Enhancing Household Fuel Choice and Substitution in Kenya

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Abstract

This study looks at the fuel choice and fuel substitution in Kenya. It focuses on three issues: it analyzes the factors influencing households' fuel of choice; it studies the factors influencing woodfuels expenditures; and, it investigates the factors that influence substitution from either traditional or transitional fuels to modern fuels. Theoretically, the study is founded on the basics of the energy stack model, where households are hypothesized to combine fuels rather than to switch completely to other fuels following a shock, as predicted by the energy ladder model.

The study analyzed a sample of 13,158 observations using cross-sectional data from the Kenya Integrated Household Budget Survey conducted in 2005/2006. The study employed multinomial logit model to analyze the factors influencing household fuel use and fuel substitution. It also used Heckman model to analyze the factors determining woodfuel expenditure. The factors examined are categorized into economic and non-economic. The non-economic factors include household headship, education, gender, location of the household size, household residence, type of dwelling, and house with chimney. The economic factors comprise distance to fuel source, fuel prices, proportion of woodfuel expenditures to total household expenditure, total household expenditure, rent expenditures, and access to electricity and water. The results show that Kenyan households combine various types of fuel to meet their energy needs. In addition to total household expenditures (a proxy for income), gender, fuel price, location of residence and distance to fuel source, education and houses with chimney are factors considered by households in making decisions on fuel use. Households are also keen on factors such as household expenditure, fuel price, education and electricity access when carrying out fuel substitutions. Total household expenditure, was not found to be important in determining amount of woodfuel expenditures but older household heads and education are found to be the driving factors determining woodfuel expenditure. To enhance sustainable use of wood fuel, encouraging efficient cooking stoves, revitalizing village woodlots and investment in commercial wood plantations is important. In addition, promotion of modern fuel through developing dependable energy distribution systems and carrying out public education campaigns are also recommended.

Abbreviations and Acronyms

DPMC	Department of Price and Monopoly Control
ERB	Energy Regulatory Board
ERC	Energy Regulatory Commission
IEA	Institute of Economic Affairs
IIA	Independence of Irrelevant Alternatives
IPP	Independent Power Producers
KIHBS	Kenya Integrated Household Budget Survey
KIPPRA	Kenya Institute for Public Policy Research and Analysis
LPG	Liquefied Petroleum Gas
MDGs	Millennium Development Goals
NOCK	National Oil Corporation of Kenya
PES	Public Electricity Supplies

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1. Introduction

The growing demand for energy services[1] and the pursuit of better living standards have, to a large degree, catalyzed growth of modern energy sources. In the same token, lack of access to modern energy services deprives the poor of opportunities for improved living standards and dampens economic growth. Key services of modern energy include lighting, cooking, heating, refrigeration, transportation, motive power and electronic communications, as well as the powering of employment and income generating plants.

Modern sources of fuel such as electricity and LPG (Liquefied Petroleum Gas), use energy efficient technologies that require energy saving appliances that have positive links with the environment, productivity and health. Efforts to encourage households to make substitutions that will foster more efficient energy utilization and limited adverse environmental and health impacts are advocated in many countries. This has made issues relating to energy choice and substitution an important policy standpoint.

Unsustainable use of wood fuel[2] can have deleterious effects on the environment, productivity and human health. Mwakubo *et al.* (2007) report that 70 per cent of the population in Kenya rely heavily on wood fuel. Moreover, consumption of wood fuel is used along with inefficient fuel appliance technologies with attendant loss of energy. Promotion of modern energy thus forms an integral part of future energy policy.

Biomass fuels, which constitute high percentage of the energy used in Kenya, are mostly referred to as traditional fuels and are associated with poverty and underdevelopment. About 2.4 billion people in developing countries rely primarily on traditional biomass fuels[3] for cooking and heating, and 1.6 million women and children die each year from exposure to the resulting indoor air pollution (Institute of Economic Affairs, 2006). As a result of continual inefficient use of such traditional

[1] The term 'energy services' refers to the benefits produced by using energy supplies, generated from a variety of primary energy sources – oil, gas, coal and renewables.

[2] Wood fuel forms a substantive share of traditional fuels. Most traditional fuels are considered as solid fuels consisting of firewood, charcoal, animal wastes and other agricultural residues. Non-solid fuels consist of among others kerosene, LPG and electricity.

[3] Biomass fuels include firewood, charcoal, animal wastes and agriculture residues as sources of energy.

fuels, and subsequent effects of reduced forest cover, negative effects on productivity is evident (World Bank, 2003).

Historically, the use of biomass fuels in Kenya encourages illegal forest resource extraction, which has adverse impacts on the ecosystems.[4] In Kenya, it is estimated that forest products and services contribute about 1.1 per cent annually to the economy while in terms of sectoral analysis, agriculture and forestry comprise, on average, 15 per cent of the total wage employment (Government of Kenya, 2007). However, the link between fuel wood utilization to forest degradation and soil erosion is more complex than it is usually acknowledged.

The five main household's fuel of choice in Kenya are firewood, charcoal, kerosene, LPG and electricity, in that order. The projection of biomass consumption/supply is shown in Table 1. The current biomass energy consumption (demand) surpasses supply.

In future, Kenya's population is expected to increase and this will lead to a corresponding increase in biomass consumption. However, this growth in demand for biomass will not match with the sustainable supply for biomass. Consequently, this calls for urgent measures in addressing the deficit by supplying sustainable biomass.

About 1.6 billion people worldwide have no access to network electricity (mostly in sub-Saharan Africa and South Asia), and 80 per cent of them are the rural poor of developing countries. Table 2 shows the actual consumption of LPG and Kerosene in Kenya.

Table 1: Projection of biomass consumption/supply

Years	2000	2005	2010	2020
Population	28,686,600	32,694,400	36,810,700	44,981,800
Consumption (tons/yr)	35,119.60	39,896.60	44,599.35	53,416
Sustainable supply tons/yr	15,024.50	15,488.90	16,634.60	19,559.74
Deficit (tons/yr)	-20,095.10	-24,407.70	-27,964.80	-33,856.70
Deficit (%)	-57.20	-61.20	-62.70	-63.40
Deficit (tones/person)	-0.70	-0.75	-0.76	-0.75

Source: Kamfor, 2002

[4] An example is Mau Complex excision. The Complex supports many sectors including energy, agriculture, tourism and water supply. To date, 208,723 hectares of Mau complex have been excised (United Nations Environment Programme, 2006).

Table 2: LPG and kerosene actual consumption in the Kenya

Year	LPG (tons)	Rate of growth %	Kerosene(tons)	Rate of growth %
2001	35,600	-	306,100	-
2002	40,500	13.76	273,600	-10.62
2003	40,929	1.06	190,000	-30.56
2004	41,884	2.33	236,100	24.26
2005	48,827	16.58	307,000	30.03
2006	64,639	32.39	287,000	-6.51
2007	74,017	14.51	283,209	-1.32
Average annual growth		13.44		0.88

Source: Pakter, 2008 and KIPPRA, 2007

LPG energy consumption increased from 40,500 tons in 2002 to 40,929 tons in 2003. The consumption later increased in 2006 to a peak of 64,639 tons, and to its highest peak in 2007 of 74,017 tons. The consumption of kerosene had its highest drop in 2002 to 273,600 tons from 306,100 in 2003. In 2005, kerosene consumption was 307,000 but dropped to 283,209 in 2007.

The household choices of fuel and amount to consume are as a result of confluence of various factors including income, availability of fuels, gender, age, education and fuel price, household size, ownership of the main dwelling unit, type of dwelling unit and electricity access among others. The large population presently consuming biomass has been prompted to this fuel choice by factors such as energy availability (especially in rural areas), affordability (mainly in the urban areas) and lack of alternatives (particularly in rural areas). The factors motivating a switch to modern and clean fuels include better availability of alternative fuels, where alternative fuels are generally available to people located in urban areas unlike in rural areas. Income also affects choice of fuel, with those with high income consuming cleaner modern fuels while those with low income rely mainly on traditional fuels (among them firewood) and transitional fuels like charcoal and kerosene. Generally, there is limited literature on the importance of gender in fuel choice and substitutions.

Goals of substitution policies typically include reducing high fuel costs for the poor, increasing consumer welfare, saving wood fuel, and protecting the environment. The government, in Vision 2030, aims at protecting the environment as a national asset and conserving it for the benefit of future generations. Emphasis has been directed towards financing extension of electricity supply in the rural areas as part of basic infrastructure to stimulate economic growth and employment. Subsequently, the government has formulated energy access scale-up programmes through which one million households will be connected with electricity between 2008 and 2012.

However, it should be noted that petroleum industry in Kenya is constrained by limited supply facilities for fuel including LPG. The government aims at constructing 6,000 common use LPG import handling facility in Mombasa, which is among the flagship projects to be implemented from 2008 to 2012. This is expected to increase parcel sizes imported, thus reducing freight cost and making LPG cheaper to Kenyans. In addition, 2,000 tons common user LPG handling facility will be constructed in Nairobi. With increased storage space, supply sources will increase, thus competitively priced LPG can be obtained.

Access to and use of cleaner energy remains the major issue in policy discussion about sustainable economic development and clean environment. The focus in energy policy discussion is on achieving a secure and sustainable environment, efficient use of energy, better health and other social benefits which are associated with interventions that enhance fuel substitution. Policy decision on these issues requires research and analysis on household fuel choices and substitution behaviour.

1.1 Statement of the Problem

In Kenya, wood fuel constitutes over 70 per cent of primary energy supply with 90 per cent consumed by households mainly in rural areas (Mwakubo *et al.,* 2007). With the increase in population, the current wood fuel consumption exceeds the total sustainable supply with the deficit standing beyond 50 per cent to date, even when projected to 2020 (Kamfor, 2002).

Consumption of wood fuel is not itself an issue. Nevertheless once resources are reaped unsustainably and energy conversion technologies are inefficient, there are severe adverse effects for health, the environment and economic development.

About 1.6 million people – mostly women and children – die prematurely every year because of exposure to indoor air pollution from use of wood fuel, dung and other biomass fuel for cooking (Institute of Economic Affairs, 2006). Use of dung as fuel rather than as fertilizer leads to land degradation and reduces agricultural productivity. Though use of wood fuel for cooking and construction among others, generates income for most households, it has resulted in deforestation and forest degradation. The current forest area cover is less than 2 per cent and also way below the recommended international standards of 10 per cent. Valuable time and effort is devoted to fuel collection instead of education or income generation, which reduces productivity (World Bank, 2003). Nevertheless, rapid increases in fossil fuel use in Kenya also represents a growing contribution to the increase in local and regional air pollution as well as atmospheric concentrations of greenhouse gases such as carbon dioxide.

A potential option to reducing both urban and rural demand for wood fuel is through shifting from wood fuel to using commercial modern fuels. Despite introduction of this effort over the last couple of years, there are still many households that rely on traditional fuels as their primary source of energy. With this massive use of wood fuel, factors driving woodfuel expenditures still remain unclear. Therefore, there is need to carryout a study on the factors that influence household fuel choice, fuel substitution and wood fuel expenditures.

Information on the factors influencing household choice is limited and studies that have been done using econometrics to quantity effects are less forthcoming. Although recent studies have been done for example Pundo and Fraser (2003), their emphasis was on household fuel choice with specific focus on rural areas. There is still no study in Kenya focusing on both household fuel choice and substitution in urban and rural areas. This study is thus an attempt to inform policy making in the energy sector by providing a comprehensive analysis of the households' motivation to choose particular fuels and the households' reasons to substitute fuels.

