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Household Fuel Consumption Based on Multiple Fuel Use Strategies: A Case Study in Kibera Slums

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Abstract

Recently, it has been argued that, contrary to earlier energy ladder thinking, households in developing countries do not switch to modern energy sources but instead tend to consume a combination of fuels. This article aimed to gather a better understanding of the relative importance of fuel substitution and fuel complementation, especially among charcoal, fuel briquettes and kerosene, and the factors associated with these choices. In this paper we present results of a household survey conducted during October 2010 in Kibera slums in Nairobi, Kenya. The results revealed that widely various household characteristics influence demand for charcoal and briquettes for cooking. In addition to these factors, the household income level affects the use of kerosene for cooking. At the same time, we found the fact households tend to switch to multiple fuels strategy as their increasing in income instead of completely switching from the consumption of traditional fuels to modern energy sources.

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1. Introduction

Woody biomass, especially charcoal, is well known to be an important energy source in Kenya. Urban households in informal settlements are almost entirely reliant on charcoal for their basic cooking energy needs

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[1]-[4]. Charcoal is preferred because it produces little smoke and its calorific value is twice as that of wood and lasts longer, especially when used with improved cook stoves. Charcoal is regarded as affordable, economical, and convenient. Moreover, its extensive distribution network ensures its availability in informal settlements, makes it into one option of cooking fuels among many poor residents. A previous study has found that the annual charcoal world production in 2004 was 1.6 million tons [4]. Population increase in addition to urbanization, has led to the increasing charcoal demand in sub-Saharan Africa. This trend, coupled with inefficient charcoal production and consumption technologies, and inaccessibility to other modern energy sources, is not likely to change in near future [5].

Charcoal production is considered the major cause of deforestation, mostly due to unsustainable harvesting and inefficient production techniques [6], [7]. Charcoal is usually produced by using inefficient kilns. That means the production process of charcoal must be wasteful. For instance only 10-20% of the raw wood is converted to charcoal during its production process [4], and about 10-15% of charcoal is wasted along the supply chain as charcoal dust [8]. It is also well known that indoor air pollution from burning charcoal cause threats to health. There are severe health risks from polluted smokes especially to women and children, who spend the most time by the fire around the kitchen [9]. Substituting charcoal with electricity or liquid petroleum gas (LPG) should be one of the solutions to reduce pressures on deforestation and to reduce health risks from indoor air pollution [1]. Even though it has now become obvious that access to cleaner energy is essential, only about 30% of the population has access to electricity while 90% relies on traditional fuels for cooking and heating [10]. Regarding relations between household economic growth and energy consumption, some empirical and micro-level studies have revealed an “energy ladder” hypothesis, which states that an increase in income helps households to shift their energy source from traditional biomass to modern fuels [11]-[13]. Income is a strong key factor in explaining the substitution from private fuels to commercial energy sources [14], [15]. Additionally, market access and the distance to the forest as well as the price of modern fuel are important factors for adopting modern fuels [16].

Recently, it has been argued that, contrary to earlier energy ladder thinking, households in developing countries do not switch to modern energy sources, but instead tend to consume a combination of fuels. The study in Ethiopia has shown that households do not switch completely from biomass to modern fuels but rather increase the number of fuels used as their total expenditures rise [17], [18]. In Kenya, the adoption of fuel briquette is spreading among urban and rural area, with a huge potential to supply affordable and good quality cooking fuel, and it can also create employment and income generation. The dust produced in charcoal production processes, which still has considerable energy value, can be recycled as fuel briquette. At the same instant, however, kerosene is the most important modern energy option for the poor in Nairobi, in terms of its share in total energy expenditure. They consider it quick and easy to use, although the cost of kerosene is high [19]. Thus, they may choose among a variety of fuels, depending on their budgets, preferences, and needs [20]. This led to the concept of fuel stacking, as opposed to fuel switching on energy ladder hypothesis [21], [22].

