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WOOD ENERGY AND PRESERVATION OF WOODLANDS IN SEMI-ARID DEVELOPING COUNTRIES

The Case of Dodoma Region, Tanzania*

Julia C. ALLEN

University of California, Santa Barbara, CA 93106, USA

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At present little land and labor resources are expended on energy production, but the woodlands in Dodoma are disappearing, causing villagers to save time by switching from fuelwood collected on foot to charcoal shipped in by truck. Results of a linear program show that if the costs of growing the wood for charcoal are counted the switch to charcoal saves time only in areas where population is relatively dense and natural woodland remote. Woodland preservation in Dodoma will require more plantations, increased plantation productivity, improved efficiency of charcoal kilns or stoves, and ultimately a switch to some other fuel than wood.

1. Introduction

Rising population, a high percentage of population reliant upon wood for fuel, and a decreasing area of forest to supply wood are three features typical of almost all developing countries. The interactions between wood energy, deforestation, and economic development have attracted increasing attention over the last decade [U.S. Congress, OTA (1983), U.S. Interagency Task Force on Tropical Forests (1980), FAO/UNEP (1982a, b, c)]. While the linkages are complex, it appears that economic development based on continued reliance on wood energy is basically at conflict with the maintenance of environmental quality and perhaps even agricultural productivity [Hufschmidt et al. (1983), Eckholm (1982)]. Developing countries are faced with a two-edged sword: if wood cutting continues at its present rate, most natural forests will sooner or later disappear; but if forests are protected from cutting, or if they disappear due to overharvesting, poor rural and urban populations will be forced to shift to other, perhaps more costly, sources of energy.

Until recently wood has been the cheapest and most abundant fuel in

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developing countries. However, the costs of wood fuels appear to be increasing rapidly due to cumulative overharvesting and clearing, making wood more scarce and difficult to obtain. At the same time deforestation is apparently contributing to the costs of other economic activities, such as farming, by causing erosion, declining soil fertility, reservoir sedimentation, and flooding. Despite these increased costs to the economy as a whole, it is often assumed that the best energy policy for a developing country is continued reliance on wood fuels, especially given the high foreign exchange costs of imported petroleum-based fuels.

The semi-arid Dodoma region (fig. 1) in Tanzania is typical of areas in many developing countries. The current pattern of wood production and other land use activities in Dodoma have reduced the area of natural woodland. Many of the urban poor in Dodoma rely on charcoal produced in the natural woodlands and transported to urban markets by otherwise empty trucks returning from deliveries in the rural areas [Allen (1983)]. Thus the current system of wood fuel supply to urban areas in Dodoma and elsewhere in Africa makes use of underutilized truck capacity, but has contributed to

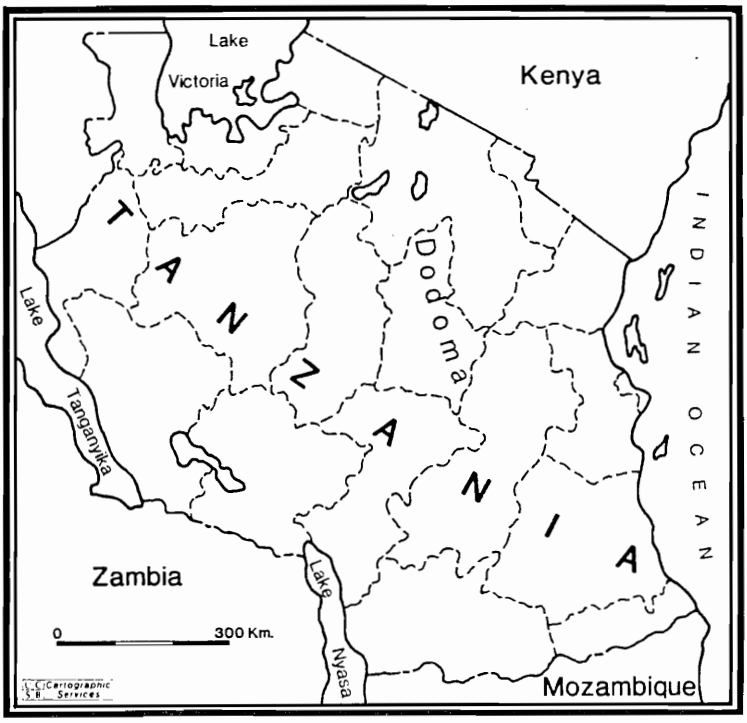


Fig. 1. Dodoma and the other regions of Tanzania.

the gradual disappearance of woodland in circular areas around the cities. This pattern is obvious from aerial photographs of Dodoma region over the period from 1956 to 1978. Wood availability in deforested areas is consequently limited by the capacity to transport wood fuels from other areas, and by the rates of growth that can be attained either by regenerating natural woodland or by so-called fast-growing exotic tree species. In Dodoma, the decline of natural woodlands, the increasing concentration of population, and the lack of alternatives to wood as a source of fuel have created a situation in which plantations of fast-growing exotic tree species,[1] and management of existing natural woodlands are necessary, both to prevent complete deforestation and to meet fuel demands. Plans to produce wood for fuel on local plantations are being implemented by the Forest Department, while other projects are establishing forest plantations to counteract soil erosion in the region [Mnzava (1980), Skutsch (1983)].

2. Method

2.1. Forest management models

The use of plantations for sustained yield of wood fuels is quite new in most developing countries [Earl (1975), Schmithusen (1983)]. Numerous models have been designed to guide plantation management over the past several decades, including single objective linear programs [Johnson and Scheurman (1977)], goal programming [Chang and Buongiorno (1981)], dynamic programming [Chen et al. (1980), De Kluyver et al. (1980)], mixed integer programming [Weintraub and Navon (1976)], and optimal control [Lyon (1981)]. However, these models are not readily applicable to wood fuels production in developing countries, which is complicated by the common property nature of the forest [Hardin and Baden (1977), Thomson (1981)], rising costs of wood harvest with cumulative overharvesting [Levhari and Liviatan (1977)], and the spatial variability of wood-producing areas. This study used multiobjective programming to compare several alternative policies to manage the transition from clearing of old-growth natural forests[2] to plantations, which are a sustainable source of wood fuels. Common property woodland will be overharvested and will retreat; this phenomenon can be represented in the model by increased transport costs of wood fuels with cumulative woodland clearing. Spatial variability was represented by multiple wood-production sites.

[1]An exotic tree species is one which is not native to the region where it is planted.

[2]An old-growth forest is one which has been relatively undisturbed for at least several decades, if not centuries. In contrast, regenerating forests are forests in the early stages of succession following clearing.

3

2.2. Multiobjective program

The multiobjective problem with three objectives can be written as

$$\begin{aligned} &\text{Minimize} \quad \vec{Z}(\vec{x}) = z_1(\vec{x}), z_2(\vec{x}), z_3(\vec{x}), \quad \text{s.t.} \\ &g_i(\vec{x}) < 0, \qquad i = 1,2,\ldots,m, \\ &(\vec{x}) > 0, \end{aligned} \tag{1}$$

where $Z(x)$ is the vector of objectives and $g_i(x) < 0$ and $x > 0$ are the constraints.

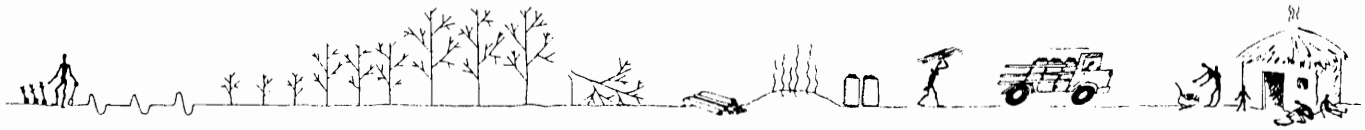
The multiobjective linear program calculated the activities necessary to perpetuate the present wood fuels consumption pattern with strictly limited cutting of old-growth natural woodlands in Dodoma. Given a limited endowment (50,000 ha) of old-growth woodland, the model solved for the drawdown of this stock and the simultaneous buildup of reserves of newly planted forests. The program scheduled tree planting and harvesting, decided on fuelwood/charcoal production ratios, and determined the distribution of fuelwood and charcoal to meet wood fuel demands in Dodoma over a five-year period of transition to managed forestry. The model was also solved once with an unlimited endowment of old-growth woodland to illustrate the continuation of the current system of cutting with no replanting of trees. Given projected fuel demand, the linear program calculated the minimum cost combination of activities required at each stage of wood fuels production, answering the questions:

(1) How many hectares of each tree species should be planted at each site?
(2) How long should the trees grow before they are harvested?
(3) How much of the wood produced should be burned as fuelwood, how much converted to charcoal?
(4) Which villages can collect wood on foot from nearby plantations, and which should receive shipments of charcoal?