1.2 Research Questions

The following questions postulated below guide this study:

i. What are the drivers of household fuel choice?

ii. What are the key aspects that influence household substitution from traditional fuel and transition fuel to modern fuels?

iii. Which factors affect wood fuel expenditure?

iv. Which policies can promote fuel substitution towards greater use of sustainable forms of energy?

1.3 Research Objectives

The study aimed at analyzing factors that influence household fuel choice and substitution. Specifically, the study seeks to:

i. Analyze factors influencing household choice of fuel

ii. Examine the determinants of wood fuel expenditure

iii. Investigate the factors influencing fuel substitution from traditional to modern fuels

1.4 Justification of the Study

Understanding fuel choice and substitution is critical because sustainable availability of fuel choices is requisite to maintaining the momentum of the current economic recovery in Kenya. Currently, Kenya's fuel choice is limited by a myriad of factors and there is no flexible option of substitution. Transformation of the Kenyan economy into a globally competitive nation with high quality of life, as envisaged in Vision 2030, requires, among other interventions, steady, predictable, variety and affordable supply of energy to all sectors of the economy.

Therefore, a study is needed to establish the underlying factors, drivers and household motivations in the area of energy use. Moreover, previous policies in Kenya have poor and inadequate empirical literature foundation due to few studies done on the subject. Therefore, this study will assist policy makers in designing policies that will enhance household welfare while sustaining the environment as stipulated in the Millennium Development Goals (MDGs) and Vision 2030 (Government of Kenya, 2006). In addition, this study will provide the needed policies that will guide households towards more use of high-calorific, efficient fuels and away from traditional solid fuels that pose indoor air pollution and deforestation among other resultant deleterious environment impacts.

1.5 Organization of the Study

The study presents the factors that determine the household choice of fuel and substitution in Kenya. The discussion paper is structured as follows: Section one presents the introduction, statement of the problem, research questions and justification of the study. Section two discusses household fuels, energy policies and household fuel expenditures in Kenya. Section three review's literature on the household fuel choice.

Section four describes the methodology employed in the analysis, while Section five summarizes the overview of the household fuel use in Kenya. Section six provides the analysis and findings of the study and Section seven concludes the study and provides recommendations.

2. Overview of the Household Fuels in Kenya

2.1 Sources of Household Fuels

Biomass

Biomass fuels include agriculture residues, animal wastes, firewood and charcoal. Biomass is always perceived as poor people's source of energy. For instance, the rich only use charcoal for roasting meat during parties and wood in their fire places for heating.

Firewood is obtained mainly from agroforestry or on-farm sources (84%), trust lands (8%) and gazetted forests (8%). Approximately 76 per cent of households obtain all their firewood free of charge, 17 per cent of households regularly purchase it, while 7 per cent supplement their free collection by purchasing some firewood (Mwakubo *et al.*, 2007).

Firewood and charcoal fuels provide 90 per cent of rural households' energy requirements and 85 per cent in urban areas (Mwakubo *et al.*, 2007). The principal drivers of both charcoal and firewood energy demand are population, lack of access to biomass energy substitutes and the growing incidence of poverty in Kenya. Charcoal may be more damaging to the environment compared to wood fuel.

Most of the wood fuel energy is lost in the production process. Charcoal users consume more than those consuming wood fuel directly. Charcoal is produced in sizable batches, it is rarely linked with sustainable forestry practices and is further frequently linked to clear-cutting practices. Though sources of charcoal may be plantations, chances are that it may be sourced from land cleared for agricultural purposes or from smaller areas cleared for charcoal production.

Most charcoal producers come from the rural areas. The demand for charcoal is in the urban areas, as those in rural areas are too poor to consume it. Although charcoal policies have been studied, facets of health, social and environmental impacts have been neglected.

Charcoal is considered to have high energy density than other biomass fuels and can be stored for future use without insect inhabitations. It burns evenly for a long time and can be easily extinguished and reused. Also, food cooked using charcoal has a tasty flavour (Israel, 2002).

Kerosene

Kerosene is one among other petroleum-based fuel produced in oil refineries. Sclag and Zuzarte (2008) observed that kerosene is used by 57 per cent of urban households in Kenya, 15 per cent in Tanzania and 4 per cent in Uganda. Since it produces soot and other particulates when burned, it is not considered as a clean cooking fuel.

Kerosene also has the same ill effects as wood fuel consumption and is linked to indoor air pollution. This affects the household's health in addition to degrading the environment. In addition, being a byproduct of petroleum, its price is determined by other external factors resulting in high cost since Kenya relies on imported petroleum products.

LPG

LPG is a petroleum product. It faces competitive market structure and higher costs of energy. It is easy to access, clean and is an efficient source of energy for resolving poverty and underdevelopment. However, it faces many obstacles such as the substantial uptake cost whereby households have to pay for the consumed fuels, invest in a stove and purchase or give deposit for the cylinder. The average costs of the cylinder, regulator, hose pipe, stove burner and gas as given by retailers, are shown in Table 3.

In Kenya, 11.9 per cent of urban and 0.7 per cent of rural households use LPG as their main source of cooking fuel (Government, 2005/6).

Upfront cost of the durable goods needed for LPG use is Ksh7,150 and Ksh6,530 for 12kgs and 13kgs gas cylinder respectively, from various retail fuel stations. The fixed costs required for kerosene is quite minimal since cooking requires one small burner with a simple fuel container. The kerosene stoves cost ranges from Ksh350 to Ksh2,000. Cooking with charcoal requires a metal *jiko*[5] whose fixed cost averages Ksh150 upto Ksh200, while

Table 3: Upfront costs of LPG from various retail fuel stations

Upfront cost of LPG use			Retail Prices in Ksh *
Gas cylinder (empty)			13kgs @3500
Gas fuel costs for:	-	13kgs	13kgs @ 2200
	-	15kgs	15kgs @ 2500
	-	6kgs	6kgs @ 1100
Regulator			700
Hose pipe 1.5m			200
Cooker			2000
Burner			-

Source: Author, 2009
**Dec 2008 prices*

firewood requires only three stones (hearthstones) which hold the pot. Some three stones are sourced freely while others are purchased at a maximum cost of Ksh150. These costs suggest the existence of barriers towards use of clean modern fuels.

Electricity

In Kenya, households use electricity mainly for lighting, rather than cooking. It is considered as a clean modern source of fuel, accounting for 9 per cent of total energy use with inclusion of the household sector (Mwakubo *et al.*, 2004). However, its penetration has been low especially in rural areas. Use of electricity demands acquiring modern electrical appliances. These are expensive for most households.

2.2 Household Fuel Expenditure Patterns

Household fuel consumption comprises 47.7 per cent of non-food items. Table 4 shows percentage distribution of the household expenditures in Kenya.

The rural households are seen to have higher expenditures on fuels with 4.1 per cent compared to transportation, health and water which have 3.9, 0.8 and 0.6 per cent, respectively. The urban households' fuel expenditure is 5.3 per cent which is lower than transport expenditures of 8.7 per cent and higher than health and water expenditures which are 0.2 and 0.6 per cent, respectively.

Table 4: Mean monthly food and consumption per adult equivalent (%)

Region	Kenya	Rural	Central	Coast	Eastern	North-Eastern	Nyanza	Rift – Valley	Western	Urban
Food	51.1	62.3	57.3	68.1	63.9	76.3	65.2	60.0	66.2	39.6
Non-food	47.7	38.4	47.4	37.2	40.5	26.9	39.7	32.2	38.8	58.8
Water	0.9	0.6	0.8	2.1	0.9	1.3	0.4	0.3	0.2	1.2
Fuels	4.7	4.1	5.8	3.9	3.7	3.4	4.3	3.4	3.4	5.3
Clothing & footwear	8.0	8.3	8.5	6.9	8.0	8.5	10.1	7.8	8.5	7.6
Transportation	6.1	3.9	5.9	3.7	3.4	1.2	3.3	3.6	3.5	8.7
House rent	9.9	6.7	8.3	8.0	7.1	4.1	7.5	5.0	7.7	13.7
Education	5.9	5.5	6.7	3.4	6.5	2.7	4.9	4.8	6.3	6.3
Health	0.7	0.8	1.2	0.5	0.8	0.4	1.0	0.5	0.8	0.6

Source: Government of Kenya, 2005 and 2006

[5] A jiko is a cooking stove.

2.3 The Development of Energy Policies

Kenya experienced unprecedented power shortages in 1999 and 2000, which had a major impact on the country's economy and livelihoods (Mwakubo *et al*., 2004). The shortages underscored the need to write an overall national energy policy, hence the development of the *Sessional Paper No. 4 of 2004 on Energy*.

The sessional paper spells out Kenya's national energy approach with specific strategies and their implementation modalities. Before this, Kenya had been relying on other policy statements such as the 1987's National Energy Policy and Investment Plan. Table 5 gives a summary of the development of the energy policies.

2.4 Lessons from Other Countries

Attempts to motivate households to use modern fuels have been successful in some countries, but somewhat gloomy in Kenya. The use of LPG and electricity are currently encouraged primarily for their clean nature.

In Africa, few countries have been successful in promoting use of LPG. In Tanzania, the uptake of LPG has been limited due to unavailability of fuel and equipment, but the introduction of tax reductions has improved the situation. Other measures used include providing direct subsidies to LPG and creating and establishing an LPG market.

Senegal's adoption of LPG as cooking fuel has increased demand substantially. The government has also exempted modern fuel appliances from import duties, introduced direct fuel subsidies on LPG fuel cylinder funded by taxes on other petroleum products, and offered discounts on smaller units of LPG fuel.

In addition to subsidy on LPG, Burkina Faso has introduced forest taxes and levies in an effort to drive up the market price of firewood, which is the main fuel of choice for both rural and urban areas.

Table 5: Synopsis of the Kenya's energy policies

Energy policies	Focus	Role
Sessional Paper No. 10 of 1965	The Electric Power Act (Cap 314)	To regulate the electricity sector
Sessional Paper No. 1 of 1986	The Establishment of the Department of Price and Monopoly Control (DPMC)	To monitor acts of restraint of trade and to enforce pricing in various sectors including petroleum.
National Energy Policy and Investment Plan	On the importance of energy availability, effective use of energy, and generation of the resource.	
The Electric Power Act No. 11 of 1997	It was legislated to replace the Electric Power Act (CAP 314)	-It aimed at facilitating private sector participation in the provision of electricity. -It led to the establishment of Energy Regulatory Board (ERB) in 1998, with the goal of regulating the generation, transmission and distribution of electric power in Kenya. -The Act unbundled the generation from transmission and distribution of power thereby creating a framework for Independent Power Producers (IPP) to sell electric power in bulk to Public Electricity Supplies (PES). Therefore, KENGEN was established in 1998 as a generating company and Kenya Power and Lighting Company is the only licensed PES in Kenya. -It also formed the basis of the rural electrification on a limited scale using renewable energy technologies.
Other petroleum policies and Act of Parliament	The Petroleum Act (Cap 116) The Petroleum Exploration and Production Act enacted in 1984	-Has been used in the petroleum sector. -It gave the National Oil Corporation of Kenya (NOCK) the mandate to oversee oil exploration activities in the country.
Sessional Paper No. 4 of 2004	This Sessional paper was on Energy sector	-It aimed at replacing the Petroleum Act (Cap 116) and established a one stop shop for licensing importers and wholesalers of petroleum fuels and also it creates an inspectorate to enforce compliance with petroleum regulations, and oversee petroleum industry operations. - The Sessional paper was targeted to accelerate provision of cost-effective, affordable and adequate quality energy services.
Energy Act No. 12 in Dec 2007	Effected in July 2007 and consolidates EPA of 1997 and the Petroleum Act, Cap 116	- It converted the Energy Regulatory Board (ERB) into Energy Regulatory Commission (ERC) with statutory mandate to offer regulatory stewardship to electricity, petroleum and new and renewable sub-sectors.