Understanding the interfuel substitution and diversification are crucially important for policy planning aimed at facilitating sustainable development, given the multiple connections between woody biomass use and environment, health and social impacts [23]. Carefully developed and maintained data and implications on household fuel consumption should be crucially required by policymakers in order to identify, quantify, and address key issues related to household energy usage. So as to produce effective policy interventions for sustainable biomass energy development pathways it is necessary to enhance the understanding of factors affecting urban energy demand and the estimation of impacts related to that demand on rural resources [24]. It is critical to understand the factors affecting cooking energy consumption patterns, i.e., substitution and diversification of energy sources by lower-income urban households in sub-Saharan Africa (SSA), rather than simply assuming the energy ladder hypothesis. A more policy relevant and realistic theory of household energy demand is necessary, because the benefit of policies that ignore fuel stacking may be lesser than

hypothesized. Studies that undertake a rigorous examination of multiple fuel use in SSA are very limited [17]. The causes of fuel stacking in SSA are also not well understood, although studies from Mexico have found that multiple fuel model, rather than simple energy ladder scenario, more accurately depicts cooking fuel use pattern in rural households [21].

The purpose of this paper is to assess the determinants of household fuel choice and the scope of energy policy affecting it. A particular aim is to gather a better understanding of the relative importance of fuel substitution and fuel complementation, especially among charcoal, fuel briquettes and kerosene, and the factors associated with this choice. In this paper, we will presents results of a household survey conducted during October 2010 in Kibera slum in Nairobi, Kenya.

2. Materials and methods

2.1. Study Area

The study was conducted in the Kibera slum in Nairobi, the capital city of Kenya. Kibera, which includes 10 villages, is located approximately seven kilometers southwest of the city center. Several actors (governmental and local institutions, NGOs, scholars, mass media) have provided and published growing estimates of the slum population over the years. Most have reported that it is the largest slum in Africa, with more than 1 million residents. Others say it is the second largest slum after Soweto in South Africa. Its cosmopolitan population includes people of different regional backgrounds and ethnicity. The settlement, covering an area of 256 ha, is placed strategically to provide labor to Nairobi's industrial area and city center [18]. Because of the settlement's high density, unplanned residential areas, and crowded houses, together with a lack of infrastructure, acute problems of drainage, sanitation, and solid waste management have worsened continuously. Fuel use and demand patterns of Kibera's households largely revolve around household energy end-uses such as cooking and lighting as well as energy sources for home-based commercial and productive activities in small micro-enterprises (SMEs).

2.2. Study design

A household survey was conducted in Gatwekera village in Kibera slums during October 2010. The households in the village have a choice of briquettes as an energy option due to the presence of the briquette production site. Fifty households were selected randomly along four footpaths and a total of 199 were interviewed. The households were selected by picking every fifth household on each footpath located within a 250 m radius from a briquette production site.

Primary data related to types, amounts and costs for cooking and lighting energy were collected by interviewing household members using a questionnaire. Data on expenditure on the different fuels consumed (charcoal, briquettes, kerosene, electricity, etc.), and types of cooking appliances (stoves) used was also collected. In addition, information about preferences and reasons for using the different fuels was gathered. Two under graduate students in the University of Nairobi were trained and administered the questionnaire.

2.3. Model specificatioin

Interfuel substitution might be attributable to a number of different factors, but it is usually based on the household perceptions of cost, efficiency or convenience of a particular fuel. The fuel mix adopted by a particular household results from its subjective assessment of its status. At the same time, the household's decision about the type of fuel to use and its energy consumption behavior can be assumed to be different

with fuels of respective types.

To discuss the substitution among fuels of three types—charcoal, briquettes and kerosene—we categorized fuel consumption behavior as combinations of fuel types used for cooking purposes. We specifically address three major types here: type [1] users all of kerosene, charcoal, and briquettes; type [2] users of kerosene and charcoal; and type [3] users of charcoal and briquettes (Table 1). Substitution among the three energy sources is examined by comparison among these categories. From our analysis, the 29 households that are not included in these classifications were removed from the sample. Therefore, the analysis is confined to the remaining 170 samples. The definitions of socioeconomic variables and descriptive statistics of the samples are presented in Table 2.

