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Biofuel consumption rates and patterns in Kenya

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Abstract

A questionnaire survey was conducted in rural and urban Kenya to establish biofuel consumption rates and patterns. The survey targeted households, commercial catering enterprises and public institutions such as schools and colleges. Firewood was the main biofuel used, mostly by rural households, who consumed the commodity at average consumption rates in the range 0.8–2.7 kg cap^{-1} day^{-1}. Charcoal was mostly consumed by the urban households at weighted average rates in the range 0.18–0.69 kg cap^{-1} day^{-1}. The consumption rates and patterns for these fuels by restaurants and academic institutions, and those for crop residues are also reported. The rates largely depended on the fuel availability but differed significantly among the three consumer groups and between rural and urban households. Other factors which may have influenced consumption rates are discussed. Although good fuelwood sufficiency was reported in the country in 1997, there were increasing difficulties in accessing these resources by most households, a situation having both short- and long-term implications for biofuel consumption rates and patterns.

Keywords: Biofuels; Per capita consumption; Kenya

1. Introduction

The energy-use patterns among households in Kenya have drawn considerable attention from planners and policy makers during the 8th development plan period [1], owing to the rapid deforestation and the rising prices of commercial energy required to meet the needs of the growing population [2]. Official reports place the demand for energy from charcoal and firewood at 68% of the total energy supply [3]. Our perusal of available literature revealed a considerable number of biofuel consumption studies in Africa. A fair proportion of these were carried out in Kenya (Table 1) by various interested groups. These studies bring to light an annual per capita consumption range of 690–890 kg for firewood and 70–110 kg for charcoal (air dry weight in both cases), varying mainly with commodity availability.

The reported ranges in consumption rates for all biofuels between individual studies are quite large. Where national studies were done, poor sampling techniques were employed, for example, excluding certain important consumer groups such as communal and commercial institutions. A majority of these studies covered small ethnic locations and urban centres, not representative of the national picture. Furthermore, spatial and temporal patterns are not clearly reported. In

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Table 1
Data on biofuel consumption rates in Kenya from studies between 1979 and 1995. All values in kg cap^{-1} yr^{-1}

References	Secondary references	Comments	National	Rural	Urban
Firewood					
Hosier (1985) [4]	Akinga (1980) [5]	Survey of the Kenya Forest Department (1979)	892	—	—
Hosier (1985) [4]	—	Central Bureau of Statistics, 1981	792	—	—
Hosier (1985) [4]	—	Questionnaire survey, 572 households, 1981	—	726	—
Senelwa and Hall (1993) [6]	CBS (1984) [7]	Energy flow chart	713	—	—
Prasad (1987) [8]	O'Keefe and Raskin (1985) [9]	—	—	666	49
FAO (1995) [10]	—	FAO estimates for 1993	695	—	—
Ellis et al. (1984) [11]	—	NW Kenya, Turkana, 4 households 1981–82	—	402 (329–511)	—
Mungala and Openshaw (1984) [12]	—	SE Kenya, Machakos district, 1977–1978	—	707	29
Jensen (1984) [13]	—	S Kenya, Amboseli Maasai, 97 interviews 1981	—	355	—
Ensminger (1984) [14]	—	SE Kenya, investigation in 3 rural areas:	—	—	—
		Nomadic Galole	—	392	—
		Sedentary Galole	—	529	—
		Sedentary Chaffa	—	400	—
Milukas (1993) [15]	—	S Kenya, Nairobi	—	—	68
Milukas (1993) [15]	—	SW Kenya, Nakuru	—	—	66
Charcoal					
Hosier (1985) [4]	Akinga (1980) [5]	Survey of the Kenya Forest Department, 1979	96	—	—
Hosier (1985) [4]	—	Central Bureau of Statistics, 1981	111	—	—
Hosier (1985) [4]	—	Questionnaire survey, 572 households, 1981	—	17	—
Barnard (1987) [16]	Burley (1982) [17]	—	—	—	100–170
Prasad (1987) [8]	O'Keefe et al. (1984) [18]	—	—	179	1271
Senelwa and Hall (1993) [6]	Senelwa (1988) [19]	Energy flow chart	70	—	—
FAO (1995) [10]	—	FAO estimation for 1993	76	—	—
Mungala and Openshaw (1984) [12]	—	SE Kenya, Machakos district, 1977–1978	—	25	146
Milukas (1993) [15]	—	S Kenya, Nairobi	—	—	71
Milukas (1993) [15]	—	SW Kenya, Nakuru	—	—	148
Firewood and charcoal					
Openshaw (1981) [20]	—	SE Kenya, Machakos district, 1977–1978	—	786–1071	—
Millington et al. (1994) [21]	World Bank (1994) [22]	data for 1990	1071	—	—
FAO (1995) [10]	—	FAO estimation for 1993	1008	—	—
Agro-residues					
Senelwa & Hall (1993) [6]	—	Energy flow chart	87	—	—
Dung					
Senelwa & Hall (1993) [6]	—	Energy flow chart	22	—	—

addition, despite the importance of agricultural residues in fuelwood substitution, no national data for the consumption of residues is available for Kenya. A clear understanding of biofuel-use patterns and parameters influencing them is imperative. Additionally, there is need to have reliable biofuel consumption data as a basis for formulating sound energy policies.

This paper presents results from a questionnaire survey carried out in Kenya during the dry season between January and March 1997. The survey was among the initial phases of a wider study to estimate the contribution of biofuel-use in Kenya to the regional and global trace gas budgets. It aimed at determining consumption rates for all common biofuels used by households, communal institutions and commercial catering centres and the factors influencing the observed use patterns.

1.1. Background

The country has a land surface area of 582,646 km^2. The national census results for 1999 released recently (March 2000, Central Bureau of Statistics) reported a national population of 28.6 million, of which about 77% live within the rural areas. The shares of the major economic sectors in the gross domestic product (GDP) in the 1990–1995 period were agriculture 26%, industry 14% and services 60%. The country's rapid urbanisation was expected to reach 23% in the year 2000 up from 17% in 1989 [1]. Apart from the high population growth rate of 2.7% [1], little agricultural land available also limits Kenya's agricultural and agroforestry production, since about 81% of the population is concentrated in the humid and sub-humid regions where these activities are intense.

Kenya enjoys a variety of climates and soils in different parts of the country. The potential of land for vegetation cover and agricultural production has been classified mainly on the basis of moisture availability. On this basis, we carefully combined the diverse classifications employed by various authors [23–27] into four regions which in this study will be referred to as agro-ecological zones (AEZ). These are the highlands (AEZ I), the savanna (AEZ II), the coastal region (AEZ III), and the Nyika plateau or arid and semi-arid lands (ASAL, AEZ IV). The zones have distinct humidity ranges, mean annual temperatures, rainfall and altitudes, that largely dictate their respective ecological potentials as described in Table 2.

