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Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability

Tuyeni Heita Mwampamba*

Department of Environmental Science and Policy, University of California Davis, One Shields Avenue, Davis CA 95616, USA

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Abstract

By lumping together charcoal and firewood consumption to determine the threats to forests from widespread use of woodfuel energy in sub-Sahara African, studies have greatly underestimated the individual impact of charcoal. Where high consumption levels are coupled with poor forest management and negligible regulation of the charcoal trade, the threat of an impending crisis caused by charcoal alone needs to be revisited. This study uses a survey of 244 households in six Tanzanian cities to determine whether current consumption levels, charcoal production techniques and forest management practices are sufficient to meet present and future charcoal demand. Projections to year 2100 were made to determine whether forests can continue to meet future demand under 24 scenarios that capture the numerous uncertainties that exist of converting charcoal consumption into forest needed. The findings suggest that the scenarios containing median consumption levels, low kiln efficiencies and low replenishment of harvested forests could deplete forests on public land by 2028. Best-case scenarios occurred when the opposite conditions existed. The study concludes that charcoal consumption is a real threat to the long-term persistence of forests in Tanzania and proposes policy interventions for alleviating forest loss.

Keywords: Charcoal consumption; Forest loss; Tanzania

1. Introduction

It is a known fact that, with the exception of South Africa, biomass accounts for >75% of final energy consumption in sub-Saharan nations and that wood (in the form of firewood and charcoal) is the most common type of biomass utilised (Byer, 1987; Energy Information Agency (EIA), 1999; Hall and Moss, 1983). Up to 85% of the wood is used to meet household cooking requirements (Hoek-Smit, 1991; Van der Plas, 1995; Wood Energy Today for Tomorrow (WETT), 2000).

The tight link between wood and forest resources inspired numerous studies in the mid-1970s and early 1980s to determine whether there was sufficient forest to meet the demand of the time and that of future generations. Some of these studies reported an impending woodfuel crisis, arguing that population growth coupled with inefficient consumption techniques would increase demand and decimate forests by the turn of the century (FAO, 1981; Mnzava, 1981; Kamweti, 1984). Other studies reported contradicting results, concluding instead that woodfuel scarcity was limited to very few and specific locales (Munslow et al., 1988; Hosier, 1993); that more often than not, its extraction rarely resulted in forest loss (Chidumayo, 1993); that the actual driving force behind deforestation was agricultural expansion (Foley, 1985) and a play between socio-cultural, political and land tenure issues (Dewees, 1989; Hosier et al., 1990). For a time, the crisis studies received the most attention, inspiring governments (GoTs) in the region to initiate programs that would improve efficiency of cooking stoves and charcoal kiln, or that would encourage consumers to switch to alternative fuels, such as kerosene and liquid petroleum gas (LPG). In 1993, the International Journal on Energy Policy published a special issue dedicated to 'Urban Energy and Environment in Africa', which highlighted ongoing research and findings of the time. Works presented in the issue dismissed the 'woodfuel crisis', arguing that it was misleading and incorrect to attribute high forest loss solely to extraction

*Tel.: +1 530 758 2047; fax: +1 530 752 3350.
E-mail address: thmwampamba@ucdavis.edu.

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for woodfuel. Expansion of agricultural land and heavy grazing pressure were presented as the major culprits for the heavy loss of forests suffered in the region (Hofstad, 1990; Hosier, 1993). By the mid-1990s, enthusiasm for the GoT programs had waned: programs were rarely registering success and it was becoming apparent that woodfuel scarcity was not a universal phenomenon (Girard, 2002).

For those studies that made a distinction between rural versus urban consumption of fuelwood and between firewood versus charcoal forms of fuel, the threat to forests has always been clear: while firewood use rarely poses a threat, the implications of charcoal are quite different (Hosier et al., 1993; van der Plas, 1995; Johnsen, 1999). Charcoal is the main source of cooking energy in urban homes in most sub-Saharan nations (Hosier and Milukas 1992; Bailis et al., 2005; Kammen and Lew, 2005). Inefficiencies in the production process results in consumers of charcoal using 4–6 times more wood than consumers of firewood (van der Plas, 1995; Kammen and Lew, 2005). Moreover, the preferred charcoal is that made from wood that produces a dense, slow-burning coal, characteristic of slow growing species that are particularly vulnerable to overexploitation (Chidumayo, 1991; Girard, 2002). As African cities grow, they require more charcoal. It is estimated that for each 1% increase in urbanisation there is a 14% increase in charcoal consumption (Hosier et al., 1993). The high rates of urbanisation prevalent in the region suggest that by 2050, more than 50% of Africans will reside in cities (United Nations, 2001). High and ever-increasing demand for charcoal, coupled with improper forest management, and poor regulation of the trade present a solemn future for forests in Africa. In nations where this combination of factors exists, the woodfuel crisis needs to be revisited.

This study examines the situation in Tanzania (Fig. 1), an East African country in which many of the conditions necessary for fuelwood to become a threat to forest resources exist. More than 80% of Tanzania's urban population consumes charcoal while rates of urbanisation are known to be as high as 5% in most cities (Hosier and Kipondya, 1993; Tanzanian Traditional Energy Development and Environment Organisation (TaTEDO), 1998, Tanzania National Bureau of Statistics (TNBS), 2004). Although 50% of forests are in reserves and national parks, it is a known fact that their protection is poor to non-existent, and that illegal harvesting is rampant and

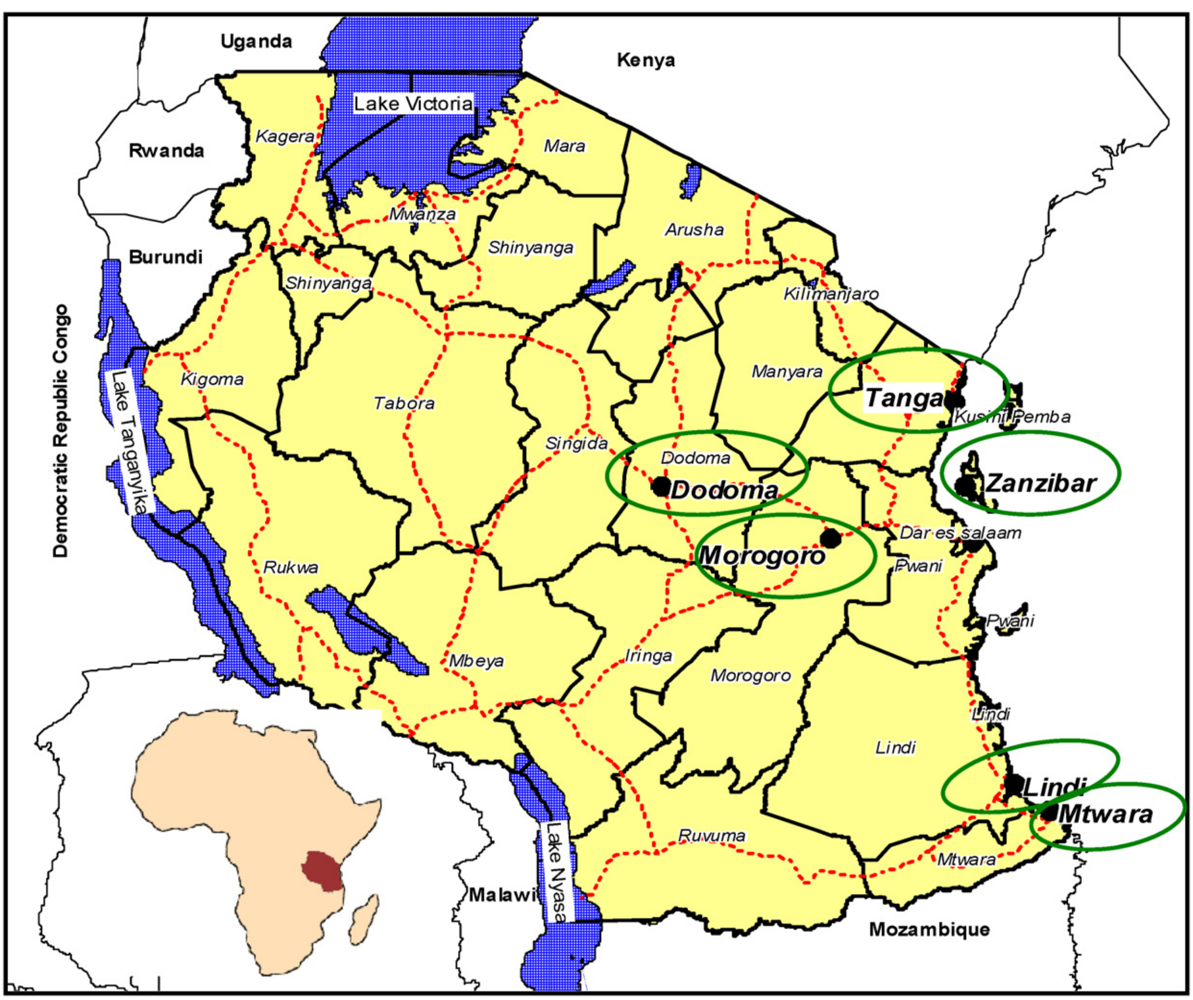

Fig. 1. Map of study sites in Tanzania.