The model is illustrated in fig. 2 and described in detail in the appendix.

Most forest management models consider only the objective of wood production [Johnson and Scheurman (1977), Chen et al. (1980), Lyon (1981)]; but other possible objectives might be wildlife or watershed protection, conservation of species-rich forest, or reduction of labor expended in energy-related activities [Clawson (1975)]. This model has three objectives: efficient wood production, efficient labor allocation, and preservation of 'miombo' woodland.

Wood production and watershed protection are stated objectives of the Tanzanian Forest Department [Mnzava (1980)]. A difficult issue arises in defining the wood production objective for Dodoma. Standard forest



How much land should be planted with which species at each site ?

How long should the trees grow before they are harvested ?

How much of the harvested wood should be burned as fuelwood, and how much should be converted to charcoal ?

Which villages should collect fuelwood on foot, and which should receive shipments of charcoal ?

DECISION VARIABLES L_{iukt} $EMPTY_{it}$ H_{iukt} X_{ijt} Y_{ijt}

INDICES i = index of sites; u = index of age classes; k = index of species; t = index of years; j = index of fuel-consuming villages

UNITS hectares hectares m^3 tonnes

CONSTRAINTS continuity capacity planting reserves harvests exceed shipments shipments meet demands

OBJECTIVES 1. Minimize cost of labor for planting, maintenance, and harvest of trees 2. Minimize labor for transporting fuel from plantation to village

PARAMETERS

CAP_{it} = land available for trees at site i in year t (ha)

ℓ_{iukt} = labor required for planting, maintenance, and harvest of trees (man days/ha)

g_{ik} = growth rate of species k at plantation site i (m^3/ha/yr)

α = charcoal kiln efficiency (m^3 wood / tonne charcoal)

β = combustion efficiency $\left(\frac{\text{Btu/tonne charcoal}}{\text{Btu}/m^3\text{ wood}}\right)$

$DEMND_{jt}$ = demand for fuel at village j in year t (m^3 wood)

t_{ij} = time required for person from village j to collect a bundle of fuelwood from plantation site i (man days)

t'_{ij} = time required to transport a sack (gunia) of charcoal from plantation site i to village j (man days)

Fig. 2. Stages of wood fuels production and forest management activities: land preparation and tree planting, growth, harvest and wood conversion to fuelwood or charcoal, and transport and distribution of wood fuels.

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5

management models maximize forest value based on stumpage price[3] but stumpage prices are extremely difficult to estimate in a context in which wood is collected freely by manual labor and little wood is bought or sold, as is the case in Dodoma and most parts of developing countries. In fact the value of the natural woodland under such circumstances is ill-defined. One approach to valuing the woodland is to estimate the opportunity cost of producing the wood in some other way, such as in plantations, and to compare this cost to the cost of wood production under the current system; this is the approach taken in this paper. The wood production objective minimizes the total cost of planting, growing, and harvesting wood from old-growth woodland, regenerating woodland, and plantations [see appendix, eq. (A.8)].

The second objective, labor saving, was formulated in recognition of the fact that people in developing countries walk long distances to collect wood. It is frequently implied that energy policies should attempt to reduce the amount of labor time spent collecting wood, based on the idea that labor freed from this chore could be used more efficiently elsewhere in the developing economy [Smith (1981), Eckholm (1975), World Bank (1978)]. The second objective minimizes fuel transport time and thus mimics the current trend of increased charcoal consumption associated with deforestation. This objective represents charcoal as a less costly fuel for urban areas because it has more energy per unit volume and therefore it takes less time per unit delivered heat to transport than fuelwood, while at the same time it uses otherwise empty truck capacity [see appendix, eg. (A.9)].

The third objective, preservation of indigenous 'miombo' woodland, was considered to be so important that it was expressed as a constraint. Miombo woodland is the dominant natural vegetation type in Dodoma region, and is an important source of wood, wildlife habitat, and watershed protection. Miombo is the name given to the extensive woodland type of the Zambezian domain dominated by tree species of *Brachystegia* spp. and *Julbernardia* spp. [Brenan (1978), White (1965)]. It occurs generally within the Sudano–Zambezian phytogeographic region, which encompasses the large tract between the equator and the Sahara as well as parts of equatorial East Africa. The miombo woodlands are floristically and to a lesser extent structurally quite different, however, from the Sahelian and Sudanian woodlands, which are characterized by various *Acacia* spp., *Isoberlinia doka* and *Khaya senegalensis*, as well as from Kenyan savanna woodlands of *Acacia* spp., *Commiphora* spp., etc. The Zambezian domain, which includes miombo, is much richer in species (>330) and has a higher rate of endemism (65 endemic genera) than the other domains of the Sudano–Zambezian region.

[3]A stumpage price is the value of the standing timber in the forest net of harvest, transport, and processing costs.

6

Miombo is characterized by a single canopy formed by fairly regularly spaced trees with a basal area of 4–12 $m^2 ha^{-1}$ for trees [Malaisse (1978)] and 7–23 $m^2 ha^{-1}$ including shrubs [Boaler and Sciwale (1966), Strang (1974), Malaisse et al. (1972), Goffinet and Freson (1972)]. Miombo thus supports a woody biomass somewhat greater than savanna woodland but less than closed forest.

In addition to its woody biomass and relatively diverse species composition, miombo provides a habitat for a diverse fauna of mammal, bird and insect species [Malaisse (1978)]. Moreover, clearing of miombo and its replacement by grazed shrubland thicket or cultivation has been associated with greatly increased rates of erosion and sedimentation in Dodoma region [Rapp et al. (1972)]. While rapid rates of soil erosion have been measured on cleared or grazed plots in Dodoma and similar arid regions of Kenya [Rapp et al. (1972), Dunne et al. (1978), Christiansson (1981)], no plot studies of the rate of erosion under undisturbed miombo woodland have been undertaken. Given the geology and geomorphology of the region, background natural rates of erosion could be quite high. Moreover, no studies have separated the effect on erosion rates of simple wood cutting for fuelwood from that of grazing or clearing for other purposes. Given this uncertainty it would be misleading to impute increased soil erosion to wood cutting per se. More important is the fact that due to the extremely low organic matter content, few weatherable minerals, and deeply weathered soil profiles of most of the region [Allen (1983), Muir et al. (1957), FAO/UNDP (1983)], the loss of upper soil layers is likely to make little difference to soil fertility. Certain soils are more fertile, and more vulnerable, than others, but soil characteristics are site specific and not necessarily associated with the presence or absence of woodland. Consequently it was assumed that the principal reason for preserving the miombo woodland was to maintain the woodland resource for future generations; and because no quantifiable value could be ascribed to it, the woodland preservation objective was expressed as a constraint on the number of hectares that could be harvested [see appendix, eq. (A.5)]. Because the need for plantations is the direct consequence of protection of the woodland, their cost, estimated in the program below, is a measure of the cost of woodland preservation.[4]

2.3. Constraints

Constraints in the model represent all stages of wood fuels production, including land preparation and tree planting, growth, harvest and wood conversion to fuelwood or charcoal, and transport and distribution of wood

[4]This is the surrogate market price approach to environmental benefit estimation. See Freeman (1979) and Hufschmidt et al. (1983) for more discussion of methods for estimating the benefits of environmental protection.

fuels from the forest or plantation sites to the wood consuming villages [see fig. 2 and appendix, eqs. (A.1)–(A.7)].