Land use in Kenya can therefore be broadly categorised into two types: those occurring in the high and medium potential areas (AEZ I–III) with medium to high rainfall, and those occurring in the ASAL (AEZ IV). The medium and high potential areas cover approximately 165,240 km^2 and are primarily agricultural, including dairy farming. Lakes, forests, urban centres and industries are also found here. The ASAL occupies about 70% of the country's total area and supports up to 6% of the country's population, 50% of the livestock herd and a major proportion of wildlife resources. Pastoralism is commonly practised here.

2. Methodology

2.1. Site stratification and sampling

Thirteen stations — which cut across the various population densities, cultures and land-use practices, vegetation, and relief — were selected countrywide from the various agro-ecological zones. For purposes of this work, a station was either a political district that was considered for rural classification or a municipality in the case of urban stations. Within each station, several clusters were chosen (Table 2) based on the method of Hosier [28] for rural areas, and on the house types and their respective locations in the case of urban centres. Unlike the other three urban centres in the sample, Nairobi and Mombasa were stratified into four groups based on various socio-economic variables. Our reconnaissance tour revealed a wide range in income between the first (very highly paid) and the next of the other three groups. We did not therefore consider this high-income group in our sample.

We stratified the clusters, basing on house type, farm sizes, crop types and number of animals. Using this framework, rural households fell into three main categories — food-crop farmers, cash-crop farmers and wage workers — with various general characteristics distinguishing one group from another.

2.2. Data collection

Data were gathered based on a 0.04% sampling intensity countrywide. In total, 2202 households, 54

Table 2
Stratification and general characteristics of selected sample sites. A household (HH) cluster consists of 20–40 households

AEZ	Centre	HH	(clusters)	Institutions	Restaurants	Suppliers	Pop. density[a] (per km^2)	Altitude[b] (m)	Rainfall[c] (mm mon^{-1})	Mean temp[c] ($^{\circ}$C)	Area[a] (km^2)
I	Kakamega	350	(13)	14	6	13	411	1600	135.8	20.9	3520
	Nakuru	298	(10)	8	10	11	118	2600	23.3	19.5	7024
	Nyeri	198	(6)	3	6	6	186	2000	54.9	17.8	3284
	Eldoret[d]	75	(3)	1	4	3	800	2300	40.8	17.1	—
	Meru[d]	74	(3)	3	3	3	740	1650	33.3	18.4	—
II	Kisumu	213	(6)	3	6	6	320	1100	89.3	23.5	2093
	Bungoma	160	(6)	3	—	4	240	1300	67	21.0	3074
	Machakos	134	(5)	3	6	3	100	1550	51.8	22.5	14178
	Bungoma[d]	74	(3)	—	—	2	590	1300	67	21.0	—
	Nairobi[d]	280	(12)	4	5	8	1911	1900	59.3	20.1	—
III	Kilifi	122	(4)	3	3	3	46	350	24.1	26.5	12414
	Mombasa[d]	161	(6)	3	6	3	1637	0–30	12.9	27.4	—
IV	Isiolo	63	(3)	3	2	5	3	850	8.2	30	25605
	TOTAL	2202	(80)	54	63	74	37				

[a] *Source*: Statistical Abstracts [31]. No areas for the municipalities were readily available.
[b] *Source*: Teel [27].
[c] Meteorology Department, Nairobi. Averages for January and February 1997.
[d] Urban sites.

boarding academic institutions and 63 commercial catering enterprises were sampled. Table 2 describes the distribution of these across the AEZs. The questionnaire used in this survey was adopted from that of Marufu et al. [29] with some minor adjustments to suit the Kenyan situation. This survey instrument was designed for the purpose of verifying existing rural, urban and national biofuel consumption estimates for Kenya (Table 1), while addressing specific issues that may influence the observed levels for various fuel types and consumer groups.

The questionnaire put emphasis on daily combustion activities such as cooking, heating and lighting. Fuel properties influencing combustion characteristics and consumption rates and patterns, such as moisture content and biofuel type, were noted. This instrument systematically addressed the fuel end-uses, frequency and duration of all the daily combustion sessions. Information on the fuel sources, sourcing patterns and the general fuel supply situation across the study areas were gathered as adequately as possible.

Eight enumerators were employed and trained in advance of the exercise. The enumerators, under supervision of the investigator, moved randomly from one household to another within the chosen cluster. They interviewed household heads or their representatives and weighed the presumed daily household biofuel needs using a weighing balance. The number of households visited per station and cluster was determined largely by the population density of any given station. The highly populated stations had more clusters than those with low populations.

The accuracy of the data gathered depended on the respondent's memory. To account for this, 3–5% of households per station were subjected to actual consumption experiments, in which an enumerator weighed the actual biomass burnt in each of the several daily combustion sessions. These data were used to derive correction factors where necessary. Information from catering enterprises and academic institutions was collected by an investigator.

2.3. Computation of per capita consumption

Per capita biofuel consumption of any given biofuel (air dry weight) was calculated separately for all fuels and consumer groups during the study period, using the expression

$$Consumption = C_w/P,$$

where C_w is the weight of the total fuel consumed daily in kg and P is the total sample population. The consumption rates are given as the means in kilograms per capita per day (kg cap^{-1} day^{-1}) and later converted to annual values to allow for comparison with other literature values. The users-only consumption rates reported are the averages of consumption rates calculated by considering data for only the households reporting the use of a given biofuel. Owing to the difficulty in establishing the actual number of meals served each day in restaurants, this study assumes that each guest takes only one meal each day. Hence the approximate number of guests per day is preferred for use in per capita consumption estimates. At various stages, data were tested for correlations and significant consumption differences by one-way ANOVA (analysis of variance) and conventional comparison of means. Charcoal is assumed to be produced at 17% kiln efficiency from wet wood of about 30% moisture content. 1 kg of air dry firewood, charcoal and crop residue is assumed to have 18, 31 and 13.5 MJ of energy content, respectively.

3. Results and discussion

3.1. *Socio-economic characteristics of survey areas*

Determination of actual household incomes was difficult to achieve using our questionnaire, as most household heads preferred not to reveal what they earned. For peasants, it was not possible to exactly gauge, inter alia, the monetary value of their produce. The factors discussed in the following sub-sections influenced biofuel consumption rates and patterns.

3.1.1. *Meal type, number per day and cooking duration*

Between 75 and 90% of both rural and urban households reported having 3 meals per day. *Ugali,* a pasty substance made by stirring corn flour in boiling water, was the most popular food across the AEZs and is relatively faster to prepare. This food was also the most popular in urban and rural centres, where 73 and 71% of the households, respectively, reported preference. Whereas rice was the second most preferred food by urban people (19% of urban households), *githeri*, a mixture of maize, beans and sometimes vegetables, was the next most preferred by rural people. Dry maize was boiled overnight in many households, while others did so the whole morning before mixing with raw beans.