widespread. Multiple attempts to ban charcoal production have failed; initiatives to establish woodlots and to encourage the widespread use of more efficient cooking stoves have registered very little success (TaTEDO, 1998; Johnsen, 1999); kerosene, LPG and electricity remain unaffordable for most (Foley and Barnard, 1984; Masoud, 1990; Hosier, 1993).

Several studies have attempted to capture the dynamics of charcoal production and consumption in Tanzania (Hosier and Milukas, 1992; Boberg, 1993; Hosier et al., 1993; Hofstad, 1997; Frey and Neubauer, 2002). With the exception of Hosier et al., 1993, none of these studies have systematically explored the amount of forest that is needed to meet national charcoal demand. It is unclear whether current consumption, production and forest management trends are sustainable and whether wood supply for future charcoal consumption is secure. Are interventions necessary? One cannot argue with the claim that "If all woodfuel consumption ceased tomorrow, deforestation in Tanzania would not be halted" (Ministry of Natural Resources and Tourism (MNRT), 1989). But given the high and seemingly unquenchable demand for charcoal by Tanzanian cities, the true role of charcoal relative to other forces of forest degradation, needs to be revisited. The objectives of this study were, therefore, to (a) investigate the contribution of charcoal to forest loss in Tanzania, (b) to project future forest availability based on current charcoal consumption and production trends and (c) to propose policy recommendations for lowering the burden on forests placed by nationwide dependency on energy from charcoal. In an attempt to control for the numerous uncertainties implicit in such predictions, 24 scenarios for estimating a time when forest on public land would cease to exist in Tanzania were explored. The scenarios consider only the contribution by households to charcoal consumption and all predictions are based on the assumption that it is natural forests that supply the bulk of the charcoal produced.

2. Methods

The study design consisted of four stages, each contributing to the gradual build-up of information necessary to quantify forest availability for meeting charcoal consumption needs from 2002 to 2100. First, a consumption rate for the nation had to be determined, based on estimates of per capita charcoal consumption. The second stage required translating rates of consumption into forest equivalent, which led to the third stage, that of formulating scenarios that represent different possible outcomes for forest availability. The fourth and final stage applied the scenarios to Tanzania's current figures on forest cover to predict forest availability up to 2100.

2.1. Determining per capita and national consumption

Estimates of the amount of charcoal that is consumed in urban mainland Tanzania are often based on a findings by the Tanzanian Urban Household Survey of 1990, reported by Hosier and Kipondya (1993) which was undertaken in only three of the nation's 23 urban centres (Dar es Salaam, Mbeya and Shinyanga). Estimates for consumption on Tanzania's offshore islands, on the other had, are based on a Zanzibar Town survey conducted in 1989 by Masoud (1991). Updates of the surveys have only been reported for Dar es Salaam (CHAPOSA, 2001), but as the largest and most developed city in the country, they are rarely a gauge for nationwide trends. In an attempt to update the data, and in order to obtain a figure more generalisable to the nation, I conducted a rapid assessment of six cities (Dodoma, Lindi, Morogoro, Mtwara, Tanga and Zanzibar), five of which had never been surveyed before (Fig. 1). The study was initially designed to cover 12 cities, but sampling error in six of the cities deemed half the data useless. The six remaining cities have different population sizes (Table 1) and varying proximities to forested areas and are believed to be good representatives of other urban areas in Tanzania. They are, however, all clustered in the eastern half of the country, which may or may not produce bias in the results.

Between February and April 2002, a total of 244 households across two income levels were interviewed in the six cities. Two course income groups were identified based on location of houses within the city and dwelling style. At arrival into a town, I consulted first with the natural resource and planning staff from the municipal offices. From them I obtained city statistics and guidance to how the city was economically subdivided into 'rich' (*uzunguni*) and 'poor' (*uswahilini*) areas. In the 'rich' areas, I only interviewed households that occupied a single building to themselves; and in the 'poor' areas, I only interviewed households that occupied rooms within multi-family buildings. These groups were later classified as the 'middle and 'low' income groups, respectively. The initial study design contained a 'high' income group consisting of single-building occupancy in 'poor' areas, but as there were few such cases and they did not differ significantly from the 'middle' income group, the data were merged to form a single 'middle' income group. Once within a subdivision of the town, interviews took place in the first 20 households that met the dwelling criteria *and* whose occupants were

Table 1
Distribution of sample size across towns and income groups

	Low income group	High income group	Total *N*	Urban population size
Dodoma	18	9	27	213,243
Lindi	34	24	58	126,396
Morogoro	25	20	45	473,849
Mtwara	34	15	49	228,539
Tanga	20	20	40	301,196
Zanzibar	12	13	25	326,686
Column total	143	101	244	

willing to be interviewed. Households that used charcoal for activities other than cooking for the family were excluded from the study. Within each town only one *uzunguni* and one *uswahilini* area were surveyed.

The questionnaire was designed to take no more than 15 min. The interviewees provided information on household size; on the amount of charcoal used per day, week or month, and; on the price paid per unit of charcoal bought. Respondents tended to be female household heads, sometimes in conjunction with the maid. In cases where the local unite of charcoal measurement were unfamiliar (e.g. *debe*, *kikopo*, *kiroba*, *kalai*, *pakacha*), conversions to the more common sack unit were done with the help of local charcoal dealers and vendors.

Annual per capita consumption (C_c) was calculated for each income group and for each town based on the following equation:

$$C_c = \frac{12S}{H}, \tag{1}$$

where S is the number of sacks consumed by the household per month and H is household size. Of the 244 households interviewed, responses from 243 interviews were possible to use in the analysis. A total of 12 values for household sizes were missing in Zanzibar; this was corrected for by using an overall mean generated from the available data for the town.

National charcoal consumption by households was determined by multiplying per capita consumption (C_c) with urban population figures obtained from the 2002 National Population Census (TNBS, 2002). A standard amount of 80% was assumed to be the proportion of the national population that utilises charcoal. This is an approximation based on a range from 69% to 86% reported in numerous (Masoud, 1991; Hosier and Kipondya, 1993; Ishengoma and Ngaga, 2000; CHAPOSA, 2001).

2.2. Translating consumption into hectares of forest

Converting consumption rates into hectares of forest needed to produce charcoal contains many degrees of uncertainty. It is, however, necessary to perform the conversions if one is to gain insight into the potential impact that charcoal use has on forest availability. A definitive answer cannot be obtained, nor is it the purpose of this study. Rather, a range of possible outcomes is desirable and may be the only realistic approach to understanding where and what policy strategies are appropriate. By controlling some of the most important sources of uncertainty and allowing them to feature into the conversions, a set of scenarios were produced.