2.4. Solution

The multiobjective program is solved by forming a weighted combination of objectives, or by optimizing one objective while all others are constrained to some value [Cohon (1978)]. In this case, objectives z_1 and z_2 were combined, and objective z_3 was expressed as a constraint,

$$\begin{aligned} &\text{Minimize} \quad w_1 z_1 + w_2 z_2, \quad \text{s.t.} \\ &g_1(\vec{x}) < 0, \qquad i = 1,2,\ldots,m, \\ &(\vec{x}) > 0, \quad \text{and} \\ &z_3(\vec{x}) < L, \end{aligned} \tag{2}$$

where $z_1(x)$ is the wood production objective, $z_2(x)$ is the labor saving objective, and $z_3(x)$ is the miombo woodland preservation objective; w_1, w_2 are the weights on objectives z_1, z_2, and L is the constraint on harvests of old-growth miombo woodland. Solutions to the model explored the tradeoffs between plantations of exotic species versus management of natural woodland, and the tradeoffs between charcoal and fuelwood production, emphasizing the differences between plans based on efficient plantation management versus plans based on a reduction of fuel transport labor.

2.5. Scenarios and sensitivity analysis

The linear program is based on constant factor relationships and linear production functions and does not incorporate factor substitution, price changes with time, economies of scale, or other adjustments to changing relative prices. While the system represented in the multiobjective program is intrinsically of limited flexibility, solutions to the model with different weighted combinations of objectives and different sets of parameters can illustrate in a preliminary way the effect of different assumptions on the solution value [Cohon (1978)]. To illustrate some alternatives to the present system of wood production in Dodoma, the linear program was solved using four sets of assumptions: (1) the current system, in which all wood is cut from old-growth miombo woodland, (2) a base case in which all wood is grown at currently attainable growth rates in regenerating natural woodland or plantations of exotic species, and charcoal is produced using current pit kiln technology, (3) an efficient kilns scenario which assumes that a doubling of current kiln or charcoal stove efficiency is attainable, and (4) a fast growth

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scenario which assumes that a tripling of the current growth rate of exot plantation species can be achieved. The model assumed that villagers a indifferent between fuelwood and charcoal, and scenarios of the mod illustrated possible technological responses to resource scarcity, such a switching from fuelwood to charcoal, or improving the efficiency of charco kilns. Note that an improvement in kiln efficiency has an equivalent effect t an improvement in the efficiency of charcoal burning stoves because bot reduce the demand for wood to make charcoal.

3. Data sources for model parameters

The model was solved given several sets of parameters. Paramete included:

- available land for plantations and miombo woodland,
- growth rates of plantations and miombo woodland,
- labor requirements for plantation establishment and wood harvest,
- time spent collecting fuelwood and transporting charcoal,
- kiln efficiency,
- relative heat content of charcoal to wood, and
- fuel demand [Allen (1983, app. A)].

The parameters in the model were based on data collected by the author i Tanzania and from other (often unpublished) sources collected as part of th ARDEN Energy and Development Program at Resources for the Future.

3.1. Available land and growth rates

The total area of Dodoma region is 41,176 km^2 [Mnzava (1980)]. Much o this land is unsuited for tree plantations, and much of it is unoccupie woodland presently harvested for fuelwood. It was assumed that 8000 km (19.4%) of Dodoma region is suitable for wood production of some kin (either regenerating natural woodland or plantations of exotic species) at fiv sites of 160,000 ha. each dispersed around the region [Allen (1983), FAO/UND (1983)].

Fuelwood plantations in Dodoma are all less than seven years old, dating from 1978 when the government began to encourage the establishment o small dispersed voluntary woodlots [Mnzava (1980)]. Almost exclusively exotic species are planted in plantations: *Acacia mearnsii*, *Cassia siamea*, *Eucalyptus citriodora*, *Eucalyptus maidenii* and other *Eucalpytus* spp., *Cupressus lusitanica*, *Schinus molle*, *Grevillea robusta*, *Delonix regia*, *Ceiba pentandra* (kapok), *Anacardium occidentale* (cashew), *Citrus* spp. (lemon, orange), and *Mangifera indica* (mango). Plantations of these exotic species in Dodoma have high mortality and slow growth rates due to lack of nutrients, excessive

or inadequate drainage, seedling predation by termites, low rainfall, and the long dry season [Allen (1983), Mnzava (1980), Skutsch (1983)]. Although exotic species achieve fast growth (up to $25\,m^3\,ha^{-1}\,yr^{-1}$) in plantations in the wet parts of Tanzania [Adegbehen (1982), Lundgren (1978)], plantations of *Cassia siamea* and *Eucalyptus citriodora* measured by this author in Dodoma were growing at only $3\,m^3\,ha\,yr^{-1}$ or less (see table 1).

Vegetation and land use maps, recent aerial photographs, and satellite imagery indicate that the remaining old growth miombo woodland is located in the remote parts of Dodoma region [Government of Tanzania (1976 a, b), Ministry of Lands (1956, 1978), NASA (1978)]. Aerial photographs for the 1956–1978 period show the disappearance of the woodland, partly as a result of cutting by rural people who produce charcoal for Dodoma town. Few growth estimates of miombo woodland are available because of the lack of annual rings in miombo species. The estimates available based on girth increments and other measures indicate that indigenous miombo woodland in Dodoma grows even more slowly than plantations, at as little as $1\,m^3\,ha^{-1}\,yr^{-1}$ [Boaler and Sciwale (1966), Mnzava (1980), Malaisse

Table 1

Estimated standing volume and growth rates (mean annual increment) of plantations of exotic fuelwood species in Tanzania. Average annual rainfall at Morogoro and Arusha sites is 1000–1200 mm; at Dodoma, 600 mm.

Fuelwood species	Basal area[a] Plot[b] (m^2)	Hectare[c] (m^2)	Height[a] (m)	Standing volume[d] ($m^3\,ha^{-1}$)	Age[a] (yrs)	Mean annual increment ($m^3\,ha\,yr^{-1}$)
Acacia mearnsii (Morogor region)	0.62	9.9	15	49.6	6 (14)[e]	8.3–3.5[e]
Eucalyptus citriodora (Dodoma region)	0.19	3.0	15	15.2	11	1.4
Cassia siamea (Dodoma region)	0.46	7.4	10	24.5	11	2.2
Cupressus lusitanicus (Arusha region)	1.27	20.3	18	121.9	14	8.7[f]

[a]Measured by the author.
[b]Basal area of 25 × 25 m measured plots.
[c]There are sixteen 25 × 25 m plots in a hectare.
[d]Assuming conical trunks, volume = 1/3 basal area × height.
[e]Calculated growth rate depends upon the age of the stand, but there was some confusion among villagers as to the date of establishment of this plantation.
[f]Growth could be as much as twice this rate, as mean annual increment was estimated from the remaining 35 of an original stand of 63 trees, 28 of which had been cut recently.

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(1978)]. Solutions to the linear program are sensitive to the relative rates of growth of plantations and miombo; therefore two different sets of growth rates were used to account for possible error due to the small sample size of growth estimates.

3.2. Labor requirements for plantation establishment and wood harvest

The analysis used domestic factor prices rather than world market prices or shadow prices to calculate the cost of wood fuels production.[5] According to Mnzava (1980) using data collected by the Forest Department of Tanzania, plantation establishment requires about 20 man days per hectare in nurseries and seed time, 45 days per hectare in land preparation, planting and refilling, and an additional 37 days per hectare per year in weeding and protection. Wood harvest requires an estimated five man days per hectare on woodland and plantation sites. Both men and women in Dodoma participate in tree planting, watering and weeding; only men harvest large trees, run charcoal kilns, and drive charcoal trucks; and predominantly women and children collect fuelwood on foot. The official daily wage paid to all men, women and children was 20 Tanzanian shillings per day (about $2.50) in February, 1982.