Except for households in AEZ III, between 34 and 54% of the households in all AEZs cooked for periods lasting 2–3 h daily. Most of the households (36%) in AEZ III cooked for 3–4 h daily. Whereas the periods reported for urban households appeared normally distributed about the 2–3 h interval, the distribution of cooking duration for rural households were negatively skewed towards longer cooking periods.

Whole-grain foods such as *githeri* require a long period of boiling and therefore have a substantially higher energy requirement. Being simple to make, cheaper and easily acquired from farms, the whole-grain foods are popular among academic institutions and the lower class populations. Food types and frequency of preparation may, to a considerable extent, define the socio-economic class of given households. Dewees [30] also highlighted the importance of food types in determining firewood consumption patterns. Schools and colleges provided an average of three simple meals each day, although colleges had frequent instances of fuel substitution with gas and charcoal, leading to the lower firewood consumption per student each day of only 0.34 kg. Universities on the other hand, provided a variety of foods on their diets, which were also served more frequently per day. This could lead to higher per capita consumption, although charcoal, gas, electricity and diesel-powered steam cookers were also used concurrently in most of their kitchens.

3.1.2. *House type*

About 74% of the interviewed urban households lived in permanent houses, 62% of which were supplied with electricity; and 23% of the urban households lived in semi-permanent housing, with the rest (3%) dwelling in temporary structures. Permanent housing, for the purposes of this study, comprised stone, concrete or brick-built structures covered with brick tiles or corrugated iron sheeting. Semi-permanent houses were those constructed from mud with supporting poles and roofed with corrugated iron sheets. Timber and iron-sheet-walled structures with iron sheet or tin roofing and grass-thatched mud-walled huts were classified under temporary housing.

A majority (57%) of rural households lived in semi-permanent houses, while another 26% were found in temporary, mainly wooden housing. The rest lived in permanent brick or stone housing, 4% of which were supplied with electricity. Electrified, permanent and semi-permanent houses were largely concentrated in AEZs II and III, while temporary houses were common in AEZs I and IV. None of the interviewed households in AEZ IV (only 2% permanent houses) had access to electricity.

3.1.3. Occupation of household heads

The highest fraction of interviewed household heads (about 29%) among urban dwellers were businessmen, followed by the category "other", that included employees in the private sector and non-governmental organisations (NGOs). Urban centres also registered the highest number of civil servants and casual labourers. About 30% of the rural household heads were farmers, involved in mixed farming as small holders; and 20% were casual labourers, mainly on larger farms, forming the second largest occupational group among rural household heads. Between 12 and 18% were civil servants, small-scale businessmen or employees in the rural-based private sector.

Some of the small-scale commercial activities included food vending and brick making, which involved 5 and 4%, respectively, of all rural household heads. Other rural household heads were engaged in tobacco curing and iron casting, especially in AEZ II. Beer brewing (though illegal) and herbal medicine preparations were popular among the urban lower class, whose most popular small business was also food vending. The highest percentage of urban household heads were reported to be businessmen, casual workers and farmers in the zones of the ASAL, coastal region and highland, respectively, while the AEZ II held the most civil servants and private sector employees.

3.1.4. Farm sizes

Less than 5% of the urban population owned farms, mainly plots within the city, most being between 0.01 and 1 ha. The situation was different within rural areas where 21% of the households owned between 1 and 2 ha. Those with over 4 ha comprised 16% of the rural household sample. All the rest belonged to either the 0–1 or the 2–4 ha categories. The highest percentage of households reporting land ownership were located in AEZ I. According to official statistics, small farms in the highlands zone are defined as those between 0.2 and 12 ha, while large-scale farms measure an average of 700 ha each [31]. About 25% of farms in this region range between 20 and 50 ha. In the ASAL, 2% of the zone's population were farm owners with 1 and 2 ha.

3.1.5. On-farm crops and livestock

Maize was the most popular crop with 70% of the rural households reporting annual planting. Thirty-three percent reported planting various other crops mainly for subsistence. Beans and potatoes were especially popular in AEZ I and II; and cassava and coconut featured mainly among coastal communities, being reported by 19 and 7%, respectively. Cash crops such as coffee, tea, sugarcane and pyrethrum, were mainly reported by households in AEZ I. Common animals included cattle, goats, sheep, chicken and donkeys among rural homesteads. Camels and traditional *Zebu* cattle dominated the ASAL nomadic households.

3.1.6. Academic institutions

The country has three main categories of academic institutions. In 1994, there were about 16,000 primary schools with an enrollment of about 6 million pupils, and about 2900 secondary schools with approximately 650,000 students [31]. Under tertiary institutions, there were about 66 teachers training and technical colleges and government administration and special education institutes enrolling about 33,450 students. This category also included three national polytechnics and six state universities enrolling about 10,900 and 38,510 students, respectively. The 12 private universities in the country have an enrollment of about 4490. A vast majority of the secondary and tertiary academic institutions, and a significant number of primary schools in Kenya are boarding institutions.

3.2. Per capita biofuel consumption rates and patterns

This survey was conducted during the dry season and the consumption rates and patterns reported here apply mainly to that part of the year. This is so because there may exist seasonal variations in fuel choices, demand, availability and sourcing patterns. Apart from the biofuels, the other two fuel types found in use were kerosene and liquid petroleum gas (LPG), whose consumption rates were estimated as 0.06 l cap^{-1} day^{-1} and 0.007 kg cap^{-1} day^{-1}, respectively, whereas 95% of the sampled population used kerosene for various purposes, only 8% reported the use of LPG for domestic purposes, owing to the high costs involved. Electricity was mainly used for lighting, with a few urban households reporting its use for cooking owing to high cost of electric power. Furthermore, rural electrical power supply is so low that it can only be used for lighting.

Household firewood consumption was the highest of the three consumer groups, generally tending to decrease with decreasing ecological potential. Restaurants recorded the highest per capita charcoal consumption rates. There were, however, no significant variations across the AEZs or between rural and urban locations. Owing to the localised nature (all in AEZ I and II) and small number of institutions reporting charcoal use (20%), we did not consider estimates for institutional charcoal consumption per AEZ. The users-only charcoal consumption rate reported was 0.13 ± 0.21 kg cap^{-1} day^{-1} among institutions. Only 33% of restaurants reported using firewood, none of them being in AEZ IV, leading to the users-only estimate of 0.94 ± 1.15 kg cap^{-1} day^{-1} among restaurants.

