 km^2 of which 22,686 km^2 is occupied by Lake Albert. Forests constitute a relatively smaller portion of about 12% (7123 km^2) of the total area. The district generally has a pleasant climate with small variations in temperature, humidity and winds through out the year. Rainfall ranges from 700-1000 mm/annum and mean annual temperature is 28°C with a range of 15-32°C.

Vegetation is very varied ranging from medium altitude moist forests through forest/savannah mosaic, swamp to post cultivation communities. Grass savannah is derived from forests, wooded savannah and thicket by repeated cultivation, grazing and burning. They occur in sub-counties of Buseruka and Kigorobya on off-shore tips of Lake Albert. The soils are mainly weathered basement, yellowish-red clay loams on sedimentary beds. There are also complex formations of the pre-cambrian age, which consist mainly of metamorphic and igneous rocks, largely composed of gneisses and granites.

Hoima district has a total human population of 340,000, with a high population density (> 300 persons km^{-2} in the west and approximately 200 in the east) (UBOS, 2002). Subsistence agriculture has remained the major economic activity contributing 48% on districts gross production. Approximately 83% of the population depend on agriculture for their livelihood with a small landholding size (0.48 ha family^{-1}). Given the limited opportunities for rural employment and low agricultural production, a few households have migrated to other adjoining districts. Susceptible to accelerated soil erosion and declining soil fertility, the sources of livelihood of the rural people have been threatened. Fuelwood is an important form of rural energy in Hoima district, nearly 97% of all household cook with fuelwood at least part of the time. The average household fuelwood consumption is 65 kg/week/family; in addition, rural households burn small amounts of charcoal and agricultural residues (Jacovelli and Caevalho, 1999; Kalumian and Kisakye, 2001).

Data collection and analysis: The field work was conducted during September-December, 2004 and 3 data collection methods were employed, namely surveys, open-ended interviews and review of project records and other published literature. The interviews were combined with simple Participatory Rural Appraisal (PRA) tools in order to ease the acquisition of information (Dovie *et al.*, 2004). Data collection emphasised household approaches rather than community level enumeration because fuelwood use takes place at the household level. The survey included 120 rural and urban households (63% sampling intensity). Another sample consisted of 20 cottage industry firms including bricks burners, tobacco curers, bakeries, restaurants, producers of sugarcane molasses, ceramics and pottery.

The study was based on data from a large survey of the demand for fuelwood and an analysis of options for meeting that demand. This use of large-scale survey was intended to determine the magnitude of fuelwood demand and the various factors that affect this demand. The demand survey invested consumption and uses of wood and charcoal fuels. These questionnaires elicited data on time spent in collecting firewood, proportion and source of firewood collected and proportion grown for own use. All the amounts of fuelwood were converted into actual weights because of lack of standardization of commonly used units.

Special emphasis was placed on preferences for the types of woodstoves and attitudes toward tree growing in order to develop policies directed at solving the wood fuels shortage. Some questions in the consumption survey also were directed toward consumption of other biomass fuels such as bamboo, rice husks, bagase and animal dung, as well as conventional such as kerosene, gas and electricity, to determine the extent to which these currently serve as substitutes for fuelwood.

Some fuelwood was collected by household members and some was bought in the market. Thus, market prices were available for valuing purchased fuelwood, although there was considerable variation in prices. However, a shadow price was estimated for collected, own-consumption fuelwood. The shadow price of fuelwood was derived using on revealed preferences method. We assumed that the value people place on wood fuel was at least equal their costs in collecting it as a free good, including travel time to collection sites and related transportation costs. Thus, transport time was valued at its opportunity cost in terms of foregone labor. Based on relative productivity and opportunity cost factors, a child's labor time was valued at one-half of the adult wage rate. In cases where there was extensive surplus labor due to underemployment or unemployment, the opportunity cost of labor time for collecting fuelwood was low. Transport costs were very low because family members

Table 1: Farm inputs of tree farming enterprise in Hoima district, Uganda (ha^{-1})