Charcoal-carrying trucks were estimated to cost $10,000 with a five-year lifetime, based on world market prices and taking into account distortions caused by fixed exchange rates, taxes, and tariffs as of February, 1982. Gasoline costs were estimated from domestic prices, which were fixed at 10 Tanzanian shillings per liter (about $5 per gallon) in February 1982. Improved charcoal kilns were estimated to cost $100 [Earl (1970)].

Constant returns to scale were assumed throughout. This is a weakness of the linear programming formulation; in fact economies of scale may develop as plantation and charcoal shipping operations expand. Future costs were not discounted, based on the rationale that the future costs of woodland and other public goods should not be discounted [Lind (1982)].

3.3. Wood prices and fuelwood collection time

No prices exist in Dodoma for fuelwood because it is not bought or sold. Charcoal prices reflect the cost of transport by truck and the market power of charcoal truck drivers rather than the value of the wood from which the charcoal is made. In fact, based on the author's spot market surveys in Dar es Salaam, Morogoro and Dodoma in 1979, 1981, 1982 and 1983, charcoal prices vary widely from season to season and from region to region. While

[5]This practice incorporates existing distortions in the economy but illustrates the choices open to the Forest Department or to individuals living in Dodoma region, for whom factor prices are given.

average charcoal prices increased steeply (approximately doubling each year from 1979–1983), they followed the trend in the black market exchange rate for the Tanzanian shilling. Real fuelwood prices in other developing countries vary widely but on average did not increase from 1967 to 1979 [FAO (1981)]. Consequently it was not possible to infer wood value in Dodoma from prices, nor to use them as an indication of increasing wood scarcity.

In the absence of market prices for wood, the cost, or the value of the time spent collecting wood, is the best available indication of the value of the wood from natural woodland. Since wood is volumetrically the most important forest product, it follows that the present value of expected wood production, estimated by the value of the labor spent to collect it, is one estimate of the value of the woodland itself.[6]

In many areas of Dodoma wood is still relatively abundant and can be collected within 1–3 km of the village. Studies of fuelwood consumption in rural Tanzania and elsewhere in Africa and Asia indicate that women and children rarely walk more than 5–10 km to collect wood [Araya (1981), Digernes (1977), Ernst (1977), Hammer (1982), Malawi (1981), Openshaw (1980), Roy (n. d.); other unpublished sources cited in Barnes et al. (1982)]. Since women in Dodoma on average carry headloads weighing 20–30 kg and a household on average consumes 3400 kg yr^{-1} [Skutsch (1983)], two to three such trips a week suffice to meet a household's wood fuel demand. At a walking speed of 3 km hr^{-1}, three round trips take 3 to 20 hours a week, or <1 to 12.5% of each of three person's time in a 56 hour week. This estimate falls within the range of 6–60 hr $week^{-1}$ cited in time budget studies for Africa and Asia [Brokensha and Riley (1978), Mnzava (1980), Winterbottom (1980), other unpublished sources cited in Barnes et al. (1982)]. Using aerial photographs to estimate the average distance from each village to the nearest woodland, a fuelwood collection time was assigned to each village in Dodoma region, and used with the population of each village to compute the total amount of time spent each year collecting fuelwood in the region. The amount of time spent transporting charcoal was also estimated for each village.

3.4. Kiln and fuel efficiency

Charcoal is less efficient than fuelwood to produce but more efficient to transport. Currently in Dodoma charcoal is produced in pit kilns, or earth pits in which wood is piled and burned; in this system about 10 m^3 of wood are consumed to make one tonne (2000 kg) of charcoal. An improved kiln has been designed to increase charcoal production efficiency. This kiln consists of a steel ring about 1 m high and 2 m in diameter and can be rolled

[6]This is an application of the travel cost method for estimating benefits from forest preservation. See Freeman (1979) and Hufschmidt et al. (1983).

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easily from site to site. It has an efficiency approximately twice that of a p kiln (i.e., 5 m^3 wood tonne $charcoal^{-1}$) and can be produced for $100 [E (1970)]. Some of the energy lost in the conversion of wood to charcoal recouped when charcoal is burned, since charcoal has a heat content per u weight approximately twice that of dry wood [Hughart (1979)].

3.5. Fuel demand

Fuel demands were assumed to remain constant per capita but to gr with population. Rural population in Dodoma region is growing at abo 2% per year, and the urban population of Dodoma town, includi migration, may be growing at 5% or faster each year [Mnzava (1980)]. Ma studies have measured fuelwood consumption in rural areas in Africa a Asia [Arnold and Jongma (1978), other unpublished sources cited in Bar et al. (1982)]. The mean of these estimates is 1 m^3 $person^{-1}$ yr^{-1} in a ran of 0.5–40 m^3 $person^{-1}$ yr^{-1}.

The high rates of consumption occur in areas where wood is used f heating as well as for cooking, while the low consumption occurs in drough stricken areas such as Somalia. Skutsch (1983) found that each person in t small and median villages in Dodoma region consumes the Btu equivalent 1 m^3 solid air-dried wood per year. No studies of energy consumption Dodoma town are available; it was assumed from the author's observatio and informal interviews that electricity, kerosene and gas are used in le than 10% of urban households. In the runs of the model in which ki efficiency was 0.1 m^3 wood tonne $charcoal^{-1}$ (see below) each urban dwell was assumed to use the equivalent of 5 m^3 yr^{-1}; in the model runs with doubled kiln efficiency, 2.5 m^3 yr^{-1}.

4. Results

The solutions to the model illustrate different sets of planting, harves fuelwood and charcoal production and shipment activities of the variou wood production scenarios. Solutions to the model under different sets assumptions illustrate how changes in the growth rate of trees or t efficiency of kilns would affect the cost of producing wood. The solution expressed in physical units such as man days, trucks and kilns, were used t calculate wood production costs using prices of labor and materials and t current exchange rate (as of February, 1982). Based on the rationale that t future value of woodland and other public goods should not be discounted

[7]The higher the discount rate used for planning, the more short-sighted the policy is likely be. Wood fuels planning with a high discount rate leads to earlier forest exhaustion because discounts the value of old-growth forests to future generations. See Lind (1982) for a compl discussion of the use of discounting in energy resource policy decisions.

the undiscounted future costs of alternatives to deforestation were interpreted as the shadow price of wood and the social opportunity cost of the present wood production system in Dodoma.

Table 2 shows the total cost of wood production in Dodoma region estimated by the linear program under four different sets of assumptions. The table assumes that under the current system a person living in Dodoma region spends on average 3 to 5% of his or her time collecting fuelwood and transporting charcoal. All plantation-based alternatives cost more than the current system of deforestation, except the fast growth scenario, which is based on the asumption that trees could grow at three times the currently attainable rate in plantations.

Table 2 also shows the breakdown of total cost of wood production including fixed and variable capital costs (i.e., trucks, kilns, gasoline) and labor costs (on plantations or transporting fuel). Gasoline amounts to as much as 67% of the current estimated cost of wood production; most of the remaining costs of the current system are wages imputed to fuelwood carriers. However, if all wood were produced in plantations or regenerating woodland, the cost breakdown would shift dramatically, and plantation labor would account for from 34.2% (in the fast-growth scenario) to 62.8% (in the base-case scenario) of the cost of wood production. Gasoline and imputed wages for fuelwood carriers together would account for most of the remaining cost of wood production, irrespective of whether the linear program minimized plantation labor cost or fuel transport time.

Figure 3 shows the unit cost of energy production under each alternative forest management system. Charcoal is always a more costly fuel to produce than wood because of the large energy losses in the conversion of wood to charcoal using kilns. Under the current system charcoal and fuelwood are produced at less cost than they would be using plantations and managed natural regeneration. In other words, the most efficient of the alternatives explored is to produce wood energy by clearing old growth woodland. Deforestation would still be the least costly wood energy policy (excluding externalities) even if doubly efficient charcoal kilns were available or a tripling of current fuelwood plantation growth rates were achieved. A simultaneous doubling of kiln efficiency and tripling of plantation growth rates might allow wood energy to be produced at less cost than the current system, but this alternative was not explored in this study.