3.2.1. *Firewood consumption by households*

Firewood consumption rates in the rural study areas ranged from 0.8 to 2.7 kg cap^{-1} day^{-1}, yielding a weighted average of about 2.14 kg cap^{-1} day^{-1}. This figure translates to a conservative 780 kg cap^{-1} yr^{-1}, falling above the range for rural consumption reported by other studies as indicated in Table 3. This could be attributed to the fact that no correction for residue use by some households was made in the process. However, this figure is also likely to be an underestimate as it does not take seasonal variations in firewood consumption into consideration since the study did not transcend seasons. As observed during the study, between 70 and 90% of respondents in the cooler, high altitude AEZ I (due to Mt. Kenya and Mt. Elgon effects) reported using charcoal and firewood for space heating, whereas none of the respondents in AEZ III and IV used any fuels for space heating in the low-altitude warm conditions typical in these regions. Similar observations were made in Zimbabwe [32] and the Himalayas [33], where winter period fuel consumption rates were higher than those in summer due to the increased need for space heating.

The recorded high firewood consumption rate in the highlands zone could also be due to the higher percentage of households cooking grain-only meals such as *githeri*, other than the popular *ugali* dishes. Results obtained by Hosier [28] in a 1984 study in the region, pointed to *githeri* as being the most favourite in this zone, with ugali-based dishes being fewer among households in Central and Rift Valley provinces. A household consistently cooking *githeri* consumed 1400 kg more wood per annum than one relying on other non-whole-grain diets.

In general, in rural areas, where most of the wood used is gathered free of charge from the surrounding environment, consumption rates are basically a function of availability. Inhabitants of areas with abundant fuel supplies tend to consume more fuel per capita than those of fuel-stressed areas. Observed cooking and firing practices across the four ecological zones showed that as fuelwood becomes scarce and therefore more difficult to gather, households first respond by adopting more efficient ways of using fuel such as quenching fires with water soon after a cooking session to avoid unnecessary fuel wastage. This response strategy may lead to the lowering of consumption rates in proportion to biofuel availability. But beyond certain critical levels of fuel scarcity, households make further adjustments to supplement or completely substitute the preferred fuel with other less favoured but available fuels. An example to this was the widespread gradual shift to the use of *Lantana camara*, a hedge, in Bungoma (in AEZ II) following dwindling levels of preferred tree types.

The urban firewood consumption lay in the range 0.01–0.5 kg cap^{-1} day^{-1}, giving a weighted average of 0.14 kg cap^{-1} day^{-1}. This is an equivalent 51 kg cap^{-1} yr^{-1}, falling within the range (9–68 kg cap^{-1} yr^{-1}) of other reported rates in Table 3. Firewood use in urban areas was mainly for berbeques or by some families among the urban poor, hence the low consumption rates. Fig. 1 compares weighted daily per capita consumption rates for the biofuels reported for rural, urban and national scenarios. Compared to many other African countries

Table 3
A comparison of reported consumption rates ($kg\,cap^{-1}\,yr^{-1}$) for Kenya

Biofuel type		National[a]	Rural	Urban
Firewood	Literature[b]	695–892	355–726	29–68
	This study	637 ± 229	291–1128	4–193
Charcoal	Literature	70–111	17–179	71–1271
	This study	103 ± 43	24–169	67–252
Residues	Literature	87	—	—
	This study[c]	23 ± 53	2–268	0–22
Dung	Literature	22	—	—
	This study	0	0	0

[a]Ranges for this study are 95% confidence intervals for annual per capita consumption.
[b]Actual literature figures were obtained from Table 1.
[c]Calculated assuming a 3-month consumption period.

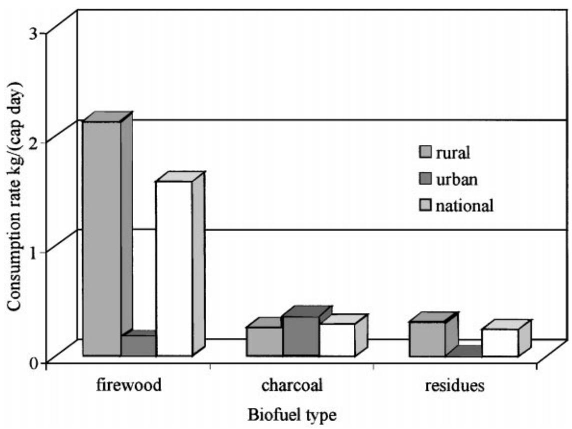


Fig. 1. A comparison of the mean weighted consumption rates of the major biofuels for urban, rural and national levels.

(Fig. 2), Kenya's rural fuelwood consumption rate was moderate but among the lowest in the region among urban households.

3.2.2. Charcoal and crop residue consumption by households

Charcoal use was common in the urban areas where the consumption rates fell in the range 0.18–0.69 $kg\,cap^{-1}\,day^{-1}$, with a weighted average of 0.37 $kg\,cap^{-1}\,day^{-1}$. This was much higher than that reported for the rural areas, 0.26 $kg\,cap^{-1}\,day^{-1}$, where households across the ecological zones consumed charcoal in the range 0.07–0.46 $kg\,cap^{-1}\,day^{-1}$. The higher charcoal consumption rates in the urban areas are mainly due to the convenience associated with its usage and cost, while the abundant firewood and the high cost of charcoal explain the observed scenario in the rural areas. The weighted consumption rates for rural, urban and national cases all fell within the reported ranges (Table 3). The charcoal used in urban areas was transported from distant rural locations where the commodity was produced. The light weight and high-energy intensity associated with charcoal makes it more attractive.

Crop residues were consumed by rural households at rates ranging from 0.01 to 0.7 $kg\,cap^{-1}\,day^{-1}$. The weighted mean consumption rate for residues by rural households was 0.32 $kg\,cap^{-1}\,day^{-1}$ maize cobs, the most common crop residue type, was consumed for an average 3 months each year (when the commodity was available) by about 22% of the sampled households. The weighted urban residue consumption rate was 0.02 $kg\,cap^{-1}\,day^{-1}$. No estimates were previously published for rural and urban residue consumption in Kenya. The value of 87 $kg\,cap^{-1}\,day^{-1}$ reported for national residue consumption was derived from a theoretical model of Senelwa and Hall [6]. Other residues such as coconut ribs, husks and shells were used not as firewood substitutes (as was the case in many households reporting maize cob use) but as the sole fuel in many households at the coast. This was attributed to the high availability of the residues from the expansive farms in the region. Other crop residues used in other parts of the country included rice straws and bagasse. All these were, however, used together with firewood at varying proportions and not in isolation, by a few households within the production zones.