3. Literature Review

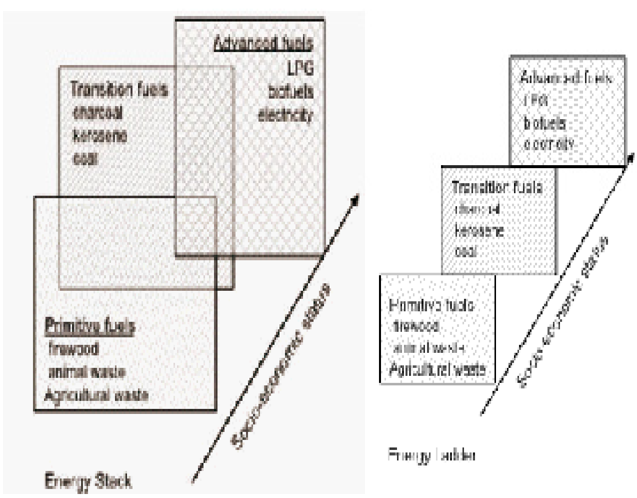
This section explains the theories surrounding household behaviour in terms of fuel choice and fuel substitution. It also gives a summary of various studies done in this area and also provides an overview of the literature.

3.1 Theoretical Literature

Households fuel choice behaviours have been analyzed for a long time using the "energy ladder" model (Figure 1). The model portrays a three-stage fuel switching process. The first stage is manifested by universal reliance on biomass. In the second stage, households move to "transition" fuels such as kerosene, coal and charcoal in response to higher incomes and other factors such as deforestation and urbanization. In the third phase, households switch to LPG, natural gas or electricity.

The main driver affecting the movement up the energy ladder is hypothesized to be income and relative fuel prices (Barnes *et al.,* 2005). However, the energy model has been criticized because of its major focus on the income factor to explain household fuel choice. It assumes that once incomes increase, the households discard the consumption of the traditional fuels and adopt modern clean fuels that they can afford.

Figure 1: The energy ladder and energy stack models



Source: Sclag and Zuzarte, 2008

The household economics framework has been used to explain the household fuel choice and fuel substitution. The framework argues that in addition to income and market prices, the opportunity costs of firewood collection also need to be taken into account in shaping the demand for all fuels. The availability of land, labour, cash and wood resources determines the opportunity cost of firewood collection. Hence, household fuel choices need to be understood in terms of relative household resource scarcities (World Bank, 2003; and Heltberg, 2003).

At present, the household energy choice is explained as a portfolio choice rather than a ladder process. This pattern of energy use is now commonly referred to as "energy stack" (Figure 1). The model states that households do not simply switch to a new fuel as income increases, but will continue using more than one fuel. The energy transition is a bi-directional process, as users can go up or down the ladder, and continue using traditional fuels (Masera *et al.,* 2000).

It is evident from previous studies (Barnes *et al.*, 2003; and Sclag and Zuzarte, 2008) that fuel switching[6] is the main response to increasing incomes in urban areas while fuel stacking or multiple fuel use dominates in rural areas. The explanation for this deviation is a substitution and an income effect working conversely.

The income effect implies that when income rises, households can afford to consume a larger variety of energy types in greater quantities, resulting in non-decreasing firewood use as documented in the rural areas. The substitution effect implies that high-income households can afford switching to costlier liquid and gaseous fuels, as seen in the urban areas.

3.2 Empirical Literature

This section summarizes several empirical studies that have been carried out aimed at explaining household fuel choice and fuel substitution.

Household fuel choice and substitution behaviour has mainly been explained using two models; the energy ladder and the energy stack. The factors that influence the movement up the energy ladder and those surrounding energy stacks can be classified into economic and non-economic factors. Economic factors consist of fuel price, household

[6] Fuel switching is defined as the choice to completely shift and use a new fuel.

income, and household expenditures while non-economic factors are household characteristics such as household size, gender, education, house ownership, type of dwelling, location of residence, household age, distance to fuel source and access to electricity.

Determinants of household fuel choice

Household income is one of the most important factors influencing fuel choice. It has been found that as a household's income increases, households not only increase consumption of their fuel choice, but they also use multiple fuels. Most empirical studies done on income effects on fuel choice have found contradicting results. In Ethiopia, the income effect dominates so that households consume more of all energy sources as budgets grow (Kebede *et al.,* 2002). Barnes and Qian (1992), using actual survey of urban household energy consumption in developing countries, found that as income increases wood fuel does not disappear completely as households continue to increase its use. The reason behind this relationship is that many high income households still use wood, reflecting the utility of these fuels for urban households. Increasing levels of income tends to result in a decrease in the share of biomass in total energy consumption (Wuyuan *et al.,* 2008).

Literature shows that household size affects fuel choice. World Bank (2003), using a Guatemala household survey data set and employing the logit and multinomial logit regressions, found a positive relationship between household size and firewood use. A number of explanations have been given to this finding. First, a larger household size may mean larger labour output (e.g. children's labour), which is needed in firewood collection. Secondly, it is assumed to be cheaper to cook for many people using firewood than its alternatives, as it is assumed that free collection of firewood lowers its price relative to alternatives that cannot be obtained freely. Mekonnen and Kohlin (2008) found similar results in Ethiopia where households with more members were more likely to use charcoal and firewood and less likely to use kerosene.

Education has a role to play in terms of household fuel choice. Pundo and Fraser (2003) analyzed data from rural Kisumu in Kenya using multinomial logit model. The study found that the level of education improves knowledge of fuel attributes, tastes and preferences for better fuels. Opportunity cost of time becomes an aspect of concern with regard to household participation on various activities. According to them, a highly educated woman is likely to lack time to collect firewood and may opt for firewood alternatives. Wuyuan *et al.* (2003) explain that when the resident's education level is higher, they use less biomass or more commercial fuel because the opportunity cost of biomass collection is increasing.

Several studies attest to the fact that household age is key in making decisions on household fuel choices. Pundo and Fraser (2003) note that women's age influences fuel choice through loyalty to firewood so that the older the woman (other things being equal), the more likely the household will continue using firewood. This has been found to be true by Mekonnen and Kohlin (2008) in areas where the study employed panel data that was collected in 2000 and 2004 in major Ethiopian cities. They demonstrated that older household heads are more likely to choose solid fuels (which include wood fuel, agriculture residues and animal residues) only as their main fuel, perhaps from habit, whereas non-solid fuels (which include biogas, electricity and LPG) are relatively adopted more by the younger household heads.

There is vast evidence implying that fuel price acts as an important factor in explaining the choice of fuel. Most studies agree that as fuel price rises, households are more likely to increase consumption of traditional fuels than modern fuels. In sub-Saharan Africa, the dominant fuel of choice is traditional fuels (biomass). Schlag and Zuzarte (2008) found that high fuel prices made household more likely to use traditional fuels than modern fuels. Similar results by Mekonnen and Kohlin (2008) show that households are more likely to choose solid fuels (charcoal and firewood) than modern fuels (kerosene). This finding is explained by Barnes and Qian (1992) to be attributed to poverty and lack of availability of modern fuels.

The possibility of choosing a fuel type depends on the distance to the fuel source. Studies have shown a negative relationship between fuel choice and distance to fuel source. Employing a Tobit model and using a cross sectional survey from 200 households in Jimma Town, Ethiopia, Albebaw (2007) found that a negative relationship exists between fuel wood[7] consumption and distance. The reason behind this finding is that households may consider distance as an additional cost to the market fuel price. In this regard, the further the distance implies that households have to bear more cost in terms of transportation and making them reluctant to choose such fuels for use.

Type of dwelling is another important factor households consider in selecting fuels. Studies have shown that households with modern houses

[7] Fuel wood is used interchangeably to refer to firewood.

are likely to use modern fuels (electricity, LPG and biogas) as their main fuel of choice. Pundu and Fraser (2003) postulate that selection of fuel is influenced by type of dwelling unit. If the dwelling unit is modern type house, the household is more likely to use firewood alternatives because these fuels are cleaner. Another reason is that, richer households who may afford the firewood alternatives, most likely own modern type houses. If the main household dwelling unit is rented, the household is more likely to use firewood alternatives. Such houses are likely to be rented and tenants must adhere to landlord occupancy rules. One disadvantage of firewood (which makes it less preferred in rented houses) is that it produces smoke that can stain walls and roofs. A summary of the empirical studies done on the determinants of household fuel choice is presented in Table 6.

Evaluations of welfare impacts of wood fuel expenditure

Empirical literature on factors influencing wood fuel expenditure are scarce. Israel (2002) analyzed impacts of income on firewood expenditure employing data from Bolivian Integrated Household Survey using Heckman two-step selection model. A number of factors employed in the model consist of household expenditures, household size, female income and number of adults. Among these factors, only household expenditure is found to be positive and significant. This implies that an increase in household expenditure would results in an increase in firewood expenditure. Consequently, increased spending power, conditional on using firewood, tends to increase firewood use.

Factors influencing household fuel substitution

Existing literature observes that households will substitute either traditional or transitional fuels to modern fuels. Pakistan integrated survey 1991 (Pfaff *et al.,* 2004) estimated Engel curves for traditional (dirty) and modern (clean) fuels using generalized Tobit model. They provided evidence of a transition; as households income rises, households switch from consuming traditional fuels to modern fuels.

Place of residence affects fuel substitution. Depending on residence, households may increase uptake on fuel of choice or carry out fuel substitution. Studies such as Israel (2002) and Reddy (2004) observe that in contrast to rural households, urban ones have a wider choice and greater accessibility to modern commercial fuels like electricity and energy using end-use equipment and appliances and, therefore, have

Table 6: Summary of empirical studies done on the determinants of household fuel choice

Country	Authors	Significant factors	Methodology
Developing countries[8]	Barnes and Qian (1992)	Income, fuel prices and urban size	Comparative analysis
Ethiopia	Kebede *et al.* (2002)	Income	Comparative analysis
Kenya	Pundo and Fraser (2003)	Household education, wife's education, wife's age and tradition/modern house	Multinomial Logit model
Developing countries[9]	World Bank (2003)	Household size and fuel prices	Tobit model
Ethiopia	Albebaw (2004)	Distance to fuel sources and housing expenditures	Logit and Multinomial Logit models
Ethiopia	Mekonnen and Kohlin (2008)	Older/younger household heads and fuel prices	Multinomial analysis
Sub-Saharan[10]	Schlag and Zuzarte (2008)	Fuel prices and cost of stoves	Qualitative analysis

Source: Author, 2009

greater potential for fuel substitution. Reddy, using Indian household data from the national sample survey (1983-2000), explains that variations in energy use exist across different sections of households as a result of not only income deviations but also different areas.

Studies such as Barnes and Qian (1992), Kebede *et al.* (2002), Kammen and Lew (2005), and Wuyuan *et al.* (2008) found that fuel price has negative effects on fuel substitution. In Ethiopia, Mekonnen and Kohlin (2008) showed that higher kerosene prices make households to choose either solid fuels only or a mix of solid and non-solid fuels, moving away from non-solid fuels.

Similar findings are found in other developing countries. Using qualitative analysis in sub-Saharan Africa, Schlag and Zuzarte (2008) found that high prices of cooking fuels and high cost of stoves resulting

[8] Developing countries include Bolivia, Haiti, Yemen, Indonesia, Philippines, Thailand, Cape Verde, Mauritania, Burkina Faso, Zambia and China.
[9] Developing countries include India, Guatemala, Nicaragua, Vietnam, South Africa, Brazil, Ghana and Nepal.
[10] Sub-Saharan Africa countries are Tanzania, Uganda, Senegal, Zambia, Malawi and Kenya.

from improved technologies, acted as market barriers to switching to clean cooking fuels. Coal is the competing fuel with biomass, so increasing the price of coal leads to more consumption of biomass (Wuyuan *et al.,* 2003).