Operation or activity	Year	Labor requirement (man-days equivalent)	Input cost (Ushs)
1 Land clearing and preparation	1	35	
2 Seedlings (5,000 ha^{-1}, spacing: 1 x 2 m	1	-	86/seedling
3 Lining, digging, and planting seedlings	1	35	
4 Seedling replacement in year 2 based on 20% mortality in year 1			86/seedling
5 Replanting seedlings	2	5	
6 Fertilizer purchase	1 2		18,500 267,000
7 Fertilizer application	1 2	7 3	
8 Weeding and brush removal	1 2	10 13	
9 Maintenance	3-8	4	
10 Weeding and single coppice tending	5	4	
11 Harvesting	5-9	1.6/solid m^3	
12 Social cost of loan administration	1		48,000
13 Social cost of nursery establishment	1		3,200,000
	2		65,000
14 Social cost of collecting loan payment	5, 6, 7, 8		2,700

Labour requirements

Year	2	3	4	5	6	7	8	9
Man-days	21	4	4	156	4	4	4	148

Note: Exchange rate at survey time (2004) US$1 = Ushs 1980

travelled on foot to collect fuelwood unless there were relatively affluent and grow fuelwood on lands their own.

Conceptual framework: Wood fuel use statistics often greatly underestimate true consumption because most wood is gathered directly by users rather than being purchased. The shortage of wood fuels leads to economic welfare looses, as well as environmental degradation from over-cutting of trees.

Fuelwood was measured by weight (in kilograms). Villagers would normally harvest and collect fuelwood in head loads, pick-up vehicles and wheelbarrows. Households provided their wood consumption data their records and observations. The mass of a wheelbarrow load (standard measure of pricing) of fuelwood was approximately 45 kg.

Based on the survey results and other secondary sources, the following data and assumptions were used: Discount rate is set at 15% per annum; pure stands yielded about 123 m^3 ha^{-1}; rural adult wage rate is Ushs. 3,700 day^{-1} (8 work h day^{-1}; child labor is rated half the adult wage; proxy market values were estimated in case of wages in-kind); Kerosene stoves cost Ushs. 17,000; improved woodstoves cost Ushs. 20,000; domestic kerosene costs Ushs. 1,200 (these prices exclude periodical taxes and subsidies). Tree-farming inputs and costs based on survey data are presented in Table 1.

Fuelwood consumption is related to food consumption, in that for each unit of consumed food, a certain amount of energy is needed for preparation. The income and availability of fuel determine the actual wood use. The abundance of fuel increases fuel consumption while at the other hand a shortage will be compensated through a rational use or a decrease of use. The high incomes result in more consumption pattern of food, which need more energy for food preparation, in cases where households have substantial incomes the wood energy is substituted by commercial fuel sources.

The shortage of energy (fuel) is an incentive to plant trees on the agricultural fields, the prices and time to gather the wood, increases so much that the production of wood can compete with the production of food. The production of wood will decrease as a result of over-cutting. As explained in the other parts of this study, there are other motivations to plant to maintain the trees on the agricultural lands. In fact it would be more meaningful if a comprehensive evaluation of the performance of the on-farm forestry practices in the region could be completed, however, such a deeper evaluation would require land resource auditing, planning and environmental impact assessment and yet this study was constrained by the limited time and research funding, therefore several important aspects of the social-cultural and ecological nature could not be studied exhaustively.

Model data collection: The input for the bio-economic model comprising of socio-economic, ecological and vegetative biomass data were collected for the Hoima district by using appropriate sampling methods.

Both primary and secondary data (on prices, growth rates, human and animal population, vegetative biomass, past soil erosion rates, etc.) were collected from published records and through a socio-economic survey, using both participatory and interview methods. Detailed input-output data on crops, livestock and livestock products and forest activities (fuel wood collection and timber harvesting) were collected for the modelling exercise. It should, however, be mentioned that these data were obtained from only the inhabited portion of the watershed.