Charcoal is also more costly per unit than wood to produce in a system which attempts to minimize time spent transporting fuel (see fig. 3). In fact the total cost of meeting wood energy demand increases, at first slowly and then rapidly, as increasing weight is placed on the objective of minimizing fuel transport time (see fig. 4).

If wood energy demand as represented in the linear program is to be met by fuelwood plantations, land, labor, and capital resources will have to be

Table 2

Breakdown of costs of various policies to meet five-year wood fuel demand in Dodoma region, Tanzania ($ million and percent).

Scenario policy objective	Total cost ($ million)	As percent of total cost							
		Trucks[a]	Kilns[b]	Gasoline[c]	Subtotal	Plantation[d]	Truck drivers[d]	Fuelwood carriers	Subtotal
Current system	468.5[e]	3.2	—	66.8	70.0	—	1.4	28.6	30.0
	357.0[f]	2.8	—	58.5	61.3	—	1.2	37.5	38.7
Base case									
Minimize plantation labor	660.1	1.0	—	20.6	21.6	57.7	0.4	20.3	78.4
Minimize fuel transport time	1,109.4	1.3	—	27.8	29.2	62.8	0.6	7.5	70.8
Efficient kilns									
Minimize plantation labor	517.3	5.7	0.0	23.2	24.3	49.3	0.5	25.9	75.7
Minimize fuel transport time	1,093.0	2.0	0.0	41.0	42.9	54.3	0.8	1.9	57.1
Fast growth									
Minimize plantation labor	418.1	1.5	—	31.6	33.1	34.2	0.6	32.1	66.9
Minimize fuel transport time	932.5	2.4	—	49.9	52.3	44.3	1.0	2.4	47.7

[a]Assuming trucks are used at full capacity (350 days per year), cost $10,000, have a five-year lifetime, and a capacity of 0.25 tonne or five 50 kg bags of charcoal.

[b]Assuming efficient kilns are fired weekly (50 weeks per year), cost $100, have a five-year lifetime, and produce 1 tonne of charcoal per firing.

[c]Assuming trucks cover 240 km in a day with a mileage of 10 km per gallon at a fuel cost of $5 per gallon. Coverage, mileage and fuel costs from author's experience, February, 1982.

[d]Assuming plantation workers, truck drivers, and fuelwood carriers are paid a daily wage of 20 Tanzanian shillings at 8.06 shillings per dollar. Official wage and exchange rate as of February, 1982.

[e]Assuming charcoal is currently brought from forests 3/4 day away.

[f]Assuming charcoal is currently brought from forests 1/2 day away.

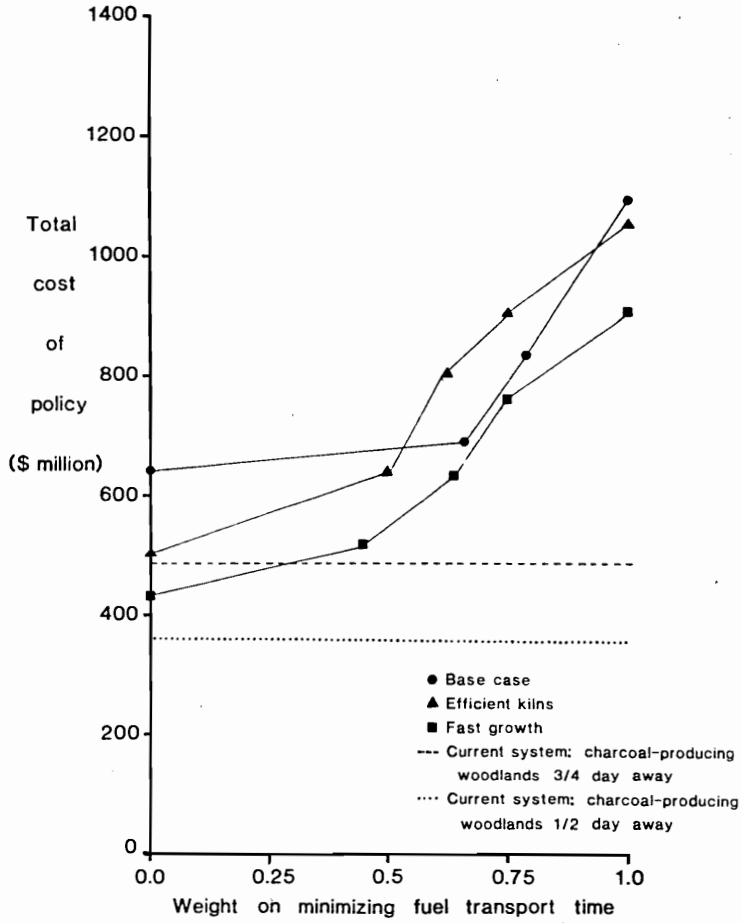

Fig. 4. Variation in cost of producing wood fuels on plantations and managed regenerating woodland with increased weight placed on the objective of saving fuel transport time.

to 29% of the labor force would have to go to work on plantations. However, the switch to plantations and managed regeneration would reduce capital costs of wood energy (gasoline, trucks and kilns) from an estimated 1.6 to 2.1% of 1980 Tanzanian GDP under the current system to 1.2 to 1.3% of 1980 GDP.

5. Discussion

At present only a small fraction of available land and labor resources is expended on energy production in Dodoma. In rural areas of Dodoma labor and land are the only cost of wood. Moreover, in the non-monetized

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13

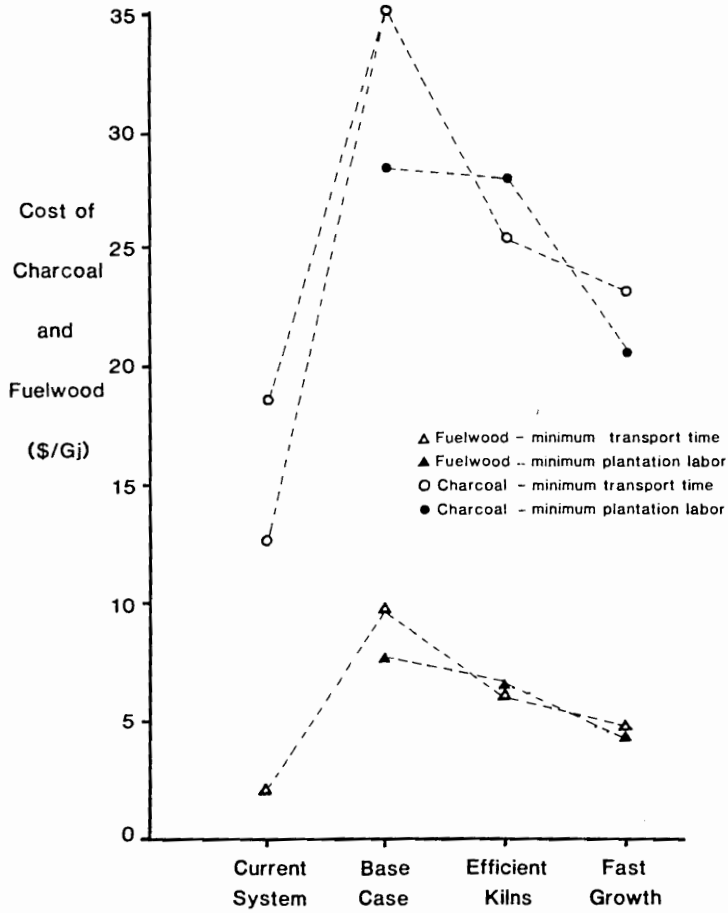

Fig. 3. Unit cost of charcoal and fuelwood under various forest management strategies.

shifted into the forestry sector. Under the current system, an estimated 2.2% of the land in Dodoma is old-growth miombo woodland that is being harvested each year (table 3). In order to preserve that woodland, approximately 20% (the average sum of the values in the first two columns of table 3) of the land in Dodoma would have to be converted to plantations or managed natural regeneration. Similarly, while approximately 6% of the labor force (3% of the population) is occupied transporting wood under the current system, an additional 6 to 15% of the labor force would have to be employed full time on plantations in order to provide the wood necessary to prevent any more cutting of old-growth woodland. If at the same time the policy attempted to relieve people of the burden of collecting wood on foot, 17.3

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14

Table 3

Average annual requirements of land, labor and capital for wood fuels policy as percentages of land and labor available in Dodoma region, and of 1980 gross domestic product (GDP), foreign assistance, and energy imports to Tanzania.