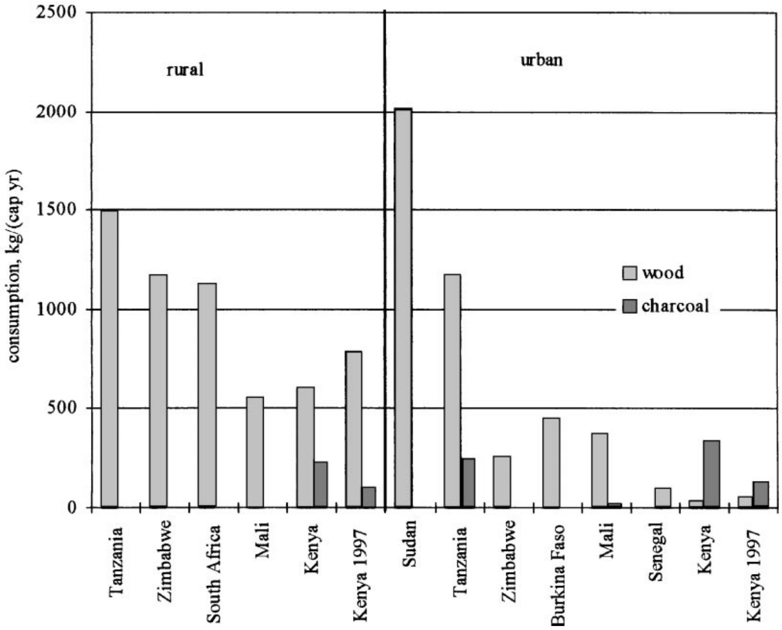


Fig. 2. Comparison of charcoal and firewood consumption in some African countries. Kenya 1997 represent levels from this study.

3.2.3. Biofuel consumption by academic institutions and restaurants

About 98% of the sampled institutions depended mainly on firewood, consuming it at the rate of 0.54 kg cap^{-1} day^{-1}. About 20% employed some charcoal, mostly for special diets on special occasions, using it at a lower rate of 0.04 kg cap^{-1} day^{-1}. Unlike the institutions, public catering units mainly preferred charcoal, and 95% of these reported consumption at a rate of 0.36 kg cap^{-1} day^{-1}. As is the case with urban households, the lightweight and high-energy intensity and general conveniences (in comparison to firewood) associated with charcoal makes it more attractive for restaurant use. About 33% of restaurants reported either full dependence on or partial use of firewood in their daily cooking programs. These were mainly in rural commercial centres within AEZ I, where farmland vegetation and timber off-cuts from saw mills are in plenty. A major observation made was that collective cooking to serve many people (such as in commercial enterprises and academic institutions) demands less fuel per capita than cooking for the small groups as in households. Some LPG was also employed for limited operations among institutions and restaurants where 13 and 32%, respectively, reported use.

3.2.4. Influence of firewood cost and source distance

Fuel cost was defined in monetary terms, where the unit cost was the amount paid by the consumers in exchange for a kg of fuel. At the study time, the currency exchange rate was 1US$ = KSh 60. The percentage of households buying firewood decreased with ecological potential from the highlands zone (45% of households) to the ASAL, where only 5% reported buying firewood. Between 40 and 50% of all households in AEZ I–III collected firewood freely from a wide range of sources, with on-farm sources being higher in the savanna than the highlands. Over 85% of the ASAL households freely collected their firewood in the shrublands and woodlands. Thirty-two percent of firewood in the rural setting was obtained on the farms, while 48% was collected on other trust lands or by road sides. Only 7.4% of the urban communities reported using firewood, of whom 61% bought their supplies from local suppliers. Owing to the abundant fuelwood supply in most rural areas, a significantly small number of households purchased their needs.

Table 4
The fuel unit costs and distances to source reported in rural and urban areas

	Distance (km)				Unit cost (KSh kg^{-1})	
	Rural		Urban		Rural	Urban
Fuel	Mean (± SD)	Median	Mean (± SD)	Median	Mean (± SD)	Mean (± SD)
Firewood	1.16 ± 0.94	0.8	1.51 ± 1.81	0.6	1.26 ± 0.45	1.64 ± 0.50
Charcoal	2.10 ± 2.31	1.04	0.57 ± 0.63	0.28	4.40 ± 0.69	5.84 ± 1.95
Kerosene	3.49 ± 2.40	2.6	0.71 ± 0.40	0.59	26.22 ± 2.07	25.14 ± 1.62
Gas	11.51 ± 17.69	4.49	1.73 ± 0.79	1.5	32.48 ± 20.60	48.62 ± 3.44

Farms within the rural areas were within about 1 km of the residential areas (taking the median of means from different clusters) countrywide, making it easy for small holders to harvest their crops and process the residues.

The mean per capita consumption of firewood in urban areas was 0.14 kg cap^{-1} day^{-1}, a mean rate which tended to increase as the unit cost of firewood and distance to source decreased. The shortest mean distance to the source (0.2 ± 0.1 km) was recorded in the ASAL, attributed to the pastoral way of life that is characterised by nomads settling near water and wood resources, while the furthest sources (1.9 ± 2.13 km) were those within the rural highland (AEZ I) locations. In such cases, wood was collected from their distant farms, to which they daily report to carry out farming activities. AEZ I was also the zone with the highest land ownership. Table 4 compares fuel source distances and unit costs in rural and urban sites studied. The mean unit costs for firewood and charcoal were higher in urban than in rural areas. This reflects the opportunity cost of the labour which is required to obtain the biofuel. A general increase in firewood unit cost was also observed across the AEZs, being cheapest in the AEZ I (KSh 1.03 ± 0.40 kg^{-1}) owing to abundant resources, and most costly in AEZ III (KSh 1.83 ± 0.67 kg^{-1}) owing to long distances to sources and preferential use of abundant coconut residues. A small drop in the pattern at AEZ IV to KSh 1.50 ± 0.5 kg^{-1} was noted.

Institutions which consumed more firewood generally paid less per kg than those consuming less wood (Table 5). Institutions in AEZ III had the highest unit cost of wood (KSh 1.93 ± 1.07, attributed to long distances to sources) yet had the lowest per capita daily consumption of 0.34 ± 0.29 kg (median 0.25 kg) and also the lowest mean institutional population of 418 ± 214 students per cluster (each cluster had 1–3 academic institutions). Most institutions in AEZ III substituted firewood with gas cookers for certain meals, despite high LPG cost. ASAL institutions, with the highest mean institutional enrollments per cluster (Table 5) consumed the largest amount of firewood (0.93 ± 0.7 kg cap^{-1} day^{-1}) yet paid the lowest unit cost for their wood (KSh 0.67 ± 0.242 kg^{-1}). Institutions in the ASAL harvested their own wood from the abundant semi-arid and arid shrublands and woodlands, only buying small quantities occasionally, with hence lower costs. Some poor parents unable to afford school fees for their children were often allowed to supply the respective institutions with firewood.