Analyzing data from the 1989 Bolivian integrated household survey, Israel (2002) found that in addition to factors such as income, the location and education of the household members, market barriers to clean cooking fuels are also important. Households with more educated household members are likely to use non-solid fuels as their main fuel (LPG/electricity). The results indicate that the cost of learning in order to switch to LPG use is likely to be lower for highly educated persons. They may be less likely to have custom or habit of firewood use in their family.

The study notes that the preference for the flavour of food cooked with fuel wood may be associated with a stronger attachment to indigenous culture and traditional cooking. They also found that barriers to choice of fuel and those to switching to cleaner fuels include high fixed costs of LPG use and missing fuel markets.

Accessibility to electricity is one important factor that has been omitted in most empirical studies. World Bank (2003) found that households connected to an electricity grid are likely to use less wood fuel. The studies explain that electricity access triggers fuel switch to LPG. Having electricity is associated with a higher probability of using LPG and a lesser likelihood of firewood usage.

A number of factors have been used by various studies to explain household fuel choice such as house ownership, type of dwelling unit, occupation, housing expenditures and the role of women. However, these factors have not been applied widely. According to Pundu and Fraser (2003), house ownership is an important factor affecting household fuel switch. If a household owns the main dwelling unit, it is more likely to use occupancy rules. One disadvantage of firewood (which makes it less preferred in rental houses) is that it produces smoke that can stain walls and roofs. Likewise, if the dwelling unit is a modern house, the household is likely to use firewood alternatives because these fuels are cleaner.

Women who are employed in white collar jobs are more likely to use firewood alternatives than their counter-parts in blue-collar job, who are mainly peasant farmers or fishing households (Pundu and Fraser, 2003). A study by Albebaw (2007) noted that relative to men, women may have stronger preferences for using cleaner source than fuel wood given their greater involvement in cooking.

Variations in energy use exist across different sections of households as a result of not only income deviations, but also location of residence; that is, rural and urban (Reddy, 2004). This result is based on the Indian household data from the national sample survey (1983-2000).

The results from Albebaw (2007) show housing expenditure[11] is higher for those who are non-home owners and this limits households from switching to cleaner fuels as hypothesized by the energy ladder model. They also explain that for many people, particularly non home owners; housing expenditure is one of the main components of consumer expenditure. Given a budget constraint, this implies that non homeowners would be restricted to rely more on less expensive traditional fuels than home owners do. Table 7 gives a summary of barriers of the empirical studies done on the determinants of household fuel substitution.

3.3 Overview of the Literature

Theory has shown that the energy ladder model does not fully explain the household fuel choice. Present researchers such as Schlag and Zuzarte (2008) observe that household fuel choice is well demonstrated by an "energy stack model" rather than "energy ladder model," where households are seen to be consuming multiple fuels. The use of more than one fuel phenomena by households is well explained by Masera *et al.* (2000).

With respect to Kenya, a review of literature related to this study has shown that most empirical studies have placed their focus more on examining one or two specific fuels at a time. Subsequently, empirical studies targeting several main household fuels at once for analysis are few. In most cases, studies have analyzed wood fuel and kerosene, while fuels such as biogas, LPG and electricity are left out. In addition, their analysis lacked the application of econometric techniques. This study focuses on fuel choice and fuel substitution, where various households' main fuels will be analyzed using econometric method.

[11] Housing expenditures are household's incomes spent on house rent payments.

Table 7: Summary of empirical studies done on factors influencing household fuel substitution

Country	Previous studies	Significant factors	Methodology
Developing countries[12]	Barnes and Qian (1992)	Government policy	Comparative analysis
Bolivia	Israel (2002)	Income, location, household education level, market barriers, flavor of the cooked food, culture and tradition cooking	Heckman model
Kenya	Pundo and Fraser (2003)	House ownership, tradition/ modern house, and occupation	Multinomial Logit models
Developing countries[13]	World Bank (2003)	Houses with many rooms and houses connected by an electricity grid	Logit and Multinomial Logit models
Developing countries[14]	Barnes *et al.* (2005)	Biomass supply, urbanization, access, affordability, efficient, convenience, and government policy	Panel data and quantitative analysis
India	Reddy (2004)	Income and location	Quantitative analysis
Ethiopia	Albebaw (2007)	Ratio of women to men, distance to fuel sources, and housing expenditure.	Tobit model

Source: Author, 2009

[12] Developing countries include Bolivia, Haiti, Yemen, Indonesia, Philippines, Thailand, Cape Verde, Mauritania, Burkina Faso, Zambia and China.
[13] Developing countries include India, Guatemala, Nicaragua, Vietnam, South Africa, Brazil, Ghana and Nepal.
[14] These include Burkina Faso, Botswana, Cape Verde, Mauritania, Zambia, Zimbabwe, Indonesia, Thailand, India, Philippines, Bolivia, Haitiand Yemen.

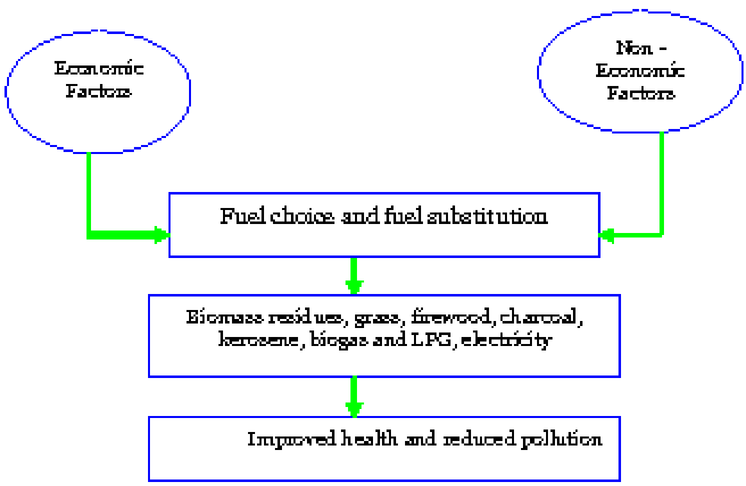
4. Study Methodology

4.1 Conceptual Framework

A household's cooking fuel choice consumption decision can be understood by analyzing its decision in a constrained utility maximization framework where it maximizes fuel utility, subject to a set of economic and non-economic constraints. The information that households have about various fuels influences their fuel choice and fuel substitution decisions. This information is affected by economic and non-economic factors. Economic factors include market price of fuel, household income and household expenditures. Non-economic factors may include a set of household characteristics such as household size, gender, education, house ownership, type of dwelling, location of residence, household age, distance to fuel source, and access to electricity.

The fuel choice and substitution models are applied to various fuels like biomass residues, grass, firewood, charcoal, kerosene, biogas, electricity and LPG. The application of this model will bring an understanding of how various factors influence the fuel choice and fuel substitution. The outcome of this behaviour may be improved health, income and reduced pollutions. Figure 2 demonstrates the conceptual framework for the study.

Figure 2: Conceptual framework



Source: Author, 2009

4.2 Analytical and Regression Models

To answer the objective of analyzing factors influencing household's main choice of cooking fuel, the study employed the multinomial logit model. Theoretically, household fuel choices are supported by rational considerations. The household selects fuel choice between a set of mutually exclusive and highly differentiated cooking fuels such as electricity, LPG, charcoal, firewood and kerosene (alternatives fuels). In making this selection, the household is assumed to act so as to maximize utility (McFadden, 1974). Its fuel choice is determined by economic and non-economic factors.

The McFadden's model can be expressed as

$Z_{ij}^{*} = \alpha w_i + \gamma_{ij}$, j=0, 1, 2, 3, ..., k; i=1,..., N ....(1)

Where:

Z_{ij}^{*} is the benefit associated with using a particular fuel, and is assumed to be a linear function of a set of observed variables, with i indexing individuals or households and j (where j=5) indexing mutually exclusive fuel alternatives, namely electricity, LPG, charcoal, firewood, and kerosene, where;

α is a vector of coefficients to be estimated;

w is a set of economic and non-economic variables; and

γ_{ij} is a disturbance term that is associated with individual i and fuel j.

If the household makes choice j in particular, then we assume that Z_{ij}^{*} is the maximum among the five fuel source; i.e. j is chosen if Z_{ij}^{*} (alternative j) $> Z_{ij}^{*}$ (alternative k),$\forall\ j \neq k$. The observed energy choice is defined as a vector $Z_i = [Z_{ij}]$of five dummy variables taking value 1 if the household's choice falls on the jth alternative, and value 0 otherwise. The probability that j is included in i's choice set is $P_i(Z^* > 1)$. This fuel choice probability can be expressed as:

$$P_i(Z_i = j) = \frac{\exp\left(\alpha_{ij} w_i\right)}{\sum_{j=0}^{m} \exp\left(\alpha_{ij} w_i\right)}$$ and j=0, 1, 2, 3, 4, 5.. (2)

Equation 2 is estimated using the maximum likelihood method. To estimate the coefficients of w, the following likelihood function is maximized.

$$L(\theta) = \sum_{i=1}^{N} \sum_{j=0}^{J} 1\{z_i = j\}.\ln P_j(w_i;\theta)$$ ....(3)

Where $L(\theta)$ is the log likelihood function, θ is a set of parameters to be estimated and is an indicator function.

To investigate the factors that affect household fuel substitution from traditional and transitional fuels to modern fuels, the study looks at the characteristics of various fuels that are key in influencing household decisions. These fuels include biomass residues, grass, firewood, charcoal, kerosene, biogas, LPG and electricity for both rural and urban areas. The multinomial logit model is employed. First, this model takes into account the possibility of multiple fuel use by grouping these fuels into three fuel categories, namely traditional, transitional and modern fuels. Second, the model shows substitution effects (cross effects) where changes in characteristics of a particular fuel category are investigated and how they influence the changes in probabilities of other fuel categories.

Equation (2) is used to examine the factors affecting fuel substitution, where j is the fuel categories (j =3). In the case of modern fuels, the study looked at the changes in characteristics of modern fuels and how this change affects choice and substitution of traditional and transitional fuel categories.

To evaluate the determinants of wood fuel expenditure, the study uses the Heckman sample selection bias correction model as in Israel (2002). The Heckman two-step statistical approach provides a means of correcting estimation biases due to non-randomly selected samples. The estimation involves determining the factors influencing wood fuel expenditures, but only observations on wood fuel expenditures for those who use wood fuel were obtained. Since the people who chose to use wood fuel are selected non-randomly from the population, estimating the determinants of wood fuel expenditures from the sub-population who chose to use wood fuel may introduce bias. The study therefore, needs to account for information that is available on non-users of wood fuel among households and this can be solved using the Heckman selection model.

The model allows the use of information from the non-users of wood fuel to improve the estimates of the parameters in the regression model. It provides consistent, asymptotically efficient estimates for all the parameters in the model, which is implemented in two stages: the first stage is the probit regression model on fuel choice, and the second stage involves correcting for self-selection by incorporating a transformation of fuel selection probabilities as additional explanatory variable in a wood fuel expenditure model. It should be noted that the same results can be achieved using the linear probability model with the first stage (Olsen, 1980).

The Heckman model shows the behaviour of household's as they move from other fuels to wood fuel. It also shows the amount spent by households as they use wood fuel. Thus, this model is both a fuel choice and fuel substitution model.