Table 1. Combinations of fuel use for cooking

	All of three fuels **[G1]**	charcoal and kerosene **[G2]**	charcoal and briquettes **[G3]**	kerosene and briquettes	kerosene only	charcoal only	briquettes only	Total
No. of HHs	53	35	81	5	14	10	1	199
(%)	(26.6%)	(17.6%)	(40.7%)	(2.5%)	(7.0%)	(5.0%)	(0.5%)	(100.0%)

Source: Household survey conducted by the authors in 2010

We divided the three types into two sub-samples and estimated separate equations for the two groups. First, to determine the effects of briquettes used, we compare types [1] and [2]. For the sub-samples of households in type [1] and [2], equations of the expenditure of kerosene and charcoal are estimated using ordinary least-squares (OLS) regression. The following expanded log-linear specification for energy consumption for cooking was used.

$$EXPK_i = b_1 FSIZE + b_2 AGE + b_3 INCOME + b_4 EMPLOY_i + b_5 Buser_i + u_i \quad (1)$$

$$EXPC_i = b_1 FSIZE + b_2 AGE + b_3 INCOME + b_4 EMPLOY_i + b_5 Buser_i + u_i \quad (2)$$

whereby $EXPK_i$/$EXPC_i$ stands for the natural logarithm of the sum of weekly expenditures for kerosene/charcoal for cooking both during the rainy season and dry season per household, FSIZE is the number of persons per household, AGE_i stands for the age of household head, $INCOME_i$ denotes the household monthly income level, $EMPLOY_i$ represents the employment status of household head, and $Buser_i$ is a dummy variable that is set to one if briquettes are used in the respondent's household and zero otherwise. In Eq. (1), the sign of the estimated coefficient of Buser indicates whether briquettes are used as an alternative to kerosene. Similarly, in Eq. (2), the sign of estimated parameter shows whether briquettes are used as an alternative to charcoal.

Secondly, for the sub-samples in types [1] and [3], equations of the expenditure of charcoal and briquette are estimated using OLS regression. The effect of kerosene use is determined by comparison these two types: [1] and [3]. The following expanded log-linear specification for energy consumption for cooking is used.

$$EXPC_i = b_1 FSIZE + b_2 AGE + b_3 INCOME + b_4 EMPLOY_i + b_5 Kuser_i + b_6 PROD_i + u_i \quad (3)$$

$$EXPB_i = b_1 FSIZE + b_2 AGE + b_3 INCOME + b_4 EMPLOY_i + b_5 Kuser_i + b_6 PROD_i + u_i \quad (4)$$

therein, $EXPC_i$/$EXPB_i$ is the natural logarithm of the sum of weekly expenditures for charcoal or briquettes for cooking both during the rainy season and dry season for a household, FSIZE is the household size, AGE_i represents the household head age, $INCOME_i$ stands for the household monthly income level, $EMPLOY_i$ denotes the employment status of the household head, and $Kuser_i$ signifies a dummy variable, which is set to one if kerosene is used in the respondent's household and zero otherwise. Finally, $PROD_i$ is a dummy variable

reflecting whether the respondent or a family member makes briquettes at home. In Eq. (3), the sign of the estimated coefficient of $Kuser_i$ indicates whether kerosene is used as an alternative to charcoal. Similarly, in Eq. (4), the sign of the estimated parameter shows whether kerosene is used as an alternative to briquettes.