The consumption rates for universities, teachers and technical colleges, and primary and secondary schools are compared in Table 5. The universities consumed the highest quantities per capita and paid the highest cost per kg of firewood. Boarding schools consumed the least wood per capita. Removing outliers (using the Dickson's Q-test, Nachmias and Nachmias [34], the more realistic mean unit cost of KSh 0.67 kg^{-1} for the schools was realised. For colleges, the enrolment, per capita consumption and unit cost lie in between those of schools and universities; however, the costs and consumption estimates among the three institution groups do not vary significantly. The unit cost of wood for the universities was the highest among institutions, attributed to the nature of wood supplied to them. The suppliers were expected to deliver specific qualities and quantities of wood within specific periods of the year. This is unlike schools and colleges, which mainly accepted whatever was delivered.

3.2.5. *Influence of charcoal cost and source distance*

Unlike firewood, charcoal in Kenya is normally delivered in 50 kg (national median obtained from

Table 5
Institutional enrolments, firewood unit costs and consumption rates

	n	Mean enrolment per institution	Consumption rate ($kg\,cap^{-1}\,day^{-1}$)	Firewood unit cost ($KSh\,kg^{-1}$)
AEZ				
I	28	565 ± 332	0.52 ± 0.38	1.13 ± 0.86
II	15	713 ± 179	0.71 ± 0.40	1.01 ± 0.61
III	6	418 ± 214	0.34 ± 0.29	1.93 ± 1.07
IV	3	733 ± 391	0.93 ± 0.70	0.67 ± 0.24
Institution type				
Boarding schools	38	520 ± 263	0.47 ± 0.42	1.19 ± 0.91
Colleges	10	783 ± 319	0.50 ± 0.34	0.72 ± 0.35
Universities	4	913 ± 337[a]	0.81 ± 0.82	2.20 ± 2.43

[a]Student enrolment for section of institution using the visited kitchens.

Table 6
Mean charcoal consumption rates, unit cost and daily guest number per restaurant

	n	Guest number per day	Consumption rate ($kg\,cap^{-1}\,day^{-1}$)	Unit cost ($KSh\,kg^{-1}$)
AEZ I	33	178 ± 122	0.55 ± 0.41	3.96 ± 0.59
AEZ II	17	217 ± 136	0.42 ± 0.24	4.61 ± 0.71
AEZ III	9	181 ± 124	0.53 ± 0.25	4.40 ± 0.58
AEZ IV	3	150 ± 50	0.10 ± 0.02	4.20 ± 1.40

our reconnaissance studies among 74 charcoal dealers involving actual weighing of packed bags ready for distribution. A large range of bag weights, 18–58 kg, with a mean of 46 ± 13 kg was recorded across the country, occasioned by the use of different wood types) gunny or polyester sacks to restaurants and many households. Some was sold in smaller quantities at local kiosks. The reported consumption rates for charcoal in urban and rural regions were 0.36 and $0.26\,kg\,cap^{-1}\,day^{-1}$, respectively, although the users-only (only those households in the sample which report use of the fuel type) rates were about three times higher in each case. No special relationships were observed from one AEZ to the next as far as charcoal consumption rates were concerned. The consumption per capita was generally low where both the distance to the source and the consumer prices of charcoal were high, in both urban and rural areas.

Except for rural areas, where about 14% the households interviewed produced their own charcoal (a small portion of what is produced for sale), almost all other households bought their charcoal from traders. In general it is worth noting that people who produce charcoal rarely use it themselves. Except for the ASAL zone, the distances to charcoal sources increased fairly linearly with decreasing ecological potential. About 33% of the responding ASAL household head produced charcoal as their sole occupation (no farming activities were reported owing to the inherent climatic conditions), and this increased the availability of the product in this sparcely populated region (population density of $3\,km^{-2}$). The bulk of it is, however, transported to urban centres in central Kenya and Nairobi where the demand is high. This partly explains why the cost per kilogram of charcoal was lowest in the ASAL (KSh 3.75 ± 0.25). The costs per kg in the highlands, savanna and coastal region zones were KSh $4.41 \pm 0.58, 5.65 \pm 2.03$ and 5.21 ± 0.80 kg, respectively. As with firewood, charcoal was more costly in the urban centres than in the rural, selling at an average KSh 5.84 ± 1.95 and $4.41 \pm 0.69\ kg^{-1}$, respectively. No special patterns were observed in charcoal use within restaurants countrywide in the four AEZs. Table 6 shows the mean costs and consumption rates for restaurants across the AEZs. The corresponding mean number of daily guests are also reported. Since continuous cooking and serving of different meals proceeds in

Table 7
Total annual quantities of biofuels purchased and their corresponding costs in 1997

Fuel type	Demand (mill. tons yr^{-1})	Purchased amount (%)	Unit cost (KSh kg^{-1})	Total cost[a] (Billion KSh)
Firewood	15.420	42.5	1.41	9.23
Charcoal	2.912	89.9	4.96	12.99
Residues	1.370	2.8	2.86	0.11
Total				22.33

[a] Portion of annual fuel demand purchased multiplied by the unit cost.

local restaurants each day, it is difficult to establish the number of meals made per day. Neither is it easy to classify meal types in such catering units. For the purposes of this paper, guest size is adopted as this conveniently facilitates the use of household equivalent in the per capita consumption estimations. The overall mean guest number per day in restaurants was 188, while the unit cost was KSh 4.00 and the per guest charcoal consumption was 0.33 kg cap^{-1} day^{-1}. No significant relationships existed between consumption rates and either unit cost or daily guest number among the restaurants.

3.2.6. *Influence of residues cost and source distance*

Agricultural residues were mainly a free commodity, only consumed among rural households. About 80% of interviewed user households reported on-farm residue production. Collection from other sources and purchase of residues was reported by 17 and 3% of user households, respectively. No household reported residue use in the ASAL, since no crops are grown here owing to the prevailing climatic conditions. Coconut husks, shells and dried palms were the only available agro-residues in the coastal zone. The consumption rate in this zone was 0.21 kg^{-1} day^{-1}. Coconut shells and husks were collected from nearby farms. The shells, like charcoal, were preferred for their high-energy density. The husks have an easy-lighting capacity. Only 13% of the responding households in the coastal zone, mainly those living away from coconut plantations, reported buying shells and husks at an average users-only cost of KSh $2.22 \pm 2.42\ kg^{-1}$. Maize cobs and dried stalks were the main residues reported in the highlands and savanna zones where they were consumed, when available, at rates of 0.63 and 0.13 kg cap^{-1} day^{-1}, respectively. The mean residue source distance was 8 km in the highlands and 11 km in the savanna zones. Of all the rural sites surveyed in these two zones, residues were only sold in parts of Nakuru and Kisumu at unit costs of KSh 13.30 ± 5.77 and $1.65 \pm 0.49\ kg^{-1}$ of crop residues, respectively. Small-scale farmers in Kenya are responsible for over 75% of the national annual maize production [1].