Estimating the amount of forest needed to produce one sack of charcoal requires knowledge of the amount of charcoal that fits into a sack (i.e. mass of the sack in kg), the efficiency of the kiln to convert the wood into charcoal (i.e. kiln efficiency in %), and the amount of wood contained in a hectare of forest that is suitable for charcoal production (i.e. stock density in t ha^{-1}). Literature contains various estimations for each of these parameters. For the purpose of this study, the following values were used: (a) that one sack of charcoal contains 30 kg (CHAPOSA 2001), (b) that kiln efficiencies range from 8% to 23% (Chidumayo 1991; Hibajane and Kalumiana 2003; Van der Plas 1995;) and (c) that forest stock densities range from 51 to 81 t ha^{-1} (Chidumayo 1991). Work in on charcoal production in Zambia has also shown that about 7% of standing stems are not harvested for the production process, indicating that 93% rather than 100% of stems are harvested (Chidumayo, 1991). The equation used to calculate the amount of forest needed to produce a single sack of charcoal (F_s) was

$$F_s = 1.075 \times 10^{-3}\left(M_s \times E_k \times \frac{1}{S}\right), \tag{2}$$

where M_s is the mass of a single sack (kg charcoal sack^{-1}); E_k the kiln efficiency (kg of wood per kg of charcoal); and S the stock density (t wood ha^{-1} forest). The coefficient 1.075×10^{-3} is a constant that incorporates: (1) the assumption of 93% stem harvest mentioned above and (2) the unit conversion of 1000 kg of wood into 1 t of wood.

2.3. Setting the scenarios

The only definite answer to the question 'How much forest is Tanzania losing due to charcoal consumption?' is: 'It depends'. There are great uncertainties in determining the appropriate values for the parameters that must be included to calculate per capita consumption, the forest equivalent of sacks consumed, or future forest availability. The objective for formulating the scenarios was to explore the full spectrum of possible forest loss under a future of continued charcoal consumption. Upper and lower limits have been applied, based on literature and on findings from the household survey conducted as part of this study. Presenting a sweep of possible outcomes to policy makers and forest conservation initiatives should encourage approaches that produce multiple and flexible solutions rather than a single (and possibly wrong) answer.

A total of 24 scenarios were considered, consisting of four alternatives for the values of F_s, two alternative values for per capita annual consumption (C_c), and three values for the proportion of forest that regenerates ($4 \times 2 \times 3 = 24$). The four values for F_s were generated from all the possible combinations of two alternative values for both K_e and S, i.e. $2 \times 2 = 4$ (see explanations in previous section). The scenarios are best summarised in Table 2 which shows the specific combination of values that went into generating them.

The amount of forest needed for any given period was determined by multiplying per capita consumption to the urban population for that period. Annual per capita consumption levels were assumed to remain constant over time, but two levels were considered: Level A assumes that

Table 2
Summary of how scenarios were formulated

(a)

Kiln efficiency (%)	Stock density ($t\,ha^{-1}$) Low (51)	High (81)
Low (8)	Fs 1	Fs 2
High (23)	Fs 3	Fs 4

(b)

Fs ($ha\,sack^{-1}$)	Per capita consumption ($sacks^{-1} person\,yr^{-1}$) Low (A) 3.12	Mean (B) 4.64
1 (0.0051)	1A	1B
2 (0.0032)	2A	2B
3 (0.0145)	3A	3B
4 (0.0092)	4A	4B

(c)

Fc ($ha\,person^{-1}\,yr^{-1}$)	% Regeneration 10%	30%	60%
1A (0.0158)	1A-10R	1A-30R	1A-60R
2A (0.0099)	2A-10R	2A-30R	2A-60R
3A (0.0454)	3A-10R	3A-30R	3A-60R
4A (0.0286)	4A-10R	4A-30R	4A-60R
1B (0.0234)	1A-10R	1A-30R	1A-60R
2B (0.0147)	2A-10R	2A-30R	2A-60R
3B (0.0672)	1A-10R	1A-30R	1A-60R
4B (0.0423)	2A-10R	2A-30R	2A-60R

Twenty-four scenarios were generated based on a steady accumulation of values for parameters that presented uncertainty in (a) the conversion of stock density and kiln efficiency into the forests needed to generate a sack of charcoal—Fs; (b) the combination of Fs with two different levels (low and median) of per capita consumption (Cc) to generate scenarios for the annual forest needed per capita—eight scenarios for Fc and (c) the combination of the Fc scenarios with uncertain knowledge of the proportion of degraded land that regenerates (10–60% regeneration)—24 scenarios (1A-10R to 4B-60R).

consumption is at the lowest level observed in the household surveys conducted for this study. This is a conservative measure equivalent to a scenario whereby households reduce their consumption by either becoming more efficient or switching to alternative energy. Level B assumes that mean consumption levels are maintained over time. In this scenario, a continuous increase in the population of consumers counteracts market forces so that prices do not necessarily reflect scarcity. Under both scenarios, GoT intervention stays negligible and alternative cooking fuels remain unaffordable to most. Levels A and B of Cc were combined with four alternatives for F_s to produce eight new scenarios for calculating the amount of forest needed per person to meet their charcoal consumption requirements (1A, 2A, 3A, 4A, 1B, 2B, 3B and 4B).

Estimating forest availability at any given time depends on forest loss in previous periods and how much forest was restored over that same period. There are no estimates available for the proportion of forests that regenerate in Tanzania, hence three values were considered: (1) 10%, (2) 30% and (3) 60%. These values were chosen based on a simple argument: that regeneration definitely occurs and is therefore not 0%, but neither does it occur in 100% of harvested forests. The value of 10% was taken to be a probable proportion, albeit a pessimistic case. The 30% was considered to also be less likely than 10%, but realistically attainable if regeneration programmes were encouraged. A 60% recovery rate is highly unlikely and was used only to gauge the regeneration levels needed to reverse forest loss. Inclusion of these uncertainties to the eight alternatives of F_c produced a total of 24 scenarios (Table 2).

2.4. Predicting present and future forest availability

For the purpose of this study, the year 2002 was used as the base year from which all future projections were launched. Estimate of forest cover for 2002 was assumed to be approximately 33.5 million ha of which 13 million ha were in forest reserves, 2 million ha were in national parks and the rest were on public land, with little to no protection (MNRT, 2000; Dallu, 2002; Mkanta and Chimtembo, 2002). Charcoal production is most suitable in miombo woodlands, which form most of the forests on public land, about 17.5 million ha (CEESt, 1999; MNRT, 2000).

Charcoal demand is directly linkable to urban population (Masoud, 1991; Hosier and Kipondya, 1993; CHAPOSA, 2001), hence predicting how much forest will be needed to meet future charcoal requirements was based solely on predictions of future urban population. Rates of urbanisation in Tanzanian cities and towns are estimated at 5% (TNBS, 2004), but for the purpose of projections into the future, it is not expected that these high rates will persist (UN, 2001; GHC, 2006). More realistic estimates predict a steady decline in rates of urbanisation between 2000 and 2030, remaining positive (i.e. above zero) and maintaining growth of cities, albeit much slower growth

(GHC, 2006). By applying a logistic equation to the United Nation's estimates of urban growth rates for Tanzania between 2000 and 2030, I derived growth rates for each year between 2002 and 2100 (Fig. 2). The annual rates were projected onto the 2002 urban population figures to estimate the number of charcoal consumers for each year henceforth. To project the amount of forest that would be needed for each time period, predicted urban population was multiplied by the eight alternative estimates of per capita forest needed (F_c). The steady value of 80%, as the proportion of the urban population consuming charcoal, was maintained for all time periods.

Assuming that demand for charcoal is always met, forest needed is equivalent to forest lost. This is not unrealistic given that "about 70% of the deforestation in the country is related to woodfuel provision" (Makundi, 2001). By subtracting cumulative forest loss from national forest reserves (33.5 million ha) and by incorporating biomass increment rates of 1.92 t ha^{-1} yr^{-1} for the proportion of forests that regenerate (Chidumayo 1988, 1990), projections could be made future forest availability.

2.5. Data analysis

Normality and variance equivalence tests performed on the household data indicated non-conformance to the assumptions of parametric statistics. Instead non-parametric statistics such as Kruskal–Wallis tests and Welch-ANOVAs were applied to check for differences across towns and income levels. Where appropriate, Student's *t*-test was used to determine differences in means.