The wood fuel use a model employed in the estimations as shown in equation 4. In that model, if a household chooses to use wood fuel, it can be represented by a binary variable Y=1, and zero if not[15] used. The associated latent variable Y^*, which is the unobserved propensity of using wood fuel, can be modelled as a function of covariate as follows:

$$Y_i^* = x^{'}\beta + \mu_i \qquad \text{(4)}$$

The probit model is shown in equation 5, where the dependent variable is an indicator variable for wood fuel use that relates to the latent variable Y^* as follows: $Y = 1$ if $Y^* > 0$ and $Y = 0$ where X_i is the vector of covariates, β is a vector of unknown parameters to be estimated, and Φ is the cumulative distribution function of the standard normal distribution.

$$\Pr(Y_i = 1 \mid X) = \Phi(x^{'}\beta) \qquad \text{(5)}$$

The Heckman sample selection term is included in the regression model for wood fuel expenditure. These expenditures are positive and can be modelled using the following regression model:

$$Z_i^* = W_i^{'}\beta + \varepsilon_i\varepsilon_i \qquad \text{(6)}$$

Where, Z_i^* is the latent variable and denotes an underlying wood fuel expenditure, which is not observed if the respondent does not consume wood fuel; $W_i^{'}$ is a vector of covariates; β is a vector of coefficients; and ε_i is a random disturbance term.

The wood fuel expenditure given an individual's household consumption of wood fuel can be specified as:

$$E(Z \mid W_i^{'}, Y = 1) = W_i^{'}\beta + E(\varepsilon \mid X, D = 1) \qquad \text{(7)}$$

Under the assumptions that the error terms are jointly normal, we have:

$$E(Z \mid W_i^{'}, Y = 1) = W_i^{'}\beta + \rho\sigma_\varepsilon\lambda(X^{'}\beta) \qquad \text{(8)}$$

Where, p is the correlation between unobserved determinants of propensity to use wood fuel μ, and unobserved determinants of wood fuel expenditures ɜ, σ_ε is the standard of ɜ, and λ is the inverse Mills ratio derived after estimating equation 5. The inverse of Mills ratio is the ratio of the probability density function to the cumulative density function. This term is automatically computed by the Heckman ML estimation procedure in STATA.

The explanatory variables included in the probit equation include wood fuel expenditure, total household expenditure, proportion of wood fuel expenditure to total household expenditure, gender, household size, older household heads, heads with primary education, heads with secondary education and distance to fuel source.

Distance to fuel source is used to identify the probit equation from the fuel expenditure equation. In the per capita wood fuel expenditure regression, all the explanatory variables in the probit regression are

[15] See also William H. Greene, Econometric Analysis, 2d ed. (New York: Macmillan, 2003).

maintained while distance to fuel source is excluded. It was the exclusion restriction that was imposed in order to identify the parameters of this model (Greene, 1993).

4.3 Data Types and Sources

The study used primary data from the Kenya Integrated Household Budget Survey (KIHBS) 2005/6 which was based on the National Sample Survey and Evaluation Program (NASSEP-IV) sampling frame and comprises 1,800 clusters selected with probability proportion to size (PPS) from a set of all Enumeration Areas (EA) used during the 1999 Population and Housing Census. The KIHBS clusters sampled in each district were selected with equal probability from the NASSEP-IV frame where a total of 13,430 households were targeted. The survey was conducted in 1,339 sampling units/clusters across all districts in Kenya and comprised 857 rural and 482 urban clusters. The study questionnaire was piloted and administered by the Kenya National Bureau of Statistics.

5. Analysis, Findings and Discussion

5.1 Descriptive Statistics

Table 7 presents the socio-economic and demographic descriptive profile. The minimum, maximum, mean and standard deviations of various variables are also presented. The sample of the households had 13, 158 observations. The largest household had 23 members while the least had only one member. Both female and male household heads are found to dominate in the rural locations with 62 and 66 per cent, respectively. Sixty per cent of the sample has older household heads. Of this, 66 per cent are from the rural areas. Generally, heads with primary education in the country account for 49 per cent while those with secondary education account for 12 per cent. Majority of the heads with only primary education (69%) and those with up to secondary education (68%) are from rural areas.

The descriptive statistics show that households from rural areas (73%) own the houses they live in and also households from rural areas (68%) have a larger proportion compared to urban households with modern house type. Out of the 7 per cent of households having houses with chimney, 56 per cent are from the rural areas.

Table 7: Socio-economic and demographic profile

Variable definition	Min	Max	Mean	Std. Dev	Urban (%)	Rural (%)	Kenya (%)
Household size	1	23	2.05	2.81	-	-	-
Female household head (1 = female)	0	1	0.31	0.46	38	62	31
Male household head (1 = male)	0	1	0.69	0.46	32	66	69
Older households heads(40 years and above)	0	1	0.60	0.49	34	66	60
Head with primary education (1= has primary education)	0	1	0.49	0.50	31	69	49
Head with secondary education (1 = has secondary education)	0	1	0.12	0.32	32	68	12
Head with graduate education (1 = has graduate education)	0	1	0.005	0.07	38	62	0.5
Head with no school (1 = has no education)	0	1	0.19	0.13	38	62	1.9
Household ownership (1 = owns house they live in)	0	1	0.62	0.49	27	73	62
Modern house type (1 = modern house)	0	1	0.61	0.49	32	68	61
House with chimney (1 = house has chimney)	0	1	0.072	0.25	44	56	7

Source: Author, 2009

Table 8 gives a summary of the household's characteristics and fuel choices. The distance to fuel sources has a minimum value of zero (0) minute and a maximum value of 300 minutes. This implies that some households spend a lot of time in search of fuel for household use. The youngest head is aged 16 years, while the oldest is aged 99 years. Of these households, 44 per cent are located in urban areas while 56 per cent are in the rural areas. The minimum monthly wood fuel expenditure is zero (0) suggesting that some wood fuel are sourced or are available freely. The monthly total household expenditure ranges between Ksh 15.81 and Ksh 191,733.50. Some proportion of female heads have no income while amongst those who have income, the highest has Ksh 127,315. From 69 per cent of the members who are female, 68 per cent are from rural areas.

The traditional stone fire was the major owned appliance among the rural households with 76 per cent owning it. Kerosene stove, gas cooker and electricity cooker are among the least owned fuel appliance with ownership of 10, 4 and 0.4 per cent, respectively.

Table 8: Household characteristics and fuel choices

Variable definition	Min	Max	Mean	Std. Dev	Urban (%)	Rural (%)	Kenya (%)
Fuel prices (Ksh)	0.0065	3600	94.71	237.54	-	-	-
Distance to fuel source (Minutes)	0	300	1.79	11.39	-	-	-
Age of head (yrs)	16	99	45.89	16.05	-	-	-
Wood fuels expenditure (Ksh)	0	7000	208.9	338.9	-	-	-
Household expenditure (Ksh)	15.81	191733.5	3719.6	6577.6	-	-	-
Female income	0	127315	1226.4	4881.3	-	-	-
Gender (1 = female)	0	1	0.49	0.49	32	68	69
Traditional stone fire (1=owns traditional stone)	0	1	0.58	0.49	24	76	58
Improved traditional stone fire (1=owns improved traditional stone)	0	1	0.08	0.26	22	88	8
Ordinary jiko (1=owns ordinary stove)	0	1	0.09	0.29	44	56	9
Improved jiko (1=owns improve jiko)	0	1	0.08	0.26	43	57	8
Kerosene stove (1=owns kerosene stove)	0	1	0.10	0.30	64	36	10
Gas cooker (1=owns a gas cooker)	0	1	0.04	0.19	74	26	4
Electric cooker (1=owns an electric cooker)	0	1	0.004	0.06	80	20	0.4

Source: Author, 2009

Table 9 shows the fuel expenditure, in addition to the descriptive statistics. A low energy budget share like that of LPG implies that modern energy services are unavailable or unaffordable; thus, households resort to firewood and charcoal. It could also mean that free biomass is available in sufficient quantities so that no one is willing to spend on commercial energy. Among all energy sources considered, charcoal and firewood have the highest budget share among its users. Sixty one per cent of firewood users are from the rural households, while 29 per cent are from urban households. In addition, 70 per cent of charcoal users are from rural areas and 30 per cent from urban areas. The consumption of kerosene is 10 per cent in the country with 51 per cent and 49 per cent consumed by rural and urban households, respectively. LPG and electricity comprise 4 and 0.9 per cent of the country's total energy consumption shares, with the urban households consuming the largest share of 66 and 64 per cent for LPG and electricity, respectively.

Firewood is the main fuel of choice by households with 65 per cent. Charcoal is consumed by 18 per cent, kerosene (10%), LPG (0.4%) and electricity (0.8%). Nationally, wood fuel account for 84 per cent and is the main choice of fuel for rural areas with 57 per cent. LPG and electricity are mainly used in urban areas with 66 and 64 per cent, respectively.

Table 10 shows a number of combinations in which households use cooking fuel. Basically, with five cooking fuels that are mainly used in the country, there are a number of fuel mixes that can be observed. The most common used combination is electricity, LPG, charcoal, kerosene and firewood at 100 per cent; the second most fuel mix is LPG, charcoal, kerosene and firewood (99%); and LPG, charcoal and firewood (88%) is

Table 9: Fuel expenditures

Fuel types	Location of residence			Descriptive statistics				Share of total household and energy budgets		
	Kenya	Rural	Urban	Min	Max	Mean	Std. Dev	Mean monthly total energy budget	Mean monthly total household budget	Proportion of total energy to total household budget
Firewood	65	61	29	0	1	0.65	0.48	165	2107	0.08
Charcoal	18	70	30	0	1	0.18	0.39	47	621	0.08
Wood fuels	84	57	43	0	1	0.84	0.37	213	2729	0.08
Kerosene	10	51	49	0	1	0.11	0.39	36	568	0.006
LPG	4	34	66	0	1	0.04	0.20	11	356	0.003
Electricity	0.9	36	64	0	1	0.08	0.09	2	69	0.003

Source: Author, 2009

Table 10: Fuel complementarities/fuel mixes

Household fuel mixes/Complementarity's	Kenya	Urban	Rural
Electricity + LPG + Charcoal + Kerosene + Firewood	100	34	66
Electricity + LPG + Charcoal + Kerosene	33	42	58
LPG + Charcoal + Kerosene + Firewood	99	34	66
LPG + Charcoal + Kerosene	32	41	59
LPG + Charcoal + Firewood	88	32	68
LPG + Kerosene + Firewood	81	34	66
Electricity + Charcoal	18	32	68
LPG + Electricity	5	66	34
LPG + Charcoal	22	37	63
LPG + Kerosene	15	54	55
LPG + Firewood	70	32	68
Charcoal + Firewood	84	30	70
Charcoal + Kerosene	29	37	63
Kerosene + Firewood	77	33	67

Source: Author, 2009

third. Other high ranking combinations include charcoal and firewood (84%), LPG, kerosene and firewood (81%), kerosene and firewood (77%), and LPG and firewood (70%). Most of these combinations are done by rural households. A number of rare fuel mixes included LPG and electricity (5%), and LPG and kerosene (15%), while electricity and charcoal (18%), and LPG and charcoal (22%) are mostly used by urban areas.

5.2 Regression Results

The multinomial logit assumes a very special property: the independence of irrelevant alternatives (IIA). IIA means that the odds are independent from the other outcomes available. It implies that estimates do not change if the set of alternatives change. The null hypothesis of IIA is rejected at 0.3 and 0 per cent level for the multinomial logit of fuel choice and fuel substitution objectives respectively as shown in the Appendix. This implies that the outcomes are distinct and not close substitutes.