Table 2. Definition of variables and descriptive statistics of sample in each category

	[G1]	[G2]	[G3]
Explanatory variables			
FSIZE: Number of household members	5.13 (1.53)	4.80 (1.39)	6.07 (1.60)
AGE: Age of household head	32.92 (8.23)	31.26 (7.73)	35.28 (8.43)
EDU: Education level of household head;			
1 = No formal schooling			
2 = Nursery school, Pre-unit baby class			
3 = Primary			
4 = Unfinished secondary	3,49 (0.82)	3.74 (1.22)	3.69 (1.00)
5 = Secondary completed			
6 = Vocational Training			
7 = Pre-college/university courses/unfinished university			
8 = College/university completed			
EMPLOY: Employment status of household head;			
1 = steady employment	0.02 (0.14)	0.03 (0.17)	0.00 (0.00)
0 = others			
INCOME: Annual income level			
1= less than the mean minus standard variable			
2 = between the mean minus standard deviation and the mean	2.47 (0.91)	2.37 (0.97)	2.81 (0.95)
3 = between the mean and the mean plus standard deviation			
4 = more than the mean plus standard deviation			
Dependent variables			
EXPK: Expenditure on Kerosene (Ksh/week)	245.8 (132.48)	285.3 (153.29)	0.0 (0.00)
EXPC: Expenditure on Charcoal (Ksh/week)	215.0 (123.44)	417.9 (267.18)	187.7 (124.81)
EXPK: Expenditure on Briquette (Ksh/week)	104.2 (72.09)	0.0 (0.00)	123.1 (88.59)

Note: USD1=Ksh78 (2010.10)
Mean (standard deviation)

3. Results and discussion

3.1. Characteristics of households

Socioeconomic conditions of the 199 surveyed households are presented in Table 3. The average slum household size was 4.39 members. The average household head was 33 years old. Most were men; female headed households accounted for 16.6% of all households. Almost a quarter of the household heads had received education at a secondary school or higher level. The average number of children below 14 years old was two. The average household income was 118,216 Ksh/year, which is far below the poverty line of 1.25 USD a day. About 73% of the surveyed households were subsisting below the poverty line.

3.2. Fuel consumption pattern

The different sources of energy use for lighting and cooking by the interviewed households are presented in Table 4. According to the survey data, fuel use among households in Kibera was classifiable into two types:

Energy for lighting and for cooking. The interviewed households used electricity, kerosene, and candles for lighting purposes. Almost all households used an electric light or kerosene lamp. Candles were used for lighting when the electricity supply was inaccessible. However, for cooking, charcoal, briquettes, and kerosene appear to be key energy alternatives in Kibera.

Results show that 90% of the households in Kibera use charcoal as an energy source, 71% use briquettes, and only 53% use kerosene. About 80% of the households using charcoal for cooking reported that they use briquettes in combination. Of the 63 households that reported using briquettes, 16 were involved in producing briquettes from charcoal dust at home for their own use. The costs and characteristics of the three fuels that are used in Kibera slums as of late 2010 are presented in Table 5. Note that briquette is the least expensive fuel in terms of both unit mass and energy content, while kerosene is the most expensive.

Table 3. Socio-economic conditions of the surveyed households

Characteristics	Mean	Std. dev.	Min.	Max.
Sample size	199			
Household size and composition				
Average household size (persons)	4.39	1.757	1	10
Female headed households (%)	16.6			
Household head graduated secondary school (%)	24.1			
Household head average age (years)	33.4	8.378	18	65
Children below 5 years of age (person)	0.88	0.773	0	3
Children aged between 5-14 years (person)	1.25	1.204	0	4
Males aged 15 years and above (person)	1.08	0.627	0	4
Females aged 15 years and above (person)	1.03	0.721	0	7
Income source (%)				
Regular salaried	11.6			
Casual laboring	35.7			
SME	40.9			
Annual Income (Ksh)	118,216	81,306	9,600	540,000

Source: Household survey conducted by the authors in 2010

Table 4. Share of household using specific type of fuel

		Dry season		Rainy season	
		percent of HHs	N	percent of HHs	N
Lighting	Briquettes	1%	1	1%	1
	Charcoal	1%	2	1%	2
	Kerosene	97%	194	97%	194
	Electricity	65%	129	65%	129
	Candle	3%	5	3%	5
Cooking	Briquettes	71%	141	71%	141
	Charcoal	90%	179	90%	179
	Kerosene	53%	105	54%	107