3. Results

Mean per capita consumption (C_c) for the six towns ranged from 3.12 to 6.01 sacks $person^{-1}$ yr^{-1}, the lowest and highest mean C_c having been observed in Zanzibar and Mtwara, respectively. Maintaining a sack-to-kg conversion of 30 kg $sack^{-1}$, this is equivalent to 93.6 to 180.3 kg $person^{-1}$ yr^{-1}. The overall mean across towns (weighted for disproportionate sample sizes—see Table 1) was 4.62 sacks $person^{-1}$ yr^{-1} (138.6 kg $person^{-1}$ yr^{-1}), $<5\%$ higher than when the overall mean was weighted for the population sizes of the six towns (4.41 sacks $person^{-1}$ yr^{-1}) (Fig. 4a). A Welch-ANOVA test (assuming unequal standard deviations) resulted in a significant difference between means ($F = 2.8035$, $p = 0.0211$), confirmed by the non-parametric Kruskal–Wallis test ($X^2 = 20.11$, $p = 0.0012$). A subsequent Student's *t*-test revealed three main levels of consumptions: that observed: (1) in Zanzibar, (2) in Mtwara and (3) in the remaining four towns, albeit with overlaps. For example, no significant difference was detected between C_c in Mtwara and Dodoma ($p = 0.1301$) nor between Zanzibar and Tanga ($p = 0.0743$) nor between Zanzibar and Morogoro ($p = 0.1159$). Income group did not have a significant effect on the amount of charcoal consumed ($X^2 = 0.85$, $p = 0.3561$) (Fig. 3b). A bivariate fit of C_c by household size, however, revealed a there negative correlation between the two variables, with increase in household size strongly implicating lower per capita consumption (Fig. 3c).

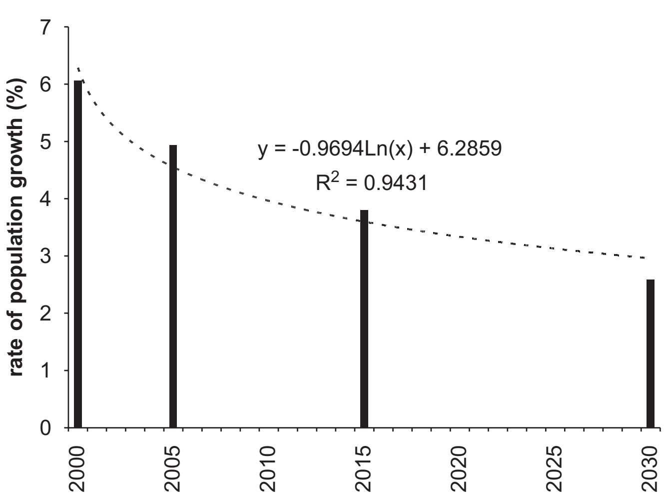

Fig. 2. Projected urban population growth for Tanzania 2000–30.

A Student's *t* test to compare the mean prices paid for charcoal across towns indicated that consumers in Zanzibar paid the highest prices; the average cost was Tanzanian Shillings (TZS) 5,280 $sack^{-1}$ (1 US$ = TZS 972.37 in 2002) ($t = 1.96998$, $\alpha = 0.05$). The lowest mean prices paid were obtained in Lindi (TZS 4,683). There was no significant difference between prices paid in Mtwara, Morogoro, Dodoma and Tanga (mean = TZS 3,051 $sack^{-1}$) (Fig. 3c). Kruskal–Wallis test on the price data indicated that these differences were significant ($X^2 = 70.08$, $p < 0.001$).

Projection of future consumption based on the eight scenarios for per capita forest needed (F_c) while assuming that the proportion of urban dwellers consuming charcoal remains at approximately 80%, all scenarios predict an increase in overall consumption (and subsequent forest loss) over time (Fig. 4). Of the eight scenarios, scenario 2A was the only one where annual forest losses of less than 1 million ha persist to year 2100. The amount of forest needed to meet 2002 charcoal demand ranged from 62,000 ha (scenario 2A) to 421,000 ha (scenario 3B) depending on whether the low mean (3.12 sacks $person^{-1}$ yr^{-1}) or median mean (4.62 sacks $person^{-1}$ yr^{-1}) was applied, respectively. Reflecting urban population size, the region that consumed the most charcoal was Dar es Salaam, whose total consumption levels in 2002 ranged from 5.8 to 8.6 million sacks (174,000 to 258,000 mt of charcoal), depending on whether low C_c (3.12 sacks $person^{-1}$—alternative A) or a mean C_c (4.62 sacks $person^{-1}$—alternative B) were used (Fig. 5). The other major consumers across the country are Mwanza (~8%), Morogoro (6%), Mbeya (5.4%) and Arusha (5.1%).

The earliest course towards complete loss of public forest occurs in year 2028 under scenario 3B-10R (Fig. 6). Under scenario 3B, increasing the proportion of land that

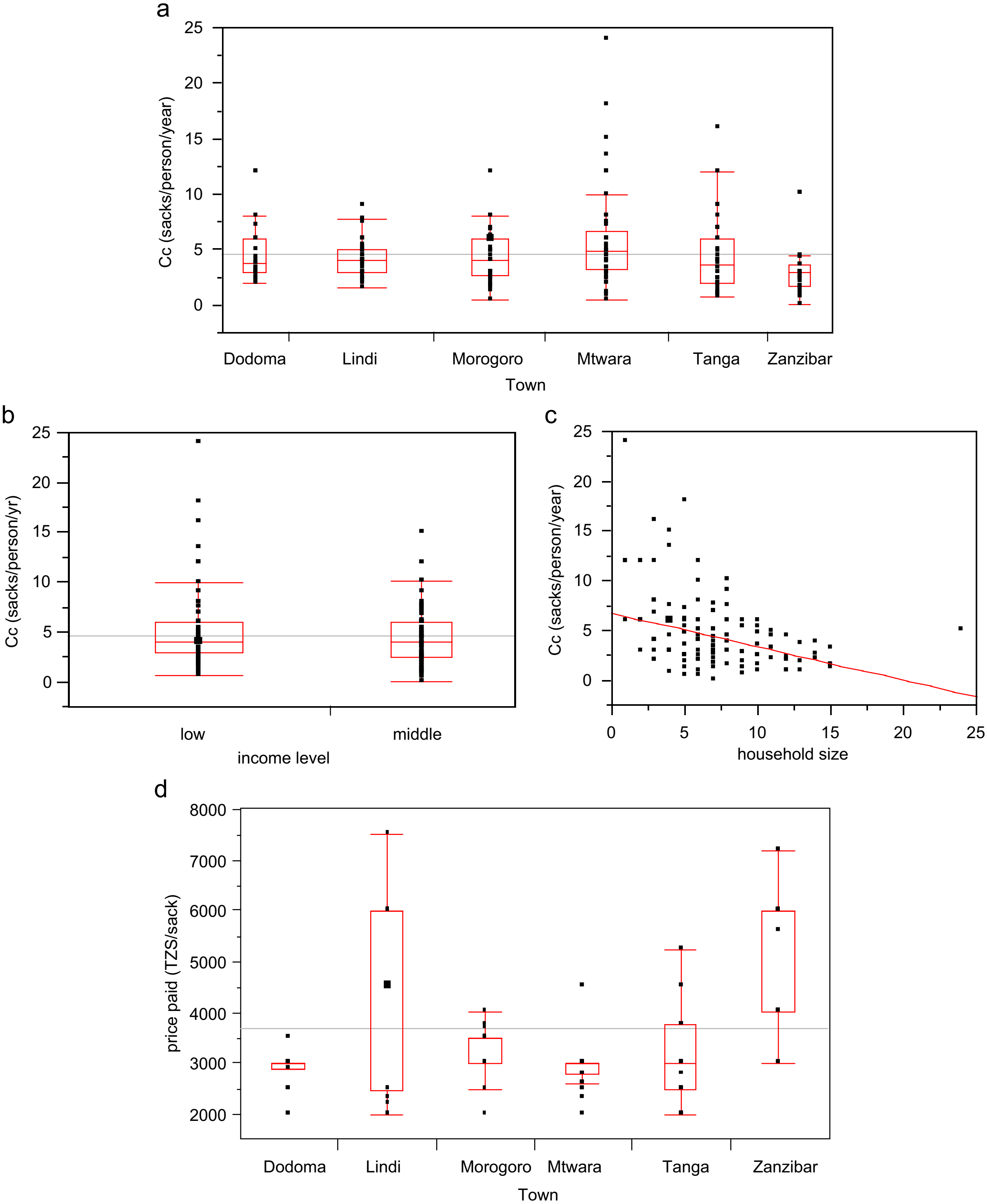

Fig. 3. Results of household survey: (a) annual per capita consumption (C_c) across towns, (b) effect of income level on per capita annual consumption (C_c); (c) relationship between per capita consumption and household size; and (d) price of charcoal across towns.