A multinomial logit of fuel choice estimation results

Table 11 shows the multinomial logit of fuel choice estimation results. The dependent variable is fuel type where the first choice is firewood, second is charcoal, third is kerosene, fourth is LPG and lastly, the fifth choice is electricity. The base (reference) fuel is firewood. Most of the variables used in this model are statistically significant.

Household expenditure

The coefficient on log of total household expenditure for charcoal, LPG and electricity are statistically significant. This shows that a 1 per cent increase in the household expenditures increases the likelihood of using charcoal, LPG and electricity by 0.3, 0.2 and 0.023 per cent, respectively.[16] This implies that when total household expenditure increases, households may increase the use of their preferred fuels relative to firewood.

The model says that when total households' expenditures increases, households increase use of almost all fuel alternatives preferences (charcoal, kerosene, LPG and electricity), suggesting that in Kenya, there is more of energy stack than energy ladder aspects. Energy stack is where households are seen to be using more than one fuel while energy ladder is where households move from the first phase where they use traditional biomass to second phase where they switch to kerosene, coal and charcoal and to third phase of using either biogas, LPG or electricity (Barnes *et al.*, 2005).

Fuel price

In economic theory, it is hypothesized that the demand for a good is a decreasing function of price of that good and this necessitates that the price elasticity of demand should be negative. The study employed the Stone Price Index, first, because of the variety in the household fuel mix hence the need to aggregate both fuel prices and household energy consumption from the respective fuels, and second, because each household faces a different set of fuel prices for LPG, charcoal, firewood and kerosene (Stone, 1954).

The coefficient on log of fuel price is positive and also statistically significant for LPG and electricity. A 1 per cent increase in the fuel price

[16] This interpretation depends on the base chosen; for example, in case of household income, the base is 1 per cent. The 1 per cent base is applied to all the interpretations of variables in this study.

will increase the probability of consuming LPG and electricity by 0.119 and 0.041 per cent, respectively. This suggests that the quality of fuel and fuel price are positively correlated.

Table 11: Multinomial logit results for fuel choice

Fuel types/alternatives	Charcoal	Kerosene	LPG	Electricity
Log total household expenditures	0.0366*	0.02406	0.02121***	0.0023*
	(0.0237)	(0.0206)	(0.0078)	(0.0023)
Log fuel price	-0.0219	0.0173	0.0119**	0.0041***
	(0.018)	(0.0179)	(0.0059)	(0.0032)
Residence (1=rural)	-0.0402	-0.0959***	-0.0203*	0.0004
	(0.0449)	(0.0452)	(0.0175)	(0.0033)
Log distance to fuel-source	0.0162	-0.0021	-0.0078*	0.0013
	(0.0139)	(0.0124)	(0.0044)	(0.0013)
Head has primary education (1 = has primary education)	-0.1127***	0.0049	0.0130	-0.0031
	(0.0361)	(0.0316)	(0.0122)	(0.0039)
Head has secondary education (1 = has secondary education)	-0.1271***	-0.0684	0.0212	0.0012
	(0.0319)	(0.0369)	(0.0278)	(0.0051)
Gender (1=male)	-0.0155	0.0336	0.0057	0.0029
	(0.0392)	(0.0314)	(0.0099)	(0.0033)
House has chimney (1 = has chimney)	-0.0161	0.1676***	0.0079	0.0109
	(0.0684)	(0.0904)	(0.0223)	(0.015)
Constant	-0.6359	-2.2479	-5.8513	-13.8991
	(0.7016)	(0.9309)**	(1.5529)***	(4.0044)***
Pseudo R^2	0.13			
Sample	439			
Percentage of correct prediction of the household's main fuel in the sample:				
Firewood		71.1		
Charcoal		15.3		
Kerosene		11.3		
LPG		2.0		
Electricity		0.3		
The standard errors are in brackets * significant at 10 %, ** significant at 5 % and *** significant at 1 %				

Source: Author, 2009

In this study, data is not available on control for quality of fuels. When LPG and electricity prices increase, households are more likely to use LPG and electricity relative to firewood. This result is inconsistent with that of Mekonnen and Kohlin (2008), and Sclag and Zuzarte (2008).

Location of residence

The coefficient on residence dummy is negative for kerosene and LPG. This means that a one per cent increase in the proportion of rural population will decrease the probability of using kerosene and LPG by 0.0959 and 0.0203 per cent, respectively. Households located in rural areas are less likely to use modern fuels compared to households in urban areas because of the poor rural infrastructure. This result is analogous to that reported by Israel (2004). In addition, rural areas face lower incomes from their main agricultural occupation compared to households in urban areas.

Distance to fuel source

Relative to firewood, the coefficients on log of distance is statistically significant and negative for LPG only. The results are consistent with that of Albebaw (2004) who also found a negative coefficient between fuel wood consumption and distance. This implies that the further the distance from the fuel source, the less likely households are willing to use the fuel.

Distance to fuel source, possibly captures aspects on security, availability and accessibility of fuels by households. In addition, households may perceive distance as an additional cost to the market fuel price.

Education

In relation to firewood, the coefficients for heads with primary education are positive for kerosene and LPG, but not statistically significant. However, they are negative and statistically significant for charcoal.

The coefficients for heads with secondary education are positive for LPG and electricity, but not significant. However, they are negative and statistically significant for charcoal and kerosene. This may imply that heads with higher education are more likely to use LPG and electricity compared to firewood.

This result is consistent with studies by Pundu and Fraser (2003) and Wuyuan *et al.* (2003). It suggests the importance of opportunity cost of time for collection and also awareness about the possible negative effects of fuel such as respiratory diseases from wood fuel use.

Houses with chimney

Relative to firewood, houses fitted with chimney are found to be positive for kerosene, LPG and electricity but statistically significant for kerosene only. This may suggest those households whose houses have chimney are less likely to use traditional fuels and are more likely to use kerosene compared to firewood. This may be because they are aware of pollution caused by these traditional fuels and the health risks associated with such pollutions.

Gender

The male gender was not found to be important. This may be because, in the Kenyan culture, males are less likely to be involved in food preparation. The rates of correct prediction of the household's main fuel are given in Table 10.

Multinomial logit results on energy substitution

The multinomial logit model was used to identify the factors that influence household's substitution from traditional or transitional fuels to modern fuels. Modern fuels are the omitted category, with which the estimated coefficients are to be contrasted. Table 12 presents marginal effects for multinomial logit results for fuel substitution while standard errors are in parentheses.

Household expenditures

The coefficients for log total household expenditures are negative for traditional fuels and positive for transitional fuels and are also found to be statistically significant. This implies that a 1 per cent increase in total household expenditure will reduce the probability of using the traditional fuels by 0.606 per cent and increase the probability of using transitional fuels by 0.563 per cent. Therefore, when total household expenditure increases, households using traditional fuels substitute them with modern fuels.

Those households using transitional fuels are more likely to increase their probabilities of using the transitional fuels compared to modern fuels. This result is similar to that reported by Barnes and Qian (1992) where income is an important factor affecting fuel use and substitution.

Table 12: Multinomial logit results for fuel substitution

Fuel sources /characteristics	Traditional fuels	Transitional fuels
Log total household expenditures	-0.0606**	0.0563**
	(0.0435)	(0.0431)
Log fuel price	-0.0317*	-0.0349***
	(0.322)	(0.03184)
Residence (1=rural)	0.0056	-0.0064
	(0.0778)	(0.0769)
Log distance to fuel-source	-0.0446	0.0448
	(0.0239)	(0.0236)
Head has primary education (1 = has primary education)	0.1259	-0.1294**
	(0.0609)	(0.0601)
Head has secondary education (1 = has secondary education)	0.2559	-0.2583**
	(0.0653)	(0.0628)
Gender (1=male)	-0.0302	0.0306
	(0.0643)	(0.0634)
House has chimney (1 = has chimney)	-0.0673	0.0690
	(0.1395)	(0.1384)
House has electricity connection (1 = has electricity)	-0.7759***	0.6202
	(0.0354)	(0.0638)
House has piped water connection (1 = piped water source)	0.1277	-0.1287
	(0.0899)	(0.0882)
Type of dwelling (1=modern house)	-0.0010	-0.0019
	(0.0625)	(0.0619)
Older household heads (1= 40 years or above 40 years)	-0.0029	0.0044
	(0.0619)	(0.0611)
Log household size	0.0324	0.029
	(0.0524)	(0.0518)
Constant	9.2283***	8.2271
	(2.3529)	(2.2193)
R^2	0.36	
Sample	440	
Percentage of correct prediction of the Household's main fuel category in the sample:		
Traditional	67.3	
Transitional	32.2	
Modern	0.5	

The standard errors are in brackets * significant at 10 %, ** significant at 5 % and *** significant at 1 %

Source: Author, 2009

Fuel price

Log of fuel price coefficient had a negative effect on both traditional and transitional fuels, meaning that a 1 unit increase in fuel price is likely to lead to a reduction in the probability of using traditional and transitional fuels by 0.317 and 0.349, respectively. Households using traditional and transitional fuels are more likely to substitute them with modern fuels when fuel prices increase.

Education

The coefficients for heads with primary education and secondary education are negative and statistically significant for transitional fuels. This means that households' heads with either primary or secondary education are less likely to use more of transitional fuels compared to modern fuels. Thus, household heads with higher education are more likely to substitute transitional fuels with modern fuels.

The result is consistent with that of Pundu and Fraser (2003), and Wuyuan *et al.* (2003). This may be because education above primary education is vital in imparting skills that are required in making many household decisions.

Infrastructure

The infrastructure of a location/area affects both fuel choice and substitution (World Bank, 2003). Households with developed infrastructure are more willing to use modern fuels. In the study, infrastructure was captured by the household as being connected with piped water and electricity. Households with electricity have a negative correlation with traditional fuels and a positive correlation with transitional fuels. This means that households connected with electricity are more likely to substitute traditional fuels with modern fuels. Having electricity is associated with a higher probability of using LPG and a lesser likelihood of firewood usage.

The Probit and Heckman estimation results

In order to investigate the factors influencing wood fuel expenditure, the study employed the Heckman sample selection model.

The Heckman and Olsen's regression results for the first and second stages are shown in Tables 13 and 14, respectively. Table 13 shows first stage regression results where determinants of fuel choice are examined, and where the dependent variable is fuel choice (1=woodfuels) with the *t*-statistics in parentheses.

Wood fuel expenditure

From the first stage regression, the coefficient on log proportion of wood fuel expenditure to total household expenditure is negative and significant. When income rises, even though amount of wood fuel expenditure is likely to rise, the proportion of households using wood fuel is likely to fall. This implies that household view wood fuel as an inferior good.

Table 13: First stage regression results

Explanatory variables	Probit model (Heckit)[17]	Probit model (Marginal effects) Heckit	Linear probability model (Olsen's)
Log total household expenditure	-0.0648 (-1.21)	-0.0184 (-1.21)	0.0151 (-1.20)
Log proportion of wood fuel expenditure to total household expenditures	-6.0747 (-9.90)	-1.7271 (-10.28)	-1.3560 (-9.47)
Residence (1=rural)	0.0069 (0.08)	0.0019 (0.08)	-0.0032 (-0.16)
Log household size	0.0199 (0.34)	0.0057 (0.34)	0.0033 (0.24)
Gender of head (1=female)	0.0492 (0.74)	0.0139 (0.74)	0.0083 (0.53)
Older household heads (1=40 years or above)	-0.0573 (-0.81)	-0.0164 (-0.81)	-0.0163 (-0.99)
Head has primary education	0.0598 (-0.81)	0.1700 (-0.81)	-0.0145 (-0.83)
Head has secondary education	-0.1059 (-0.92)	-0.0291 (-0.96)	-0.0238 (-0.89)
Log distance to fuel source	0.5023 (22.11)	0.1428 (21.36)	0.1564 (27.82)
Constant	4.9556 (7.82)	-	1.5214 (10.09)
(Pseudo)R^2	0.28		0.31
Sample size	2051	2051	549

Source: Author, 2009

The maximum likelihood estimates from the Heckman model are considered the most efficient estimators and are the ones that will be interpreted. The inverse mills ratio was found to be positive and significant. When the coefficient of inverse mills ratio is positive, there are unobserved variables that increase the probability of selection and create a higher than average score on the dependent variable.