Source: Household survey conducted by the authors in 2010

Notes: The total number of respondents does not add up to 100% beacause respondents use more than
KSH=Kenyan Shilling, USD1=KSH78 during the survey period

Table 5. Characteristics of main energy souces for cooking

	Charcoal	Briquettes	Kerosene
Cost（Ksh/kg)	25.9	2.2	88.9
Energy content（MJ/kg)	25-33	15-19	44
Cost （Ksh/MJ)	0.8-1.0	0.12-0.15	2.0
Device	improved jiko/stove	improved jiko/stove	kerosene stove
User perceptions			
Advantages	cook fast, easy to use	cheap, burns longer	cook fast, easy to use
Disadvantages	smoke, dusty, expensive	slow, dusty, difficult to use	expensive, smell, smoke

Source: Household survey conducted by the authors in 2010

3.3. Multiple fuel use in Kibera slums; the quantitative evaluation of fuel substitution

Table 6 presents empirical results obtained from the estimation of Eqs. (1) and (2) that apply to the samples of type [1] and [2]. Of the five household characteristics included in the model, only household size, age of household head, education level of the household head, and household income play roles in explaining kerosene consumption and charcoal consumption. All characteristics were found to have a significant positive association with expenditures for kerosene and charcoal. According to the results, larger households are more likely to consume charcoal and briquettes. It is expected that larger households pay more to use energy for cooking. The age and education level of the household head has a significant positive effect on consumption of kerosene and charcoal. This result reflects that households with older and better educated household heads are likely to consume more energy for cooking. Household income has a significant positive effect on kerosene expenditures. On charcoal expenditures, however, this household income has a positive effect but this is not significant. Finally, the “Buser” dummy variable has a negative association with charcoal expenditures. However, on kerosene expenditures the “Buser” dummy variable has a positive effect but not significant. This result reflects that briquettes are used as an alternative to charcoal and briquette users spend less on charcoal. It also means that, in sample households, charcoal and briquettes can be used with the same tools and equipment.

Table 6. Estimated ordinary least square models for types [1] and [2]

Explanatory variables	Dependent variable					
	EXPK (expenditure for kerosene)			**EXPC** (expenditure for charcoal)		
	Estimated coefficients		*t*-values	Estimated coefficients		*t*-values
FSIZE	0.297	***	3.978	0.254	***	2.794
AGE	0.047	***	4.029	0.063	***	4.385
EDU	0.504	***	7.054	0.517	***	5.843
INCOME	0.284	**	2.294	0.208		1.626
EMPLOY	-0.764		-1.185	-0.470		-0.585
B user	0.031		0.163	-0.490	**	-2.081
Adj.*R2*	0.975			0.962		

Signif. codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1

Table 7 presents regression results obtained for the other two groups of samples: type [1] and [3].

Estimation of Eq. (3) and Eq. (4) applied. Of the five household characteristics included in the model, all variables except for employment status have significant positive association with expenditures of both charcoal and briquettes. Employment status of the household head does not affect the expenditure for charcoal or briquettes. A dummy variable "PROD" shows a significant negative effect on expenditures for kerosene, which means that households involved in briquette making at home are less likely to purchase briquettes than households which do not make them by themselves. Finally, the "Kuser"dummy variable has a positive association with expenditures for charcoal. On briquette expenditure, however, the "Kuser"dummy variable is unaffected. This result supports the idea that kerosene is used as a complement for charcoal by sample households in Kibera slums. It is inferred that households use kerosene when they must save time by or just need high flames for cooking. The table presents advantages of kerosene over other energy sources.