Bio-economic model was calibrated and run for a period of 20 years (2004 to 2024) under four alternate scenarios, namely, Base Scenario (BASE) run with the existing data, introduction of improved agricultural Technology (TECH) where yields of major crops, namely, paddy, maize and wheat were assumed to increase by 5% per year, reduction in Population Growth (POPG), where population growth rate is halved to 0.67% per annum and increase in the prices of major agricultural crops (PP), where prices for paddy, maize, wheat were assumed to increase by 5% per year.

RESULTS AND DISCUSSION

We estimated the value of fuelwood based on the labor time used to collect it. This was probably a minimum value as it did not include any scarcity value of fuelwood nor was is it related to the cost of the next best alternative fuel source. The average family surveyed collected 65 kg week^{-1} of fuelwood and used both adult and child labor. Valuing the time spent in fuelwood collection by the appropriate wage was equivalent to Ushs 2,750 which is approximately Ushs. 42 kg^{-1}. In terms of solid, air-dried fuelwood, this is equivalent to Ushs. 32,340 per m^3 (770×Ushs. 42). We assumed that there were alternative productive opportunities available for adults and children at the specified wage rate. If such opportunities were not available or the true opportunity costs were higher or lower than assumed, the shadow price of fuelwood changed.

The mean annual consumption of fuelwood was estimated at 4,400 kg which implies that per capita fuelwood consumption in the study area was approximately 330 kg user^{-1} household, or 53 kg/capita/annum. The mean fuelwood consumption rate of 692 kg capita^{-1} of wood/annum. In this study compares satisfactorily with figures elsewhere, for example, in South Africa as summarized by Shackleton (1998), who reported a mean fuelwood consumption of 687 (49 kg/capita annum) across 12 studies. Kalumian and Kisakye (2004) reported a lower consumption figure of 485 kg capita^{-1}. On a household basis, the amount of 4,400 kg/household/annum for Hoima is comparable to 4,300 kg in parts of South Africa (Dovie *et al*., 2004). This similarity in figures represents a source of vital information for comparing analyses of the fuelwood crisis and comparing adaptive management strategies towards sustainable management of forests and allied natural resources.

Tree-farming option: Tree farming was evaluated using an Net Present Value (NPV) approach. The costs of tree-farming were derived from the data given in Table 1. The various activities occurred in different years which resulted into different labor requirement and consequently varied costs and benefits for each year. For each activity, the labor requirements were converted to Uganda shillings and input costs (seedling, fertilizer) were also calculated.

Social costs were calculated from activities 12, 13 and 14 in Table 1. Similarly, input (material) costs were only seedling and fertilizer and all these costs occurred in years 1 and 2. Labor occurred in all years. In year 1, labor is required for land clearing and preparation (35 man-days), seedling planting (35 man-days), fertilizer application (7 man-days) and weeding and brush removal (10 man-days). This adds to 87 man-days valued at Ushs. 321,900 (87×Ushs. 3,700). In the succeeding years the following amount of labour is required.

The fuelwood was harvested in years 5 and 9 and it was discovered that pure stands yielded about 123 m^3 ha^{-1}; but, even with replanting, there was some mortality (approximately 25%). Therefore, the fuelwood harvest total was estimated at 92.25 m^3 (123×0.75). Harvesting required 1.6 man-days of labour per m^3; total labor required was thus 147.6 man-days (92.25×1.6). The man-days were then converted to Uganda Shillings at the stipulated wage rate, Ushs. 3,700 day^{-1}. We, however, recognize that no costs were assigned to tools used for harvesting or fieldwork.

The production capacity of most public forest lands is threatened by conversion to non-forest land uses. Second, the future demand for fuelwood will rise in response to population growth and increases in tobacco production. Third, there exist several plans in Hoima district for the establishment of large-scale projects such as charcoal-using iron blast furnaces, which will increase the demand for fuelwood tremendously (MWLE, 2002b). As planned, these projects are assumed to provide their own wood energy resources from associated plantations. Because the slow progress in planting and high rates of mortality, however, it seems reasonable to expect that commercialisation will result in at least some degree of substitution of fuelwood from the existing traditional fuelwood sector to this new modern fuelwood sector (Jacovelli and Caevalho, 1990).