From the first stage regression, the coefficient on log proportion of wood fuel expenditures to total household expenditures and the coefficient on log of distance to fuel source are statistically significant with negative and positive effects to wood fuel use, respectively.

Distance to fuel source

From the first stage regression, the coefficient on log of distance to fuel source is statistically significant with a positive effect on wood fuel. This means that as distance to wood fuel source increases, households are

[17] Heckit means Heckman

more likely to use wood fuel. The reason to this finding is that there are no alternatives for wood fuel especially in the rural areas.

Table 14 presents the second stage regression where the wood fuel expenditure model is estimated, the dependent variable is log of fuel expenditures, the selection term is wood fuel use and the *t*-statistics are in parenthesis.

In OLS and Olsen models, some of the observations are lost after the variable "proportion on wood fuel expenditure to total household expenditures" is dropped due to collinearity with wood fuel expenditure.

Log distance to fuel source is an exclusion restriction variable in that it is included in the first stage regression (the probit and linear probability models) and excluded in the second stage regressions. This is done in order to estimate parameters of the wood fuel expenditure model without bias. In relation to the consumer expenditure function, which is non-decreasing in price, distance is seen to be a price, and from theory, the expectation is that expenditure is non-decreasing with price. Therefore, the further the fuel is from the household's location, the chances are that the consumer is likely to spend more on the fuel. In this analysis, distance is assumed to affect the probability of fuel choice but not how much households spend on fuel, which is why it is excluded from the wood fuel expenditure model.

Older household heads

From our second stage regression, coefficients of older household heads and that of heads with primary education are found to be statistically significant. A 1 per cent increase in the proportion of households with older heads increases wood fuel expenditures by 0.01427 per cent. This implies that when the proportion of households with older heads increases, households are more likely to increase spending on wood fuel, but at a smaller proportion than their increase in income. That is, fuel expenditures are inelastic with respect to household income. This may imply that from habit, experience, traditions and culture, older household heads are likely to use wood fuel. This finding is similar to Ethiopia where age is an important factor in fuel selection (Mekonnen and Kohlin, 2008).

Education

The coefficient of heads with primary education is found to be positive and statistically significant. Heads with primary education as a factor does not influence the wood fuel use but rather it affects expenditures on wood fuel. This implies that highly educated heads are unlikely to spend more on wood fuel. This may be because they are aware of the health and environmental effects of using wood fuel. In addition, education above primary education is vital in imparting skills that are required in making many household decisions.

Table 14: Estimation results for the wood fuel expenditure model

Explanatory variables	OLS estimates	Heckman ML estimates	Heckman two-step estimates	Olsen's two-step estimates
Log total household expenditures	0.0549	0.0465	0.0470	0.0500
	(0.84)	(0.71)	(0.72)	(0.77)
Older household heads (1=40 years or above)	0.1547	0.1426	0.1427	0.1432
	(1.84)	(1.70)	(1.70)	(1.70)
Head has primary education	0.1530	0.1483	0.1487	0.1497
	(1.72)	(1.68)	(1.69)	(1.69)
Head has secondary education	-0.2014	-0.1982	-0.1988	0.1966
	(-1.45)	(-1.43)	(-1.44)	(-1.42)
Residence (1=rural)	0.0233	0.0153	0.0150	0.0150
	(0.22)	(0.14)	(0.14)	(0.14)
Log household size	0.0505	0.0612	0.0609	0.0608
	(0.72)	(0.87)	(0.87)	(0.87)
Gender of head*log total household expenditure	-0.0555	-0.0493	-0.0494	-0.0518
	(-0.68)	(-0.61)	(-0.61)	(-0.64)
Selection term (Inverse of Mills Ratio)	-	-0.2083	0.1998	-
		(2.09)	(2.08)	
Selection term (Olsen's Ratio)	-	-	-	0.4319
				(-2.15)
Constant	4.9187	4.7413	4.7484	4.7038
	(28.33)	(24.66)	(24.85)	(24.85)
R^2	0.02			0.03
Wald chi-square (*p*-value)	-	11.92(0.1033)	16.24(0.2990)	-
Sample size	549	2051	2051	549

Author, 2009

6. Conclusion and Recommendations

6.1 Conclusion

The study has analyzed factors that influence household fuel choice and fuel substitution in Kenya using a database consisting of 13,158 observations from KIHBS for 2005/6.

The study differs from other previous literature in terms of methodology. First, the multiple fuel use observed by many developing countries was taken into consideration. To incorporate this, the study assumed that fuels used by households are either traditional, transitional and modern. In order to estimate fuel substitution, multinomial logit was employed with these categories in mind. This model was found to be suitable for analyzing trends on energy use. Second, the study explored the Olsen's (linear probability) model whose results whose are found to be similar to those of Heckman's model.

The descriptive analysis and the econometric findings reported in the study show that there is existence of multiple fuel use as hypothesized in the literature. Both households in rural and urban areas are seem to combine the use of various fuels. Wood fuel is mainly consumed followed by kerosene and LPG, while electricity is least consumed. Furthermore, the regression results show that in addition to income, fuel price, location of residence, distance to fuel source, education and houses with chimney are important in determining household fuel choice. Older household heads and education are driving factors to the amounts spent on wood fuel.

6.2 Policy Recommendations

According to the analysis, the population currently using wood fuel is 84 per cent. Of this, 57 per cent are from the rural areas. In order to address the unsustainable use of wood fuel alongside inefficient cooking stoves, several recommendations are suggested.

Increasing the efficiency of wood fuel

This can be done through several ways. First, to encourage the use of efficient cooking stoves such as improved traditional stones and improved *jiko* stoves. Second, enhance ventilation of the cooking area and the fuel stove itself. Though programmes were designed in the 1970s and 1980s to encourage use of improved stoves, there is still a massive population of 58 per cent in Kenya who still use traditional stone fire especially in rural areas (76%). Therefore, there is need to revitalize the wide use of efficient fuel stoves as they require fewer fuels, and are technically designed to conserve energy as well as reduce amount of smoke when cooking (with some developed stoves having features that direct smoke outside the cooking area).

Moreover, designing houses with better ventilation by having enough windows and constructing a chimney in the cooking area is also important as health risks associated with indoor pollution will decline. Deforestation rates will decline by increasing the efficiency of wood fuel and by promoting use of wood fuel alternatives. At the same time, there will be increased opportunities and higher incomes for traders under efficient fuel stoves sector resulting from increased demand for the efficient fuel stoves.

Promotion of modern fuels

Despite several efforts by the government to promote use of LPG through for example, the zero rating of LPG in 2004 and the introduction of the Common External Tariff in 2005, it is still scarcely consumed.

The study found that long distances to fuel source (which also captures availability and accessibility) limits the use of modern fuels. In place, there are already policies targeting expansion of retail networks for LPG, kerosene and common user storage facilities but aspects on unreliability and inadequacy of storage are still a major concern. Therefore, developing dependable energy distribution systems with reliable and adequate storage, and refuelling units are strongly recommended. Intensifying programmes such as accelerating rural electrification and industrialization should strongly be carried out in parallel with the promotions of LPG initiatives in order to encourage use of modern clean fuel.

Carrying out capacity building

Education is another major attribute that influences the use of modern fuels. The public should be educated on the effects on the environment and human health on unsustainable use of wood fuel and other biomass fuels alongside inefficient cooking stoves. Giving information on the negative impacts of using such fuels and the benefits derived when the public switches to modern fuels, is highly recommended for achieving increased public development, increased productivity, reduced deforestation and improved human health.

Investment in commercial wood plantations and revitalizing village woodlots

Investment on commercial wood plantations and revitalization of village woodlots may be critical as households adjust to modern fuels. In addition, implementation of the already developed policies of promoting fast-maturing trees and growing of appropriate tree species for bio-diesel production is mandatory for sustainable wood production.

6.3 Areas of Further Research

The following areas are suggested for further research:

- The effects of household fuel choice on environment and health.
- The cost-benefits analysis of the main household fuels to the economy.
- Household level of fuel switching in Kenya.

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Appendix

A1: IIA tests results of Multinomial logit fuel choice

Simultaneous results for all

Multinomial logistic regression — Number of obs = 439
LR chi2(32) = 108.33
Prob > chi2 = 0.0000
Log likelihood = -387.05794 — Pseudo R2 = 0.1228

fuel	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
2						
lnincome	.3576156	.1886514	1.90	0.058	-.0121344	.7273655
lnprice	-.1265947	.1435191	-0.88	0.378	-.4078869	.1546975
rural	-.4846979	.3335626	-1.45 0	.146	-1.138469	.1690728
lndistance	.1171588	.110646	1.06	0.290	-.0997034	.3340211
hdprims	-.877127 .	2937896	-2.99	0.003	-1.452944	-.3013101
hdsecs	-1.513374	.5669234	-2.67	0.008	-2.624524	-.4022248
gender_male	-.0621683	.2999154	-0.21	0.836	-.6499917	.5256552
chimney	.1597765	.6092226	0.26	0.793	-1.034278	1.353831
_cons	-.6359082	.7016396	-0.91	0.365	-2.011096	.7392801
3						
lnincome	.3318935	.2118783	1.57	0.117	-.0833804	.7471675
lnprice	.1697687	.1841681	0.92	0.357	-.1911942	.5307315
rural	-.9665604	.3700925	-2.61	0.009	-1.691928	-.2411925
lndistance	-.0073934	.1271412	-0.06	0.954	-.2565857	.2417989
hdprims	-.0944372	.3282264	-0.29	0.774	-.7377492	.5488748
hdsecs	-1.046455	.658243	-1.59	0.112	-2.336588	.2436776
gender_male	.3536235	.3561511	0.99	0.321	-.3444199	1.051667
chimney	1.220595	.5078467	2.40	0.016	.2252336	2.215956
_cons	-2.247903	.9309093	-2.41	0.016	-4.072451	-.423354
4						
lnincome	.9559667	.5668299	1.69	0.092	-.1549996	2.066933
lnprice	1.500425	.4677136	3.21	0.001	.5837232	2.417127
rural	-.0740135	1.296659	-0.06	0.954	-2.615417	2.467391
lndistance	.4985143	.4599053	1.08	0.278	-.4028834	1.399912
hdprims	-1.246811	1.220105	-1.02	0.307	-3.638173	1.144551
hdsecs	.1548872	1.389958	0.11	0.911	-2.569381	2.879156
gender_male	1.353229	1.32331	1.02	0.306	-1.240412	3.946869
chimney	1.97306	1.252824	1.57	0.115	-.4824303	4.428551
_cons	-13.89912	4.004422	-3.47	0.001	-21.74764	-6.050595
5						
lnincome	1.176595	.2953997	3.98	0.000	.5976225	1.755568
lnprice	.6115168	.2575844	2.37	0.018	.1066606	1.116373
rural	-1.081487	.647007	-1.67	0.095	-2.349597	.1866234
lndistance	-.3786399	.2156275	-1.76	0.079	-.801262	.0439821
hdprims	.502249	.6035504	0.83	0.405	-.680688	1.685186
hdsecs	.5533371	.8131089	0.68	0.496	-1.040327	2.147001
gender_male	.3353657	.5669879	0.59	0.554	-.7759102	1.446642
chimney	.6084627	.8846962	0.69	0.492	-1.12551	2.342435
_cons	-5.851307	1.552866	-3.77	0.000	-8.89487	-2.807745