	Land as % of total land[a]		Labor as % of labor force[b]		Capital[g]		
	Woodland	Plantation	Plantation	Transport	As % of GDP 1980[c,f]	As % of foreign assistance 1980[c,f]	As % of energy imports 1980[e]
Current system	2.2[h,i]	0.0	0.0	5.9	2.1	44.6	64.5
	2.2[h,j]	0.0	0.0	5.8	1.6	34.0	49.2
Base case							
Min. plantation labor	8.2[k]	11.2	15.8	5.7	1.2	26.3	38.0
Min. fuel transport	2.4[k]	17.0	29.0	4.0	1.9	38.5	55.7
Efficient kilns							
Min. plantation labor	14.5[k]	4.9	10.6	5.7	1.2	25.0	36.0
Min. fuel transport	8.7[k]	10.7	24.7	1.3	2.3	47.5	68.7
Fast growth							
Min. plantation labor	1.5[k]	3.9	6.0	5.7	1.3	26.2	37.9
Min. fuel transport	6.3[k]	13.1	17.3	1.3	2.4	49.5	71.6

[a]Total land in Dodoma region in 41,176 km^2, of which 19.4% is assumed to be available for plantations, managed woodland or empty land.

[b]Labor force is 51% of the 1982 population, or 551,000. If children also work, percentages should be halved.

[c]1980 gross domestic product was $4,350 million.

[d]1980 foreign assistance (public and privately guaranteed medium and long term loans) to Tanzania was $210 million.

[e]Energy imports were approximately 30% of the 1980 value of merchandise exports ($508 million) or $152.4 million.

[f]GDP, foreign assistance, and energy import figures for 1980 were taken from World Bank (1983).

[g]Cost of trucks, kilns and gasoline; does not include wages.

[h]Area of old-growth miombo woodland harvested each year.

[i]Assuming charcoal is currently brought from woodlands 3/4 day away by truck from the city.

[j]Assuming charcoal is currently brought from woodlands 1/2 day away by truck from the city.

[k]Area of regenerating woodland managed each year.

subsistence economy of rural Dodoma, labor is the major item of household income available to be allocated. By this measure, the current wood energy system in Dodoma does not require a markedly larger share of household 'income' than is devoted to the procurement of energy in other countries, including industrialized ones [Cecelski et al. (1979)]. This fact indicates that wood is still relatively abundant compared to demand in Dodoma. In other words, despite the aridity of the region and the consequent limitation on wood supply from natural sources, fuelwood collection in Dodoma does not appear to be diverting significant amounts of labor from other productive activities.

However, the estimated capital costs (trucks and gasoline) of the current system in Dodoma region, which is only one of twenty regions in Tanzania, are a significant fraction of capital resources in the entire country. Moreover, the present system is depleting the forest resource by continued cutting at rates exceeding the natural regenerative capacity of semi-arid woodlands, and will therefore eventually impose on Dodoma residents the cost of a switch to another energy source. If that source is managed plantations, energy costs will become higher than they are under the current system; sooner or later a far larger share of resources in Dodoma will have to be expended in energy production than at present.

Because it is widely perceived that labor spent collecting fuelwood is relatively unproductive, the linear program was used to estimate the cost of reducing fuelwood collection time. At present in Dodoma fuelwood is more labor intensive than charcoal or any other fuel and therefore the switch from fuelwood to charcoal saves time. This is true only because (1) charcoal is transported by truck and fuelwood is not, and (2) charcoal is produced by cutting old-growth woodland (which is free) rather than by growing the wood in plantations and managed regeneration (which are not free). If the costs of growing the wood are counted, and if charcoal is the only alternative to fuelwood, the time people would save by switching from fuelwood to charcoal is more than compensated by the increased time they would have to spend growing the wood for charcoal. Initially savings in fuel transport time can be achieved with little increase in plantation costs, but after a certain point it becomes very costly to save more transport time. This fact reflects the limited flexibility of the wood production and transport system, especially in rural areas. Small, dispersed villages in general are more efficiently supplied by fuelwood than charcoal, no matter how far their occupants must walk to collect it. Switching to charcoal is advantageous only in areas where population is relatively dense, wood sources are remote, and wood is scarce.

6. Conclusion

The multiple objectives of environmental preservation, efficient labor allocation to energy activities, and continued use of wood energy will require

16

adjustments in the systems of energy production in Dodoma region. With current low plantation productivity, low kiln and stove efficiency, and high prices of substitutes for wood fuels, the cost of immediate and total preservation of woodland in Dodoma is prohibitively high. As woodlands continue to disappear, however, the cost of collecting wood fuels will increase, leading people to conserve wood and to substitute other fuels, such as wood grown in plantations. Skutsch (1983) found that villagers who perceived fuelwood scarcity and who had to walk significantly farther to collect wood were more likely to establish plantations. Since the present scale and productivity of plantations in Dodoma is quite low, villagers will need assistance in the form of subsidized research on fast-growing fuelwood species, improved site selection, and control of termites and other pests. They will also need marketable and efficient kilns and charcoal stoves. The feasibility of wood conservation based on widespread adoption of improved kilns or stoves in Dodoma remains highly speculative as there is no example in Tanzania to date of successful adoption and diffusion of an energy-efficient kiln or stove.

If the key to woodland preservation in Dodoma in the short run is more plantations, increased plantation productivity, and improved charcoal kiln or stove efficiency, in the long run with increasing population, woodland preservation is contingent upon a switch to some other fuel than wood. Without a major shift in energy consumption, in the long run continued population influx, complete reliance upon wood, and preservation of miombo woodland are mutually exclusive policies in Dodoma. This dilemma will be apparent earlier in the most arid, rapidly growing regions of Tanzania such as Tabora and Shinyanga, and later in the wetter, less rapidly growing regions such as Mbeya. Although complete preservation of remaining woodlands is not possible, the damage caused by the unavoidable loss of some of the miombo woodland could be reduced if the resource itself were better understood. A ranking of areas of miombo woodland according to their intrinsic value, based on species diversity, productivity, or aesthetic considerations, and a ranking according to the expected productivity of the cleared land based on soil erodibility or soil fertility could form the basis for a program of managed deforestation to minimize the losses from continued clearing of miombo woodland in Dodoma.

Appendix

The linear program uses the following notation:

L_{iukt} = the number of hectares of age class u, species k, standing at site i at the beginning of year t. (If $u=1$, then L_{i1kt} indicates the area that was planted at the beginning of year t and will have 1-year-old trees at the end of year t.);

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17

L_{iu^*kt} = number of hectares of old growth forest of species k at site i in year t;

$EMPTY_{it}$ = the number of hectares of land that are bare at site i in year t;

H_{iukt} = the number of hectares of age class u, species k, harvested at site i at the end of year t. (Trees of age class u are u years old at the end of the year, when they are harvested.);

H_{i*} = the number of hectares of old growth natural forest that is available to be harvested at site i over the planning period;

X_{ijt} = the number of cubic meters of wood produced at site i, and collected on foot by villagers in demand node j in year t;

Y_{ijt} = the number of tonnes of charcoal produced at site i, and shipped by truck to villages in demand node j in year t;

α = conversion efficiency of kilns (m^3 wood tonne charcoal^{-1});

β = relative heat content of charcoal to wood (Btu per tonne charcoal/Btu per tonne wood);

g_{ik} = growth rate of species k at site i ($m^3\,ha^{-1}\,yr^{-1}$);

CAP_{it} = available land at site i in year t;

$DEMND_{jt}$ = demand for fuel at node j in year t (m^3 wood);

l_{iukt} = cost per hectare of establishing and maintaining a plantation of age class u at site i at the beginning of year t (man days). Since regeneration is free, these costs only apply to the exotic species ($k=2$). When the problem was solved, all hectares allowed to regenerate were assigned a nominal cost of 1;

h_{iukt} = cost of harvesting a hectare of trees of either species of age class u at site i at the end of year t (man days);

t_{ij} = the average time spent by a villager living in demand node j to collect a m^3 of wood from production site i (days m^{-3});

t'_{ij} = the average time spent transporting a tonne of charcoal by truck from production site i to a village in demand node j (days tonne^{-1}).

where

i = the index of wood production sites, $i=A, B, \ldots, E$;

j = the index of wood fuel demand nodes, which are groups of villages, $j=1,2,\ldots,15$;

k = the index of species, $k=1,2$;

t = index of years in the planning horizon, $t=1, 2, \ldots, 5$;

u = index of age classes, such that a hectare of age class u contains trees that will be u years old at the end of year t, $u=1, 2, \ldots, u^*$. A hectare of age class u^* contains old growth trees.