regenerates to 30% and 80% has very little effect on extending the period of public forest availability, merely postponing it to 2030 and 2035, respectively. Scenario 3B (orange trajectories in Fig. 6) assumes high levels of kiln efficiency, low stock density and mean per capita consumption (Table 2). The set of 4A scenarios represent the 'mediocre case', projecting complete loss of public forests four decades into the future (1947). Under this suit of scenarios, increasing the proportion of land under regeneration postpones 'dooms day' by 2 and 7 yr. The most

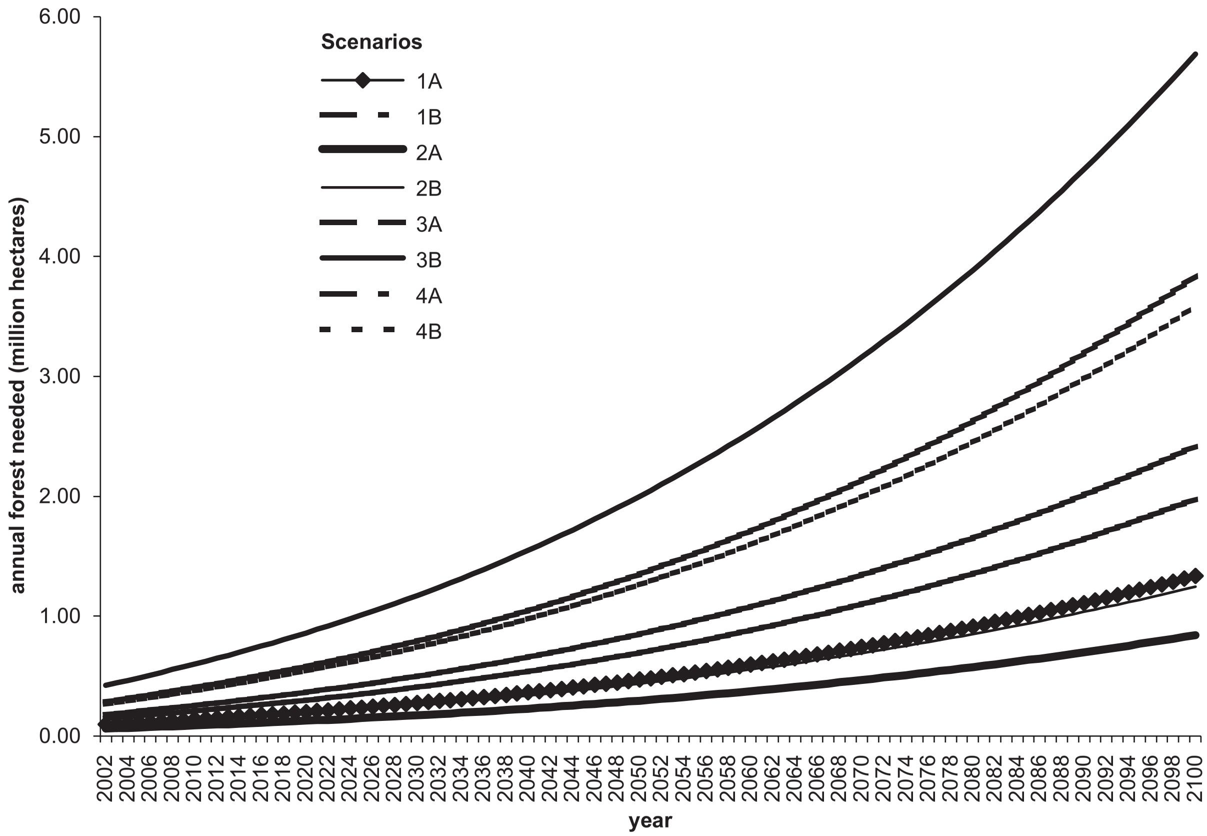

Fig. 4. Projected increase in forest needed to meet charcoal consumption 2002–2100.

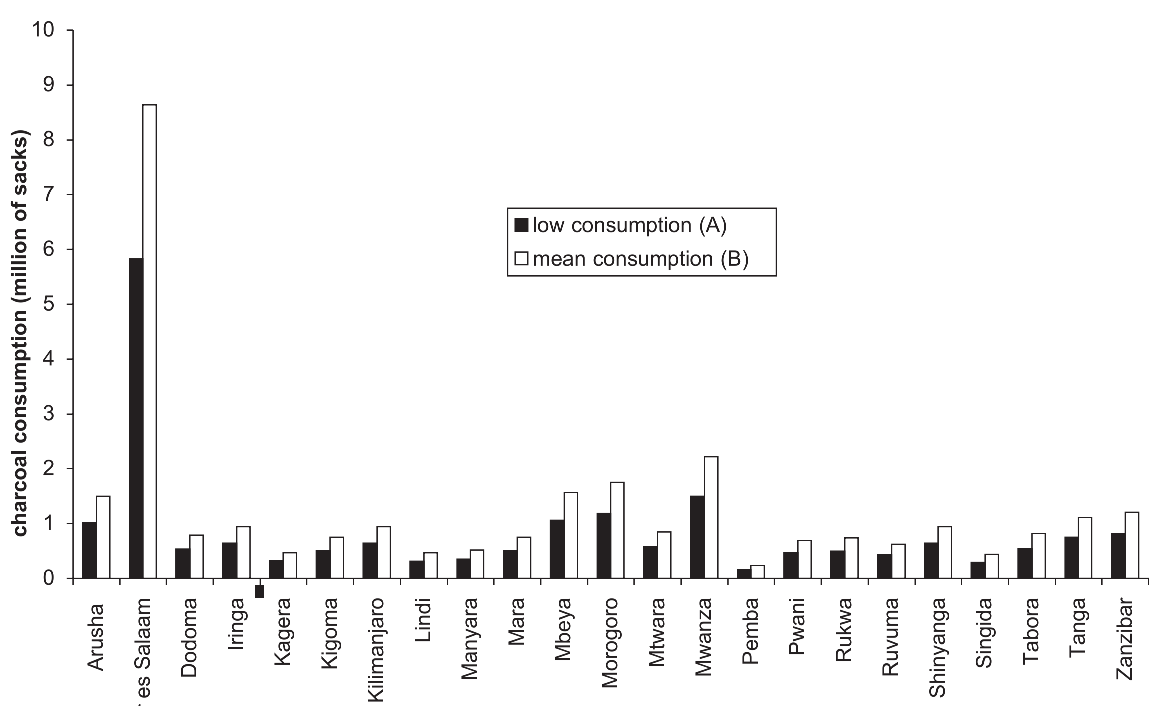

Fig. 5. Estimated charcoal consumption by households for each region (2002).