Table 7. Estimated ordinary least square models for types [1] and [3]

Explanatory variables	Dependent variable					
	EXPC (expenditure for charcoal)			**EXPB** (expenditure for briquettes)		
	Estimated coefficients		*t*-values	Estimated coefficients		*t*-values
FSIZE	0.236	***	4.328	0.265	***	4.497
AGE	0.037	***	3.716	0.030	***	2.743
EDU	0.466	***	6.741	0.371	***	4.980
INCOME	0.262	***	3.320	0.237	***	2.786
EMPLOY	0.295		0.310	-0.561		-0.547
K user	0.559	***	3.440	0.271		1.549
PROD	-1.098	***	-5.391	-0.837	***	-3.808
Adj.R2	0.969			0.954		

Signif. codes: '***' 0.01 '**' 0.05 '*' 0.1

3.4. Multiple fuel use in Kibera slums*; the qualitative evaluation of briquette by consumers*

To gather important information related to the briquettes as a substitute for charcoal, respondents are asked which has advantages in some topics (Table 8). Results show many reasons why consumers prefer fuel briquettes. First, 100% of households that used fuel briquettes preferred them to charcoal because of their low price. Moreover, 98% stated that fuel briquettes burn longer. Briquettes are a third as expensive and burn almost twice as long as ordinary charcoal, which makes them suitable for preparing foods that require a long time to cook such as dry grains, which many households are currently abandoning because of the high costs of liquid fuels. Secondly, briquettes produce less smoke. For that reason, the cooking utensils do not end up covered with soot, making them especially convenient in communities that have other survival challenges such as access to clean water and living space. Finally, the residents have easy access to briquettes: 92% of respondents felt that fuel briquette availability is equal to or better than that of charcoal.

These results indicate frequent switching between solid and liquid fuels within the same household. Our findings illustrate the diversity of lifestyles and purposes for which fuels are used. Economically better-off urban households adopt kerosene for some purposes but continue to use biomass fuels for others, in large part reflecting a cultural preference for food cooked with traditional methods. Perhaps residents find it more convenient to use kerosene for family cooking because they can cook indoors, unlike wood fires that must be lit outdoors to prevent smoke inhalation and fire hazards. On the other hand, biomass fuels are preferred for heating purposes, whereas kerosene stoves are deployed preferentially for household cooking tasks. Furthermore, briquettes are usually used as a supplemental fuel for charcoal in Kibera. Thus, households buy

several fuels and use them according to their circumstances and needs.

Table 8. Households' preferences of fuel briquettes compared to wood charcoal

	Price	Energy	Smoke	Burning time	Availability
Briquettes (%)	100	56	68	98	35
Charcoal (%)	0	43	12	1	8
Both (%)	0	1	20	1	57

Source: Household survey conducted by the authors in 2010

4. Conclusions and recommendations

This paper has analysed patterns of fuel use, fuel spending, and fuel switching by households in Kibera slums using detailed energy-specific information from a household survey data in 2010. Empirical results reveal that widely various household characteristics such as the household head age and education level, and number of household members influence demand for charcoal and briquettes for cooking. In addition to these factors, the household income level affects the use of kerosene for cooking. At the same time, we found the fact households tend to switch to multiple fuels strategy as their incomes rise instead of completely switching from the consumption of solid fuels to modern ones such as kerosene. The results show that charcoal and fuel briquette are not inferior, as opposed to the energy-ladder hypothesis, and households still continue to rely largely on solid fuels for cooking. Thus, households tend to switch to a multiple fuel-use strategy (fuel stacking) as their incomes rise, perhaps, because of a number of factors, including preferences, taste, dependability of supply, cost, cooking and consumption habits, and moreover availability of technology. The results of this study have important policy implications that such factors should be also focused on in policy design. Energy policies for sustainable development should be based on the realistic proposition that biomass fuel will remain responsible for meeting household cooking needs, such is the case for substantial proportions of the world's population as well. At least for households in developing countries, such as those in Kenya, perhaps more attention should be paid to these factors It is well recognized that household characteristics and properties of the energy sources themselves strongly influence the energy choice behavior of slum residents. The need exists for future research to gather more information about socioeconomic and demographic attributes, household attitudes, and knowledge of lifestyle variations.

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