Using data on quantities of biofuels obtained from the market, we computed the total annual cost of biofuels using the established real costs. The results are presented in Table 7. The table clearly shows that most charcoal is obtained from the market, unlike crop residues that are almost a freely available commodity. That a considerable amount of wood has to be bought shows increasing limited access to firewood resources. A total of KSh 22.33 billion was spent on biofuel purchases by the domestic sector in 1997. This is 5.1% of the country's GDP reported for 1996 [2]. The household expenditure on biofuels therefore stands at US$ 72 per annum (US$ 13 per capita per year), of which 58% was utilised for charcoal purchases. Understanding that over 47% of the rural and 29% of the urban population in Kenya live below the poverty line [1], future access to fuelwood (as determined by cost) looks bleak. This may imply changes in fuel consumption where households may tend to reduce the quantities consumed daily. The per capita consumption rates are therefore expected to decrease. However, any gains made are likely to be countered by the higher overall fuel demand that is likely to be occasioned by the increasing population growth rate.

3.2.7. *Influence of cooking stove type*

An analysis of the consumption levels based on various stove-types, revealed results tabulated in Table 8. The preferred traditional (3-stone, *Jiko*

Table 8
Comparison of consumption values based on stoves consistently used

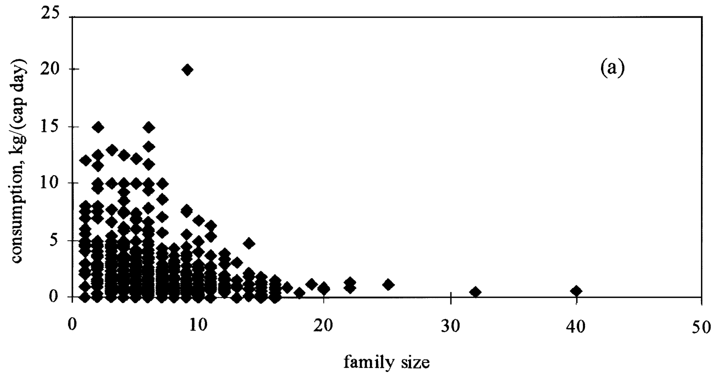
Stove type[a]	Consumption rate Mean (± SD)	($kg\,cap^{-1}\,day^{-1}$) Median
Household charcoal stoves		
KCJ	0.18 ± 0.08	0.14
Jiko	0.27 ± 0.13	0.19
Household firewood stoves		
Maendeleo	0.62 ± 0.31	0.60
3-stone	0.85 ± 0.51	0.63
Institutional firewood stoves		
Bellerive	0.52 ± 0.38	0.40
Alpha	1.42 ± 0.71	1.63
Kengo	0.50 ± 0.24	0.63
Bellerive/Alpha	0.86 ± 0.65	0.68
Others[b]	0.29 ± 0.12	0.25
Restaurant charcoal stoves		
Many designs	0.47 ± 0.45	0.33

[a]Detailed stove description in forthcoming paper.
[b]These included improvised forms such as 3-stone and metal frames.

and *Alpha*) and improved (*Maendeleo*, *Kenya Ceramic Jiko* (*KCJ*), *Bellerive* and *Kengo*) models of cookstoves from each of the three consumer groups are described in detail in a separate report in preparation. The per capita charcoal consumption for users of the traditional *Jiko* stove was higher than that for the *KCJ* stove users at the 5 and 1% levels. The consumption rates obtained from the improved *Maendeleo* firewood stove users were generally lower than those for the traditional 3-stone hearth users. Other wood-burning stove types among households were negligible in number and not significantly spread even at village level, and hence not emphasised in this study. Wood consumption using institutional cook stoves varied significantly ($P = 0.05$).

In general, institutions and households using improved stoves consumed less firewood and charcoal per capita, than the users of the more common traditional stove. Within limits of measurement error, the results also imply that a switch by a household from the use of a traditional to an improved stove saves up to 33% of charcoal and 27% of firewood of their normal daily requirements. The physical characteristics of these devices seem to influence combustion trends and hence the overall combustion rates. These characteristics, to some extent, also determine the composition of trace gas emissions from the burning biofuels.

About 54% of all households countrywide reported use of the 3-stone hearth stove while only 0.6% employed the *Maendeleo* cook stove for burning firewood. On the other hand, 39 and 11% of all responding households use the ordinary metal *Jiko* and the *KCJ*, respectively, to burn their charcoal. Forty-one percent used kerosene stoves while 7.5% had gas cookers. Numerous charcoal stove designs, all of which were of the enclosed chamber type, were used in all restaurants sampled. Only about 5% of these restaurants, mainly kiosks in rural parts of the highlands reported use of 3-stone hearth to burn their wood. About 67% of academic institutions reported using the *Bellerive* cooker, while 6% preferred the *Kengo* stove. About 5% others used the *Alpha* stove. Whereas 13% of the institutions sampled used various other stoves including gas cookers and 3-stone hearth stove to meet their daily cooking needs, 9% were still in the transition stage from *Alpha* to *Bellerive*, hence employing both stoves at varying degrees of daily usage. The improved energy-saving institutional and household cookstoves were initially fabricated and disseminated in Kenya by NGOs. These stoves are, however, not well accepted among households, owing to reasons ranging from prohibitive costs to inadequate knowledge and understanding of the inherent long-term benefits. Institutions, however, have accepted the new technologies, as shown by the large number of those



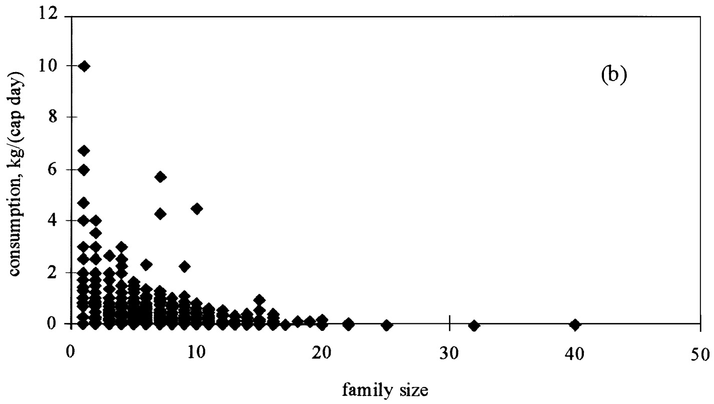


Fig. 3. Variations in the rate of consumption of (a) firewood and (b) charcoal with family size among rural households.

having the modern stoves and those in the process of installing them.

3.2.8. *Influence of demographic factors*

The effects of population density and family size on consumption rates were also investigated. There was no correlation between the mean institutional populations in each centre and their per capita firewood consumption estimates. However, the household firewood per capita consumption decreased linearly ($n = 13$, $P = 0.05$, $r^2 = 0.523$) with increase in population density. Scatter diagrams of the consumption rate for the biofuels against family size among rural households ($n = 1538$) are presented in Fig. 3 for the study period.