To construct the linear program, these variables are combined in a set of logically consistent equations representing the processes and objectives of

18

wood fuels production. Two basic processes are illustrated: land allocation and wood distribution. Fig. A1 shows the allocation of land to growth, harvest and replanting. At the beginning of any year, a site may have trees of a number of different ages on it. By the beginning of the next year, some of those trees may have been harvested, and some of that bare land replanted. This process is represented by five constraints,

$$L_{iukt} - L_{iu-1kt-1} + H_{iu-1kt-1} = 0, \qquad \forall i, u, k, t, \quad \text{(A.1)}$$

$$L_{iu^*kt} - L_{iu^*kt-1} - L_{iu^*-1kt-1} + H_{iu^*kt-1} + H_{iu^*-1kt-1} = 0, \qquad \forall i, k, t, \quad \text{(A.2)}$$

$$\sum_u \sum_k L_{iukt} + EMPTY_{it} \leqq CAP_{it}, \qquad \forall i, t, \quad \text{(A.3)}$$

$$\sum_k L_{i1kt} - \sum_u \sum_k H_{iukt-1} + EMPTY_{it} \leqq 0, \qquad \forall i, t, \quad \text{(A.4)}$$

$$\sum_t H_{iu^*kt} \leqq H_{i^*}, \qquad \forall i, k = 1. \quad \text{(A.5)}$$

Note that eq. (A.5) represents a third objective, environmental protection, by assuring that no more than H_{i^*} hectares of old-growth woodland may be cut over the planning period.

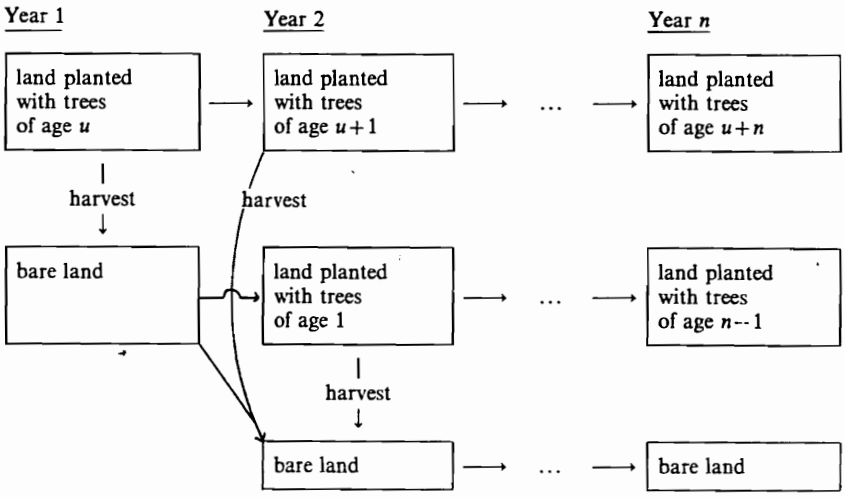

Fig. A1. The processes of growth, harvest and replanting.

The second process represented in the model is wood distribution. When a unit of land is harvested, it contains an amount of wood proportional to the age of the trees. This wood may be converted to charcoal or used as fuelwood, and the fuelwood and charcoal are allocated among wood fuel-consuming nodes so that all fuels demands are met. The fuel production and shipment process is represented by two constraints,

$$\sum_j X_{ijt} + \alpha \sum Y_{ijt} - \sum_u \sum_k u(g_{ik}) H_{iukt} \leqq 0, \qquad \forall i, t, \tag{A.6}$$

$$\sum_i X_{ijt} + \beta \sum_i Y_{ijt} \geqq DEMND_{jt}, \qquad \forall j, t. \tag{A.7}$$

Notice that the product $u(g_{ik})$ gives the total wood volume per hectare produced at harvest. A linear growth function is assumed, but a non-linear growth function could be used.

There were three objectives in the model. The first two were: (1) to minimize the costs of operating plantations of exotic species and harvesting wood, (2) to minimize the amount of time spent for fuel transport,

$$\text{Minimize} \quad \sum_i \sum_u \sum_k \sum_t l_{iu2t} L_{iu2t} + h_{iukt} H_{iukt}, \tag{A.8}$$

$$\text{Minimize} \quad \sum_i \sum_j \sum_t t_{ij} X_{ijt} + \sum_i \sum_j \sum_t t'_{ij} Y_{ijt}. \tag{A.9}$$

The third objective, woodland preservation, was expressed as a constraint [see eq. (A.5)].

The model is both predictive and prescriptive; it can be used to indicate what future resource requirements would be for a wood energy policy, or to outline in detail how forests should be managed in order to achieve different objectives.

References

Adegbehen, J.O., 1982, Growth and yield of *Pinus patula* in some parts of Eastern Africa with particular reference to Sao Hill, Southern Tanzania, Commonwealth Forestry Review 61, no. 1, 27–32.

Allen, J.C., 1983, Deforestation, soil degradation, and wood energy in developing countries, Ph.D. dissertation (Johns Hopkins University, Baltimore, MD).

Araya, Z., 1981, Village forestry in Tanzania: Problem context and organizational proposal for sustained development, Consultant report to Forest Division (Ministry of Natural Resources and Tourism, Dar es Salaam).

Arnold, J.E.M. and J. Jongma, 1978, Fuelwood and charcoal in developing countries, Unasylva 29, no. 118, 2–9.

20

Barnes, D.F., J.C. Allen and W. Ramsay, 1982, Social forestry in developing nations, Discussion paper D-73F (Resources for the Future, Washington, DC).

Boaler, S.B. and K.C. Sciwale, 1966, Ecology of a miombo site: Lupa North Forest Reserve, Tanzania II, Plant communities and seasonal variation in the vegetation, Journal of Ecology 54, 465–479.

Brenan, J.P.M., 1978, Some aspects of the phytogeography of tropical Africa, Annals of the Missouri Botanical Garden 65, 437–478.

Brokensha, D. and B. Riley, 1978, Forests, foraging, fences and fuel in a marginal area of Kenya, Paper presented at USAID Africa Bureau Firewood Workshop, June 12–14 (Washington, DC).

Cecelski, L., J. Dunkerley and W. Ramsay, 1979, Household energy and the poor in the Third World, Research paper R-15 (Resources for the Future, Washington, DC).

Chang, S.J. and J. Buongiorno, 1981, A programming model for multiple use forestry, Journal of Environmental Management 13, 45–58.

Chen, C.M., D.W. Rose and R.A. Leary, 1980, Derivation of optimal stand sensity over time — A discrete stage, continuous state dynamic programming solution, Forest Science 26, no. 2, 217–227.

Christiansson, C., 1981, Soil erosion and sedimentation in semi-arid Tanzania: Studies of environmental change and ecological imbalance (Scandinavian Institute of African Studies, Uppsala and Department of Physical Geography, University of Stockholm, Stockholm).