The benefits of fuelwood farming are the value of wood produced (direct benefits) and environmental quality benefits of maintaining land under forest cover or reforesting land. Such benefits may include reduced erosion or increased forest production from protected forest lands previously used for fuelwood collection. The direct benefits occur in years 5 and 9. Each, year, 92.25 m^3 of fuelwood are harvested. Converted to kilograms and valued at fuel wood's shadow price, the value per hectare in each year is Ushs. 3,030,000.

Table 2: Direct costs and benefits from tree farming (Ushs ha^{-1})

	Operating costs				Fuelwood	
Year	Labour	Materials	Social cost	Benefits	Net benefits	NPV (15% discount rate)
1	321,900	442,700	208,00	0	-764,600	-114,690
2	77,700	102,000	36,300	0	-216,000	-32,400
3	14800	0	0	0	-14,800	-2220
4	14800	0	0	0	-14,800	-2220
5	577,200	0	14,800	3,030,000	2,438,000	365,700
6	14800	0	14,800	0	29,600	4440
7	14800	0	14,800	0	29,600	4440
8	14800	0	14,800	0	29,600	4440
9	547,600	0	0	3,030,000	2,482,400	372,360
Total	1,598,400	544,700	95,500	60,60,000	3,999,000	599,850

When net benefit in each year are discounted at 15% and summed, the NPV is found. In this case, it is Ushs. 599,850 ha^{-1} (Table 2). If the environmental quality benefits are included, the positive NPV becomes even larger. The environmental quality benefits consist solely of effects on land quality, valued at Ushs. 65,700 ha^{-1}. These benefits begin in year 2 and continue for each succeeding year. Discounted, these benefits increase the NPV by Ushs. 256,000 for a total NPV of Ushs. 3,999,000.

If only direct costs and benefits are included (Table 2), the NPV at a 5% discount rate is Ushs. 2,302,000 ha^{-1} of tree farms. With a 20% discount rate, it is Ushs. 460,000 ha^{-1}. At higher discount rates, the NPV will turn negative since the large initial expenses involved in tree stand establishment outweigh future benefits. The inclusion of other environmental benefits not quantified in this study would increase the NPV. Since most of the costs are incurred in planting: Additional coppice rotations (> 10 years) would increase the NPV because the harvest benefits are much larger than the costs of harvesting and weeding.

Given that over 85% of Uganda's population is rural (UBOS, 2002), fuelwood contributes to the livelihoods of the majority of Ugandans. Moreover, the poorest 35% of the population who live below the poverty line cannot afford buying fuelwood and hence rely heavily on collecting from the natural forests and trees to meet their energy requirements. The use of firewood depends more on the locality than on the level of household income, as the households in urban and peri-urban communities tend to prefer charcoal for cooking. This is because urban consumers find charcoal to be a cheaper source of fuel. In 2000 for example, the cost of cooking with electricity was roughly double that of cooking with charcoal and paraffin was about 3-4 times higher than that charcoal (MWLE, 2002a).

Improved woodstove option: A new woodstove design could improve fuel efficiency from 8-20% (MoEMD, 2002). Fuelwood consumption would therefore decrease since now 0.4 as much wood would supply the energy required to cook a given amount of food. The wood fuel savings is Ushs. 40 kg (0.6×65 kg). At a price of Ushs. 43 kg^{-1}, this is a saving of Ushs. 1,700 $week^{-1}$ (Ushs. 89,900 $year^{-1}$). Over a 9-year period the annual benefits of the new stove are Ushs. 89,960. The costs are the Ushs. 21,000 purchase price and Ushs. 25,000 for administrative costs. Both costs occur in year 1. The NPV over nine years at a 15% discount rate is about Ushs. 390,000. The introduction of improved stoves appears to be very attractive based on fuel savings alone. If the new stove's fuel efficiency were only 10%, the annual fuel saving falls to Ushs. 36,000 and the first-year cash flow is negative. The NPV over nine years falls to Ushs. 8,800 which is one third of the previously calculated amount.