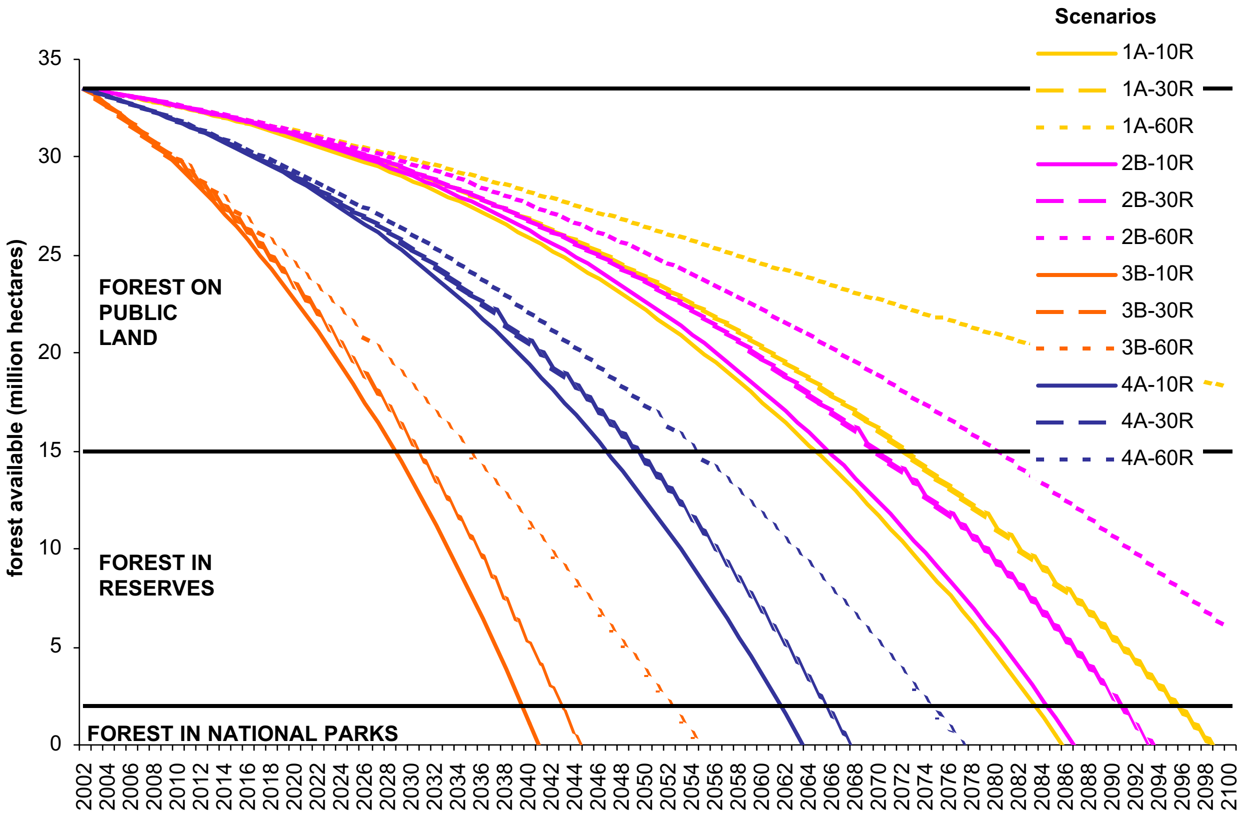

Fig. 6. Estimates of forest availability 2002–2100.

optimistic case is represented by scenarios 1A: current rates of consumption are sustained for the next five decades (scenario 1A-10R) and public forests persist (albeit at much reduced levels) beyond 2100 (scenario 1A-60R).

A sensitivity analysis was conducted to determine the leverage that each parameter has in affecting estimates of forest lost (Fig. 7). The proportion of land permitted to recover (% regeneration) is the most influential parameter, followed by kiln efficiency. The parameter "% using charcoal", representing the proportion of urban consumers, has the least effect on forest availability (indicated by the lowest slope). No tests were conducted to support the substantiality of these claims.

4. Discussion

Assuming a conversion rate of 30 kg sack^{-1}, mean consumption across towns is about 140 kg charcoal person^{-1} yr^{-1}. Given that this is the first study in Tanzania to survey more than three towns simultaneously for per capita charcoal consumption, the average across towns is a better representation of the tendency in Tanzania than any before it. The mean C_c obtained is 30% less than that reported by Hosier and Kipondya (1993); about 20% less than the average reported for Dar es Salaam (CHAPOSA, 2001), and; approximately 15% more than the national average reported by TaTEDO (1998). Previous estimates of Zanzibar Town by Masoud (1991) indicate that per capita consumption levels on the island may have doubled in the >10 yr between surveys, from 45 to 93.6 kg person^{-1} yr^{-1}. Comparisons across time for similar towns are shadowed with doubt, however, given discrepancies in the approaches used. For those studies that relied on recall information from respondents, rather than direct and quantitative measurements of use, consumption levels may have been overestimated by up to 14% (Ministry of Energy Kenya, 2002).

The prices paid for a sack of charcoal across the six towns differed significantly (Fig. 3b), suggesting that proximity to forests is reflected in the pricing of charcoal and consequently in the consumption levels observed. This trend is exemplified (albeit not proven) by the observation that the highest mean price paid for charcoal (TZS 5,280 in Zanzibar) coincides with the lowest mean consumption rate (3.12 sacks person^{-1} yr $^{-1}$, in Zanzibar), and that the low average price paid for charcoal in Mtwara (TZS 2,949) coincides with the highest mean consumption level obtained across towns (6.01 sacks person^{-1} yr^{-1}, also in Mtwara). This is not surprising if one considers that >90% of charcoal consumed on the Island is sourced from the mainland, making charcoal a scarce and expensive commodity there (Norconsult, 2002). On the other hand, it is a known fact that the largest tracts of intact forest still available in Tanzania *and* suitable for charcoal production are located in the south, where Mtwara is situated. Values obtained for Lindi, however, suggest that the dynamics of

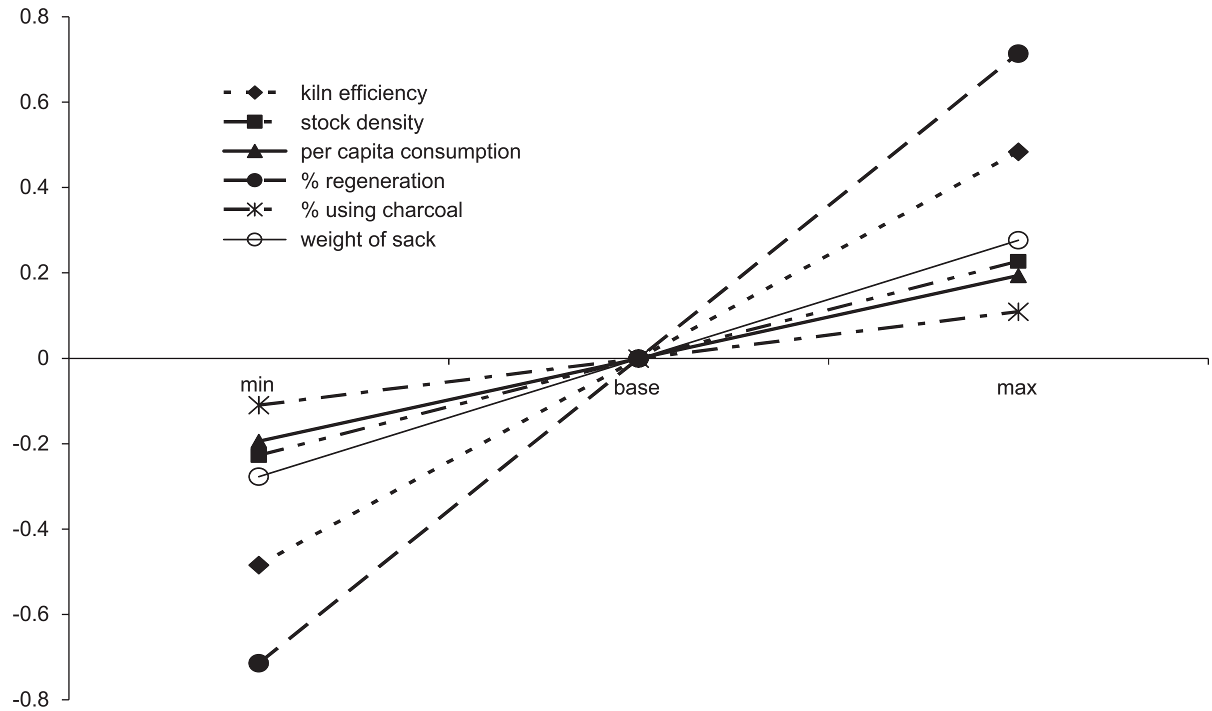

Fig. 7. Sensitivity analysis of parameters affecting estimates of future forest availability.

charcoal consumption patterns are much more complex. Lindi's proximity to large tracts of suitable forest should have resulted in above-average consumption rates and below average prices, similar to Mtwara. Instead, the prices paid for charcoal (TZS 4,683) are significantly higher than the overall average obtained and consumption levels (4.29 sacks person^{-1} yr^{-1}) are no different than the overall mean. A possible explanation may be derived from Lindi's position as the main supplier of charcoal to Zanzibar: by becoming an export commodity, charcoal obtains a value whose price echoes the high profits obtainable by selling it 'abroad' rather than the large abundance of raw material available locally. Consequently, local consumers find charcoal prices unaffordable thus justifying lower levels of use. Although a direct connection between charcoal pricing, scarcity of forests and consumption levels cannot be claimed by this study, other studies have shown such a trend to exist (Masoud 1990; Boberg, 1993; Hofstad, 1997; Johnsen, 1999). The same can be said for tendencies to equate low consumption levels with higher efficiency in charcoal use.