Clawson, M., 1975, Forests: For whom and for what? (Johns Hopkins University Press, Baltimore, MD for Resources for the Future, Washington, DC).

Cohon, J.L., 1978, Multiobjective programming and planning (Academic Press, New York).

De Kluyver, C.A., H.G. Duellenbach and A.G.D. White, 1980, A two-stage multiobjective mathematical programming approach to optimal thinning and harvesting, Forest Science 26, no. 4, 674–686.

Digernes, T.H., 1977, Wood for fuel: Energy crisis implying desertification — The case of Bara, The Sudan, Thesis (Department of Geography, University of Bergen, Bergen).

Dunne, T., W. Dietrich and M.J. Brunengo, 1978, Recent and past rates of erosion in semi-arid Kenya, Zeitschrift für Geomorphologie, Suppl. bull. 29, 130–140.

Earl, D.E., 1970, La carbonisation du bois a l'aide du four portaif Mark V, Note technique no. 164/170 (Departement forestier de l'Ouganda, Kampala).

Earl, D.E., 1975, Forest energy and economic development (Clarendon, Oxford).

Eckholm, E., 1975, The other energy crisis: Firewood, Worldwatch Paper no. 1 (Worldwatch Institute, Washington, DC).

Eckholm, E., 1982, Down to earth: Environment and human needs (Norton, New York for the International Institute for Environment and Development).

Ernst, E., 1977, Fuel consumption among rural families in Upper Volta, West Africa (Peace Corps, Ouagadougou).

FAO, 1981, Forest product prices 1961–1980 (FAO, Rome).

FAO/UNDP, 1983, Soil survey report of Dodoma capital city district, Report prepared for the Government of Tanzania (FAO, Rome) URT/73/006 (National Soil Service, Tanzania). Soil Survey Report no. 4 (Tanga).

FAO/UNEP, 1982a, Proyecto de evaluacion de los recursos forestales tropicales (en el marco de SIMUVIMA) — Los recursos forestales de la America tropical, Primera parte: Sintesis regional (Rome).

FAO/UNEP, 1982b, Tropical forest resources assessment project (in the framework of GEMS) — Forest resources of tropical Africa, Part 1: Regional synthesis (Rome).

FAO/UNEP, 1982c, Tropical forest resources assessment project (in the framework of GEMS) — Forest resources of tropical Asia, Part 1: Regional synthesis (Rome).

Freeman, M., 1979, The benefits of environmental improvement: Theory and practice (Johns Hopkins University Press, Baltimore, MD for Resources for the Future, Washington, DC).

Goffinet, G. and R. Freson, 1972, Recherches synecologiques sur la pédofaune de l'écosysteme forêt claire, Bulletin du Société Écologique 3, 138–150.

Government of Tanzania, 1976a, Map of vegetation 1:3,000,000 (Dar es Salaam).

Government of Tanzania, 1976b, Map of forest reserves 1:3,000,000 (Dar es Salaam).

Hammer, T., 1982, Reforestation and community development in the Sudan, Discussion paper D-73M (Resources for the Future, Washington, DC).

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21

Hardin, G. and J. Baden, 1977, Managing the commons (Freeman, San Francisco, CA).
Hufschmidt, M.M., D.E. James, A.D. Meister, B.T. Bower and J.A. Dixon, 1983, Environment, natural systems and development: An economic valuation guide (Johns Hopkins University Press, Baltimore, MD).
Hughart, D., 1979, Prospects for traditional and non-conventional energy sources in developing countries, World Bank Staff Working Paper no. 346 (World Bank, Washington, DC).
Johnson, K.N. and H.L. Scheurman, 1977, Techniques for prescribing optimal timber harvest and investment under different objectives — Discussion and synthesis, Forest Science Monograph 18, suppl. to Forest Science 23 no. 1.
Levhari, D. and N. Liviatan, 1977, Notes on Hotelling's economics of natural resources, Canadian Journal of Economics 10, no. 2, 177–192.
Lind, R.C., 1982, The rate of discount and the application of social benefit-cost analysis in the context of energy policy decisions, in: Robert C. Lind, ed., Discounting for time and risk in energy policy (Resources for the Future, Washington, DC) 443–458.
Lundgren, B., 1978, Soil conditions and nutrient cycling under natural and plantation forests in the Tanzanian highlands, Report on Forest Soils 31 (Department of Forest Soils, Swedish University of Agricultural Sciences, Uppsala).
Lyon, K.S., 1981, Mining the forest and the time path of the price of timber, Journal of Environmental Economics and Management 8, 330–344.
Malaisse, F., 1978, The miombo ecosystem, in: Tropical forest ecosystems: A state of knowledge report (UNESCO, Paris) 589–606.
Malaisse, F., R. Freson, G. Goffinet and M. Malaisse-Mousset, 1972, The miombo ecosystem: A preliminary study, in: P.M. Golley and F.B. Golley, eds., Tropical ecology with an emphasis of organic production (University of Georgia, Athens, GA).
Malawi, Ministry of Agriculture, Rural energy survey (Lilongwe).
Ministry of Lands, 1956, Aerial photographs 1:30,000 (Dar es Salaam).
Ministry of Lands, 1978, Aerial photographs 1:25,000 (Dar es Salaam).
Mnzava, E.M., 1980, Village afforestation: Lessons of experience in Tanzania (FAO, Rome).
Muir, A., B. Anderson and I. Stephen, 1957, Characteristics of some Tanganyika soils, Journal of Soil Science 8, no. 1, 1–18.
NASA, 1978, Land sat 2 scene Dodoma 180/64 1:1,000,000 (Sioux Falls, SD).
Openshaw, K., 1980, Rural energy consumption with particular reference to the Machakos district of Kenya (Department of Forestry, University of Dar es Salaam, Morogoro).
Rapp, A., D.H. Murray-Rust, C. Christiansson and L. Berry, 1972, Soil erosion and sedimentation in four catchments near Dodoma Tanzania, Geografiska Annaler 54A, 255–318.
Roy, R., n.d., Case studies of fuelwood collection and problems of rural women, in: Collected papers from a seminar on the role of women in community forestry, Dec. 4–9 (Forest Research Institute, Dehra Dun).
Schmithusen, F., 1983, Recent trends of forest legislation in developing countries, Resource Management and Optimization 2, no. 1, 27–40.
Skutsch, M., 1983, Why people don't plant trees: The socioeconomic impact of existing woodfuel programs: Village case studies, Tanzania, Discussion paper D-73N, Energy in Developing Countries Series in Developing Countries Series (Resources for the Future, Washington, DC).
Smith, N., 1981, Wood: An ancient fuel with a new future, Worldwatch Paper no. 42 (Worldwatch Institute, Washington, DC).
Strang, R.M., 1974, Some manmade changes in successional trends on the Rhodesian highveld, Journal of Applied Ecology 11, 207–214.
Thomson, J.T., 1981, Public choice analysis of institutional constraints on firewood production strategies in the West African Sahel, in: C.S. Russell and N.K. Nicholson, eds., Public choice and rural development, Research paper R-21 (Resources for the Future, Washington, DC).
U.S. Congress, Office of Technology Assessment, 1983, Sustaining tropical forest resources, Background paper no. 1: Reforestation of degraded lands (U.S. Government Printing Office, Washington, DC).
U.S. Interagency Task Force on Tropical Forests, 1980, The world's tropical forests: A policy, strategy, and program for the United States, A report to the President (U.S. Government Printing Office, Washington, DC).

Weintraub, A. and D. Navon, 1976, A forest management and planning model integrating silvicultural and transportation activities, Management Science 22, no. 12, 1299–1308.
White, F., 1965, The savanna woodlands of the Zambezian and Sudanian domains, Webbia 19, 651–681.
Winterbottom, R.T., 1980, Reforestation in the Sahel: Problems and strategies, Paper presented at the African Studies Association Annual Meeting, Oct. 15–18 (Philadelphia, PA).
World Bank, 1978, Forestry sector policy paper (World Bank, Washington, DC).
World Bank, 1983, World development report 1982 (Washington, DC).