We assumed that the decreased fuelwood demand reduces the cutting of forests for fuelwood production, we therefore used the previously assigned values these benefits (Ushs. 65,700 ha^{-1}) and determine what part of a hectare would not be cut if the new stove tree farming areas ($25m^3 \times 770 kg\ m^{-3} = 19{,}250\ kgha^{-1}$), the annual wood fuel benefits of about 2,111 kg are equal to 0.11 of an hectare or about Ushs. 7,400 in annual environmental benefits per improved woodstove. Other studies (Moyini and Muramira, 2002; Tumuhimise and Kutesakwe, 2003), have, however, proved that natural forest yields are substantially lower than managed tree farms and therefore the environmental benefits from each kilogram of wood saved are greater. In addition, there are other benefits from each kilogram of wood increased production of other forest products when fuelwood needs are reduced. If the natural forest's annual increment were only $5.75m^3\ ha^{-1}$, the environmental benefit would be Ushs. 31,000 $year^{-1}$. At a 15% discount rate, the total NPV for year 2-9 amounts to Ushs. 121,000.

Kerosene stove option: The kerosene stove is assumed to eliminate the need for fuelwood; 65 kg valued at Ushs. 300 $year^{-1}$. Annual fuel costs are Ushs. 134,900 (2.25 L×1153.5×52 weeks). In addition, the stoves costs

Ushs. 17,200 and there is a one time administrative cost to the government of Ushs. 24,700 per stove adopted. The direct benefits and costs are very close. In the first year, net benefits are negative Ushs. - 32,350. In subsequent years, the net benefits are marginally positive (Ushs. 8,800). If environmental benefits are included, however, this option becomes more attractive. Reasoning as before for the woodstove example, the annual land quality benefits would be Ushs. 11,360 ha^{-1} which increased the NPV by Ushs. 44,400.

We faced problems associated with the option to use commercial fuels such as kerosene. This is because Uganda imports most of its kerosene using scarce foreign exchange. The price of kerosene has greatly increased therefore, making the fuelwood the most feasible alternative for the rural poor households. A new stove may last longer than nine year hence increasing the NPV or it may require repairs and replacement parts whereby lowers the NPV.

CONCLUSION

This study has illustrated how economic valuation techniques can provide additional information to a decision maker on the various options available. The tree-farming illustrates one of the possible approaches to how the supply of fuelwood (energy) can be changed, while the woodstoves and kerosene substitution examples are policies that would reduce the demand for fuelwood. The amounts of firewood sold depend on the uses, the location and the sources.

Based on these findings we can not claim that tree-farming is definitely better than introducing new woodstoves. Both options would appear to be attractive and, if implemented, would both increase fuel supply and decrease demand. This could help to alleviate the rural energy shortage and take some pressure off existing protected forest areas. In practice, both types of options have been hindered by implementation problems in many areas.

Our results are very sensitive to the imputed shadow price of fuelwood. If this shadow price were greatly different from the Ushs. 44 kg^{-1} calculated, the different options might appear more or less attractive. The only other option discussed in this study that appears unattractive is the use of kerosene stoves. High fuel costs make this option economically unattractive although some people will opt for kerosene stoves because of convenience and availability.

Given the complicated interactions between humans, forest lands, land-use practices and fuelwood collection, it was difficult to state precisely that a given percentage decrease in fuelwood collection resulted in a proportionate improvement in forest land cover or decrease in deforestation. Regardless of the exact environmental consequences of deforestation, there is general agreement on several facts: there is a rural energy shortage; fuelwood is the most common rural fuel and its use will increase for both continued household use and for new commercial purposes, deforestation has decreased the production capacity of fuelwood and reforestation of denuded lands may assist to ensure a future resource base for fuelwood production, as well as to control environmental degradation.

We recommend that further, in-depth analysis should be done to see how the results change given different assumptions about other variables such as the price of kerosene. Tree farm yields, opportunity costs of labor and expected service tenure of new stoves.

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