A very different type of study design would be needed to show that Zanzibarians use charcoal more efficiently than residents of Mtwara; the trends observed in this study suggest that this may be so. Efficiency is better claimed in the correlation that is illustrated between per capita consumption and household size (Fig. 3d): larger households tend towards lower per capita consumption levels. This trend has already been demonstrated in Zanzibar, where it was generalisable to all fuel types (Masoud, 1991). The economy of scales is equally applicable to charcoal as to many other household commodities.

The amount of wood needed to fuel estimated levels of consumption requires that 93% of woody biomass be harvested from forests (Chidumayo, 1991). This study estimates that 62,000–421,000 ha of forest may have been needed to meet the national demand of households in 2002 (Fig. 4). Given that annual forest loss is estimated at 300,000–500,000 ha yr^{-1} (MNRT, 2000; Yahya, 2001), household consumption of charcoal would have contributed anywhere from 20 to >84% of total forest loss in that year. While the upper limit is quite unlikely (charcoal production is not the only source of forest loss), a value within a tighter range of 30–60% is plausible. A >60% loss is not completely unfounded, however, if one considers that nations have been reported to have lost up to 75% of their forest cover solely to meet their wood energy requirements (EIA, 1999). Makundi (2001) reported that 70% of forest loss in Tanzania is attributable to woodfuel consumption (charcoal and firewood), of which 43% is due to direct removals (mostly attributable to charcoal). If such reports can be supported by data more specific to the role of charcoal, then, by working backwards, one could narrow down the 24 scenarios to a few that more closely reflect the actual situation. The actual situation, however, depends heavily on better insight into the role of forest recovery, much of which occurs with no intervention by GoT.

In contemplating the implications of these findings to present and future forest availability, it is important to note that the scenarios are, by and large, conservative estimates. For example, all scenarios with the suffix 'A' consider only low C_c, which has only ever been observed in Zanzibar. Secondly, consumption by sectors other than households has not been included in the national estimates. These are difficult estimates to make and would increase forest needed by 1–20% (Hoek-Smit, 1991; CHAPOSA, 2001). If any truth exists to the rumours of charcoal exports to the Middle East from Bagamoyo (The Guardian, 2005), then an entire new and little understood source of consumption is introduced: charcoal export. Finally, as it has repeatedly been said, forests are harvested for reasons other than for the production of charcoal. Overlap and interdependency is expected between the various driving forces for deforestation (Chidumayo, 1991). These findings suggest that the individual impact of charcoal, however, may be far larger than we are wont to believe.

The biggest concern in charcoal production is the removal of woody biomass, yet this can return in as little as 15 yr, depending on the conditions of the soil, climate and other factors and whether regeneration is given an opportunity to take place (Chidumayo, 1991). The permanent ecological footprint that the production process creates is on the patch of land onto which the kiln is constructed. For the most part, this has been considered an insignificant impact because it occurs in only 2–3% of the total area harvested (Chidumayo, 1993). While this is seemingly negligible when one is looking at a single forest stand, the footprint becomes progressively larger when one considers *enmasse* charcoal production: in 100,000 ha of forest harvested, 2000–3000 ha of patches are inconducive to regeneration. What this means to the future landscape of miombo woodlands has not been implicitly explored at this scale.

When consumption levels are consolidated to represent regional patterns, one sees clearly that Dar es Salaam city is the largest consumer of charcoal in Tanzania (Fig. 5). By virtue of her high population values, this city consumes 30% of total national consumption, an estimate lower than the 50% reported by TaTEDO (1998) but similar to that in Yahya (2001). The consumption in Dar es Salaam is equivalent to a daily demand rate of 16,000–24,000 sacks, very similar to that reported by CHAPOSA (2001) for the same city: 24,000 sacks day^{-1}. Discrepancies in regional consumption levels should alert policy makers that a national strategy to reverse or slow the rate of forest loss may not be the best course of action. The policy implications of this are discussed further in the policy recommendations section that follows this discussion.

To facilitate interpretation of future forest availability, only 12 of the 24 scenarios are presented in Fig. 6. For the purpose of policy formulation these could be viewed as the worst, median and best case scenarios. Real vs. perceived forest availability is illustrated by maintaining a distinction between forests that are legally available for charcoal production (forests on public land) and those that are protected (in reserves and in national parks). Thus, the course of the 12 trajectories can be followed to indicate when it is that a scenario leads to the complete loss of public forest, a time necessitating infringement into protected areas. This approximation of 'dooms day' is more informative and useful than the downward precipitation of forest cover to zero.

Under the worst-case scenario (3B) in Fig. 6, it is forecasted that public forests will be depleted by year 2028, 2032 or 2037, depending on the proportion of land that is allowed to regenerate. Under the median scenario (4A), 'dooms day' may be postponed by two decades (to 2048) or, in the case of the very best scenario (1A-60R), may never occur. The purpose of this study and the motivation for formulating the scenarios, however, was not to provide a date for when, precisely, forests in Tanzania will cease to be. Rather, it was to provide decision makers with an indication of how forests might be affected if current trends regarding charcoal use and production persist, and thus shed light onto the types of strategies that might best be implemented. The trajectories along a timeline are merely an estimate (with no error bars) of when it is that the problem changes from being solvable to being a complete disaster; a reminder that solutions to the charcoal problem should not be postponed any further.

The findings suggest that it is not necessarily alarmist to imagine a Tanzania with sparse to non-existent public forests, brought about solely by the high dependency on charcoal as the cooking energy of urban homes. If one takes a quick look at the history of charcoal interventions in sub-Saharan Africa, the cause for alarm becomes apparent. Unlike 30 yr ago, when the first alarm of an impending woodfuel crisis was heard, today we have a much better understanding of the dynamics of woodfuel and examples of the interventions that have and have not succeeded. To date, with the exception of South Africa and a couple of other richer nations such as Namibia and Botswana, no programme in the region has been able to claim success in reducing charcoal use (Girard, 2002). The most lauded example is that of the Senegalese GoT in 1974. In a move to reduce dependency on charcoal by 50%, the Senegalese GoT first subsidised the importation of LPG stoves and then later the gas itself and manipulated the price of charcoal to encourage urban households to switch away from charcoal (UNDP/World Bank, 1983; Sokona, 1999). Instead of registering a reduction in consumption, charcoal use rose instead and this is despite the fact that the price per heat generated of LPG was one-fifth and one-sixth less than the price of charcoal and kerosene, respectively (Girard, 2002). Today, it is widely accepted that the programme's goals were never attained and that its main effect was to diversify cooking fuels in urban Senegalese homes and to enable kerosene users to switch to LPG (Sokona, 1999).