The households consumed more per capita, than either the institutions or restaurants mainly owing to savings associated with collective use of resources. Whereas the average household size was 5.5 (higher than the 4.9 provided in official records [31]), the institutions and restaurants cooked for averages of about 608 and 188 people day^{-1}, respectively. According to Fig. 3, households with smaller family sizes tend to consume more fuel per capita, than those with larger family sizes, conforming with the findings of Hosier [28] and Marufu et al. [29]. This means that larger households are not only more efficient users of fuel than smaller ones, but also that fuel costs larger households less. Collective cooking to serve many people therefore tends to demand less fuel.

3.2.9. *Biofuel availability*

Fuel availability was determined based on fuel sufficiency reported by households in all ecological zones. Between 79 and 96% of all households in all ecological zones, rural and urban regions, reported firewood and charcoal sufficiency. Those reporting supply fluctuations with climatic conditions were about 16% in rural and 6% in urban areas. Less than 3% of rural households reported acute shortages of both charcoal and firewood. These were mainly those within clusters located in ecologically low potential regions particularly in the savanna and coastal zones. Only 1.3% of the urban households sample responded to having acute shortages.

The survey revealed the farmlands as the major source of fuelwood, accounting for 78% of fuelwood from all reported sources. Tree planting accounted for over 25% of all farm trees [35] and is encouraged by the lack of access to most indigenous forests that are gazetted by the government. In most surveyed sites within AEZ I and II, the use of agroforestry technologies was exhibited on land owned by small-holder communities. Some of these areas included Meru, Nyeri and Kakamega, where trees were inter-cropped with other food crops. Apart from the fruit trees such as mango, guava and fig, other species reported included *Eucalyptus saligna*, *Grevillea robusta*, *Croton megalocarpus* and *Leucaena leucocephala*. These species are fast growing and yield good-quality firewood. Others to be found on such farms have been listed in various reports [36–39]. Industrial forests are also a major source of fuelwood in form of timber off-cuts which are bought at disposal fees by local communities and other commercial agents from the various saw mills in the area.

Eucalyptus, cypress and wattle were the most preferred tree species for both charcoal production and firewood use, in both the highlands and savanna zones. Acacia trees were the most reported in the whole of the ASAL, where most acacia and commiphora tree varieties abound. The neem (*Azadirachta indica*) and cashew nut (*Anacardium occidentale*) trees were popular at the coast where they are abundantly available. A variety of indigenous tree species and fruit trees such as mango, guava and fig were commonly used for charcoal production. This was due to high-quality charcoal associated with these species. Some of the qualities possessed by charcoal made from good-quality wood include long-burning, less smoking (hence reduced human exposure levels) and large pieces that do not easily crumble into powder [40].

Maize cobs were the most popular and available form of agricultural residues in most high and medium potential agricultural lands, with over 22% respondents reporting use whenever available

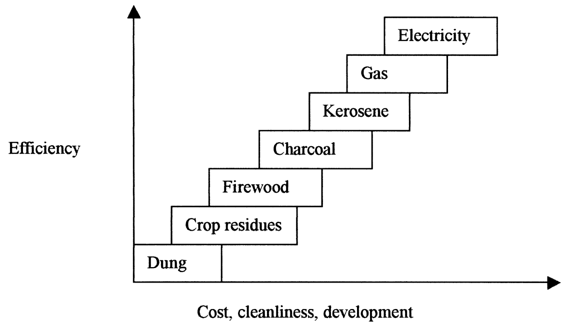


Fig. 4. Household "energy ladder" typical of Kenya in 1997.

(usually about 3 months yr^{-1}). Coconut shells and husks were utilised by about 3% of the total sample, while 1.2% reported using bagasse (dried sugarcane waste). Insignificant quantities of rice husks and sunflower stalks were also reported.

3.2.10. Inter-fuel substitution patterns

Information on recent changes in fuel preferences indicated that 18 and 6% of responding rural and urban households, respectively, had switched fuels, with over 70% in both cases opting for technologically inferior fuels. Only 4 and 2% of rural and urban households, respectively, preferred modern fuel choices. However, 21% of all households countrywide showed the desire to change fuel preferences to the cleaner commercial fuels. Kammen [41] and Smith et al. [42] described the "energy ladder" concept that describes the expected direction of fuel preference transition associated with increasing affluence and socio-economic development. Using this concept, we designed a household energy ladder typical of Kenya at the study period, as presented in Fig 4. Movement up this ladder leads towards increasing stove efficiency and cost. It also points towards the desirability of cleaner fuels by the population. The high percentage of households that changed fuel down the preference ladder in this study did so largely from kerosene to charcoal among urban users, and charcoal to firewood among the rural communities. The predominant reason was not that of scarcity but cost-cutting measures, owing to changes in socio-economic status, such as change of occupation.

Our observations with respect to fuel-change direction concur with those of Hosier and Dowd [43], Leach [44] and Marufu et al. [29], confirming that the energy transition from biomass to modern fuels is progressing slowly, given the small number of households that reported changing to cleaner commercial fuels. Income-induced substitutions move in the direction of the change in income, while scarcity-induced substitutions tend to move towards less sophisticated fuels. All of the academic institutions without modern stoves indicated plans to install the *Bellerive* stove. The analysis shows that rural households with a better economic standing are more likely to use commercial fuels such as charcoal or paraffin than the poorer households. When faced with wood shortage, a household in a given social class is more likely to substitute a less sophisticated fuel, such as crop waste (when available), than a more sophisticated fuel.

4. Conclusion

The study identified biofuel availability as the major factor determining biofuel consumption rates and patterns. There was the tendency by households to carelessly utilise fuels when they were in abundance and sparingly where there was scarcity. Other factors affecting per capita biofuel consumption rates were ambient temperature, population density, family size and stove types. Other factors that may have influenced the consumption rates and patterns include fuel cost, distance to source, meal types and frequency of cooking, and the general household socio-economic class. These factors influence the biofuel consumption rates and patterns through their impact on combustion characteristics — the duration of fire sessions, frequencies of these sessions and the burning efficiencies. These in turn influence the amount (and to some extent, the composition) of important trace atmospheric gases and aerosols emitted during combustion.

Although the interviews conducted by questionnaire revealed a healthy biofuel availability situation (reported as sufficiency), there were increasing difficulties in accessing these resources. The high annual per capita biofuel cost of about US$ 13 then, and the increasing number of households purchasing their supplies from the market will have implications for energy security and consumption rates and patterns in the medium and long terms.

The results provide a basis upon which the role played by stove and fuel types in influencing local and regional atmospheric trace gas budgets are being investigated by the authors. Policies are needed that may ensure equitable biofuel access, sustainable biofuel resource use and poverty eradication. These could result in more households jumping the energy ladder to higher-up, cleaner commercial fuels. Further studies transcending all seasons of the year to incorporate the temporal aspects of per capita consumption are recommended.

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