In Tanzania, grandiose plans to electrify homes have existed since independence and may have placed unrealistic expectations on electricity as the solution to the cooking energy problem. With less than 10% of urban homes electrified (Uisso and Mvihava, 2005) the vision of widespread use of electric stoves in Tanzanian homes is a long time coming and, may in fact, never happen. The Tanzanian GoT's response to the threat of a woodfuel decline have, at best, been lacklustre; forests continue to meet the cooking energy needs of millions of homes in the nation. Policy interventions related to charcoal are often in the form of an outright ban on charcoal production. Yet, from Kenya to Mauritania, this strategy has proven to be ineffective: bans rarely reduce production but instead drive producers underground, making it difficult to place proper control of production procedures" (Girard, 2002). The following section provides a set of policy recommendations that for addressing the charcoal problem in Tanzania.

4.1. Policy recommendations

Tanzania is fortunate in that almost 50% of her forests are under some form of protection, yet it is a known fact that many reserves are merely paper reserves, in which illegal harvesting is rampant. The policy recommendations that follow are aimed at protecting forests in reserves by ensuring that main source of wood for charcoal production is from forests on public land.

The sensitivity analysis (Fig. 7) identifies regeneration and kiln efficiency as the two most important parameters influencing the forest needed to meet charcoal demand. This would require production-end intervention, yet Tanzanian GoT efforts to decrease forest loss from charcoal consumption have, by and large, ignored the charcoal producer. Sooner or later, officials (themselves consumers of charcoal) lift bans and the flow of charcoal to urban areas resumes. While consumers rejoice, producers remain cautious and must, because bans come and go and it is best not to announce one's profession. The undercover nature of the production process makes for opportunistic, non-committal producers with little interest in improving kiln efficiencies or undertaking reforestation programs. Under this backdrop, charcoal producers can maintain low point-of-production prices, especially when trees are free and consumers are plentiful (Van der Plas, 1995; CHAPOSA, 2001; Norconsult, 2002). Two recommendations are therefore proposed. First, that a price be paid for every tree chopped to produce charcoal; that the fee be paid to the village GoT, which is then charged with allocating a proportion of the funds to reforestation efforts. Tanzania's efforts to encourage joint management of forests (JFM) and community-based forest management (CBFM) is conducive to this because it has the potential of enabling communities to have by-laws that sanction charcoal production, require payment for tree removal and acquire the funds necessary to implement a regeneration programme. Assisted regeneration (as opposed to plantations) should be the preferred course of action as it requires lower capital costs, less maintenance (Olschewski and Benitez, 2005), and promotes replenishment of indigenous ecosystems.

The second recommendation would be to implement programs that train producers in kiln construction and tending methods that improve efficiency to at least 30%. Examples have been set by neighbouring countries, such as Zambia, whose Department of Energy has produced a manual for charcoal production from traditional earth kilns (Hibajane and Kalumiana, 2003). By placing a price on the raw materials for charcoal, producers will instinctively desire better efficiency out of their kilns. By permitting charcoal production, outreach to charcoal makers is facilitated and control of the trade is enabled. This would also lead to a substantial increase in the revenue generated by charcoal transportation, which presently results in $<40\%$ collection success (Norconsult, 2002).

Efforts to reduce charcoal consumption, by improving stove efficiency or promoting alternative cooking energy should focus first on Dar es Salaam. This would immediately target 30–50% of total forest loss in a city whose charcoal marketing and sourcing dynamics are well studied. The temptation to have a countrywide programme should by all means be resisted, since the conditions in Dar es Salaam are unlikely to be echoed elsewhere in the country. Fig. 5 should guide decision makers on the regions where programmes are most needed, and care should be taken to ensure that solutions are locale- and consumer-specific. Within a region, this may necessitate further subdivisions into district and ward levels, since the conditions may not be uniform across the area. It may also require that additional studies be conducted to determine a region's specific conditions regarding forest availability, consumption levels and the supply dynamics to and from other regions. Application of a planning tool such as woodfuel integrated supply/demand overview mapping—WISDOM—will allow local and regional GoTs to identify where within their jurisdictions sustainable charcoal production programs are justified (Drigo et al., 2002).

This study looked specifically at the contribution of households to forest loss, but it is estimated that an additional 1–20% of charcoal use in homes is attributable to sectors other than households (Hoek-Smit, 1991; CHAPOSA, 2001). Policy can sometimes be more effective on the private sector than in individuals' homes. Providing incentives to the private sector to switch to more efficient stoves, or to embrace alternative and cleaner fuels (such as LPG) could reduce the burden on forests by up to 20%. Again, programmes should be locale- and consumer-specific rather than generalised to a wider target group.

Finally, conflicting policies within the GoT may contribute to the reluctance by GoT and non-GoT organisations to commit resources towards charcoal-related interventions. For the purpose of charcoal production and consumption, the Forest Act 2002 (MNRT, 2002) provides an important framework for how forests are to be managed sustainably, and in particular, for the joint management of forests by local communities. Ensuring the provision of fuelwood by forests is not specifically mentioned in the Act, but could be encompassed by objective (e): "to ensure the sustainable supply of forest products and services by maintaining sufficient forest area under efficient, effective and economical management'' (MNRT, 2002). The National Forest Programme was formulated to put the Act into practice. Within the Programme and in the Act, there is no section, for example, that relates to training of charcoal producers in efficient kiln techniques. Rather, it is clear that charcoal production will not be tolerated in forest reserves (MNRT, 1998, 2002). Unlike the documents guiding the Ministry of Natural Resources and Tourism, there is place for developing and promoting use of efficient charcoal kilns and stoves in the National Energy Policy of 2000, which guides the Ministry of Energy and Minerals (MEM). The specific objectives of this policy relevant to the charcoal situation are to: (a) provide reliable and affordable energy nationwide, (b) increase energy efficiency and conservation, (c) take into account the environmental impacts of energy activities and (d) enhance the development and utilisation of traditional and renewable energy sources and technologies (MEM, 2000). Charcoal production and firewood collection straddle both the forest and energy sectors. Interventions to control or reduce their use require a uniform message to be emanated from both these sectors. The GoT is strongly urged to reassess its forest policies and acts so that they acknowledge the heavy and long-term dependence of the nation on this sector for cooking energy. This will serve to especially facilitate the legal and rightful implementation of programmes that address producers, a group of people who have thus far been sidelined and viewed as pesky intruders and destroyers of forests.

5. Conclusions

The objectives of this study were to: (a) investigate the contribution of charcoal to forest loss in Tanzania, (b) to project future forest availability based on current consumption and production trends, and (c) to propose policy recommendations for lowering the burden on forests placed by nationwide dependence on charcoal. The work of estimating how much forest is needed to meet charcoal demand is marred with uncertainties, yet necessary for policy and planning purposes. Decision-makers, environmentalists and all those concerned with either conserving forests or ensuring continuous energy supply to urban consumers are best served by a suite of possible outcomes rather, than the false notion of a single ''best-answer''. Narrowing down the range of values used to estimate some of the parameters, as I have attempted to do here, can provide better insight into the 'actual' scenario. In the meantime, scanty data on forest loss and forest recovery are the biggest impediment to arriving at better estimates.

To appreciate the meaning of these findings, one has to concur with the presumption that the wood needed to produce charcoal originates from forests that are harvested specifically to quench charcoal demand. This is different from assuming that charcoal is a by-product of bigger forces, such as logging for timber or agricultural expansion as has often been claimed in past studies. Charcoal (a marketable commodity that is produced by human labour and skill) and firewood (a product that is harvested in useable form, directly from nature) cannot be treated as similar items and provide true insight into the nature of the woodfuel crisis. By failing to highlight this important distinction, the solo-impact of charcoal may have been grossly underestimated in the past and partially responsible for the lacklustre approach by governments in the region to pursue their 1980s woodfuel energy programs.

The rate at which Tanzania joins the global trend of containing most of its citizens in urban centres is faster than the rate at which GoT interventions get planned and implemented. It is questionable whether the GoT and NGOs will react in time and succeed to curb the progression to complete depletion of forests on public land. When cast onto such a backdrop, these findings strongly suggest that a charcoal crisis (but not necessarily a woodfuel crisis) is imminent. Interventions to reduce charcoal consumption levels and improve production procedures are urgently needed. To minimise resources and maximise the success of intervention programs, however, programs should be geared towards those areas where they would have the greatest impact.

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