(fuel==1 is the base outcome)

Simultaneous results for partial

Multinomial logistic regression — Number of obs = 146
LR chi2(24) = 53.47
Prob > chi2 = 0.0005
Log likelihood = -135.29356 — Pseudo R2 = 0.1650

fuel	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
3						
lnincome	.0261181	.2784275	0.09	0.925	-.5195898	.5718261
lnprice	.4612979	.3019655	1.53	0.127	-.1305437	1.053139
rural	-.4651279	.4731606	-0.98	0.326	-1.392506	.4622497
lndistance	-.0887786	.1688519	-0.53	0.599	-.4197222	.2421651
hdprims	.8962422	.406189	2.21	0.027	.1001264	1.692358

hdsecs	.6543129	.8732134	0.75	0.454	-1.057154	2.36578
gender_male	.4911685	.4425148	1.11	0.267	-.3761445	1.358482
chimney	1.038158	.6860985	1.51	0.130	-.3065707	2.382886
_cons	-2.524999	1.365623	-1.85	0.064	-5.20157	.1515732
4						
lnincome	.5074354	.7195984	0.71	0.481	-.9029515	1.917822
lnprice	1.928004	.6203688	3.11	0.002	.7121039	3.143905
rural	.5312138	1.549342	0.34	0.732	-2.505441	3.567868
lndistance	.509385	.4869787	1.05	0.296	-.4450756	1.463846
hdprims	-.0838527	1.27836	-0.07	0.948	-2.589393	2.421688
hdsecs	1.765388	1.704965	1.04	0.300	-1.576281	5.107057
gender_male	1.351231	1.466527	0.92	0.357	-1.523109	4.225571
chimney	1.457277	1.409742	1.03	0.301	-1.305767	4.220321
_cons	-14.71657	4.44398	-3.31	0.001	-23.42662	-6.006534
5						
lnincome	1.049525	.3795102	2.77	0.006	.3056989	1.793352
lnprice	.8936951	.3719978	2.40	0.016	.1645928	1.622797
rural	-.457994	2 .7678837	-0.60	0.551	-1.963019	1.04703
lndistance	-.326795	.2652971	-1.23	0.218	-.8467677	.1931777
hdprims	1.747308	.7003561	2.49	0.013	.3746356	3.119981
hdsecs	2.584531	1.065326	2.43	0.015	.4965296	4.672532
gender_male	.2864597	.6700972	0.43	0.669	-1.026907	1.599826
chimney	.1644194	1.048579	0.16	0.875	-1.890758	2.219597
_cons	-6.684867	1.923414	-3.48	0.001	-10.45469	-2.915044

(fuel==2 is the base outcome)

Simultaneous results for all, partial

Number of obs = 439

(Std. Err. adjusted for 187 clusters in id_clust)

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf. Interval]	
all_2						
lnincome	.3576156	.1922673	1.86	0.063	-.0192215	.7344526
lnprice	-.1265947	.1492345	-0.85	0.396	-.4190889	.1658995
rural	-.4846979	.363637	-1.33	0.183	-1.197413	.2280176
lndistance	.1171588	.1324422	0.88	0.376	-.142423	.3767407
hdprims	-.877127	.3199782	-2.74	0.006	-1.504273	-.2499812
hdsecs	-1.513374	.5586345	-2.71	0.007	-2.608278	-.4184708
gender_male	-.0621683	.2983573	-0.21	0.835	-.6469378	.5226013
chimney	.1597765	.5525416	0.29	0.772	-.9231852	1.242738
_cons	-.635908	2 .6043197	-1.05	0.293	-1.820353	.5485366
all_3						
lnincome	.3318935	.2019113	1.64	0.100	-.0638453	.7276324
lnprice	.1697687	.1181508	1.44	0.151	-.0618026	.40134
rural	-.9665604	.4349331	-2.22	0.026	-1.819014	-.1141072
lndistance	-.0073934	.1260594	-0.06	0.953	-.2544652	.2396784
hdprims	-.0944372	.3245831	-0.29	0.771	-.7306084	.5417339
hdsecs	-1.046455	.7139619	-1.47	0.143	-2.445795	.3528846
gender_male	.3536235	.3523601	1.00	0.316	-.3369897	1.044237
chimney	1.220595	.4563124	2.67	0.007	.326239	2.114951
_cons	-2.247903	.9129657	-2.46	0.014	-4.037283	-.4585229
all_4						
lnincome	.9559667	.4423259	2.16	0.031	.0890238	1.82291
lnprice	1.500425	.4588905	3.27	0.001	.6010162	2.399834
rural	-.0740135	1.397832	-0.05	0.958	-2.813715	2.665688
lndistance	.4985143	.1873942	2.66	0.008	.1312284	.8658003
hdprims	-1.246811	1.258456	-0.99	0.322	3.713339	1.219718
hdsecs	.1548872	.9256462	0.17	0.867	-1.659346	1.96912
gender_male	1.353229	1.87044	0.72	0.469	-2.312767	5.019224
chimney	1.97306	1.384859	1.42	0.154	-.7412136	4.687334
_cons	-13.89912	4.17436	-3.33	0.001	-22.08071	-5.717523
all_5						
lnincome	1.176595	.3132185	3.76	0.000	.5626983	1.790492
lnprice	.6115168	.1866258	3.28	0.001	.2457368	.9772967
rural	-1.081487	.6366288	-1.70	0.089	-2.329256	.1662825
lndistance	-.3786399	.2334559	-1.62	0.105	-.836205	.0789252
hdprims	.502249	.5455557	0.92	0.357	-.5670204	1.571518
hdsecs	.5533371	.868307	0.64	0.524	-1.148513	2.255188
gender_male	.3353657	.5317362	0.63	0.528	-.7068181	1.377549

chimney	.6084627	.6477438	0.94	0.348	-.6610918	1.878017
_cons	-5.851307	1.204717	-4.86	0.000	-8.212509	-3.490106
partial_3						
lnincome	.0261181	.2802623	0.09	0.926	-.5231859	.5754221
lnprice	.4612979	.2430222	1.90	0.058	-.0150168	.9376125
rural	-.4651279	.4923417	-0.94	0.345	-1.4301	.4998441
lndistance	-.0887786	.2019206	-0.44	0.660	-.4845357	.3069785
hdprims	.8962422	.4493511	1.99	0.046	.0155302	1.776954
hdsecs	.6543129	1.027195	0.64	0.524	-1.358953	2.667579
gender_male	.4911685	.4088342	1.20	0.230	-.3101317	1.292469
chimney	1.038158	.7058998	1.47	0.141	-.3453805	2.421696
_cons	-2.524999	1.292698	-1.95	0.051	-5.05864	.0086432
partial_4						
lnincome	.5074354	.678964	0.75	0.455	-.8233097	1.83818
lnprice	1.928004	.5000565	3.86	0.000	.9479117	2.908097
rural	.5312138	1.871726	0.28	0.777	-3.137302	4.199729
lndistance	.509385	.3449989	1.48	0.140	-.1668003	1.18557
hdprims	-.0838527	1.275593	-0.07	0.948	-2.583968	2.416263
hdsecs	1.765388	1.098713	1.61	0.108	-.3880506	3.918826
gender_male	1.351231	2.245735	0.60	0.547	-3.050328	5.75279
chimney	1.457277	1.709884	0.85	0.394	-1.894034	4.808589
_cons	-14.71657	4.678	-3.15	0.002	-23.88529	-5.547864
partial_5						
lnincome	1.049525	.3612485	2.91	0.004	.3414913	1.757559
lnprice	.8936951	.2612524	3.42	0.001	.3816498	1.40574
rural	-.4579942	.7579374	-0.60	0.546	-1.943524	1.027536
lndistance	-.326795	.3084868	-1.06	0.289	-.9314179	.2778279
hdprims	1.747308	.6977893	2.50	0.012	.3796663	3.11495
hdsecs	2.584531	1.118736	2.31	0.021	.3918491	4.777212
gender_male	.2864597	.6641619	0.43	0.666	-1.015274	1.588193
chimney	.1644194	.9333861	0.18	0.860	-1.664984	1.993822
_cons	-6.684867	1.490281	-4.49	0.000	-9.605765	-3.763969

. test [all_3=partial_3]

(1) [all_3]lnincome - [partial_3]lnincome = 0
(2) [all_3]lnprice - [partial_3]lnprice = 0
(3) [all_3]rural - [partial_3]rural = 0
(4) [all_3]lndistance - [partial_3]lndistance = 0
(5) [all_3]hdprims - [partial_3]hdprims = 0
(6) [all_3]hdsecs - [partial_3]hdsecs = 0
(7) [all_3]gender_male - [partial_3]gender_male = 0
(8) [all_3]chimney - [partial_3]chimney = 0

chi2(8) = 29.54
Prob > chi2 = 0.0003

A1: IIA tests results of Multinomial logit fuel substitution

Simultaneous results for all

Multinomial logistic regression Number of obs = 440
LR chi2(18) = 248.17
Prob > chi2 = 0.0000
Log likelihood = -222.36179 Pseudo R2 = 0.3582

mfuel	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
2						
lnincome	.3134458	.184168	1.70	0.089	-.0475168	.6744084
lnprice	-.1497066	.14607	-1.02	0.305	-.4359986	.1365854
rural	-.0565216	.3460001	-0.16	0.870	-.7346693	.6216261
lndistance	.1976436	.1081819	1.83	0.068	-.014389	.4096761
hdprims	-.593458	.2820516	-2.10	0.035	-1.146269	-.0406471
hdsecs	-1.574441	.5609503	-2.81	0.005	-2.673884	-.4749991
gender_male	.1348589	.2976045	0.45	0.650	-.4484351	.718153
elecworking	4.384121	.6360395	6.89	0.000	3.137506	5.630735
pipdwater	-.6517133	.5214936	-1.25	0.211	-1.673822	.3703953
_cons	-1.190654	.7386244	-1.61	0.107	-2.638332	.2570226
3						
lnincome	1.226343	.3783845	3.24	0.001	.4847231	1.967963
lnprice	.4128142	.2964821	1.39	0.164	-.1682801	.9939085
rural	.2707714	.7366552	0.37	0.713	-1.173046	1.714589

lndistance	.0823814	.2466962	0.33	0.738	-.4011343	.5658971
hdprims	.2453159	.6653435	0.37	0.712	-1.058733	1.549365
hdsecs	.1717089	.9910956	0.17	0.862	-1.770803	2.114221
gender_male	.2565102	.6839782	0.38	0.708	-1.084062	1.597083
elecworking	7.465595	1.216557	6.14	0.000	5.081186	9.850004
pipdwater	-.193502	1.022708	-0.19	0.850	-2.197972	1.810968
_cons	-9.379323	2.044042	-4.59	0.000	-13.38557	-5.373074

(mfuel==1 is the base outcome)

Simultaneous results for partial

Multinomial logistic regression Number of obs = 146
LR chi2(9) = 46.24
Prob > chi2 = 0.0000
Log likelihood = -43.721633 Pseudo R2 = 0.3459

mfuel	Coef. Std.	Err.	z	P>|z|	[95% Conf. Interval]	
3						
lnincome	.9636326	.3728055	2.58	0.010	.2329473	1.694318
lnprice	.5992304	.2845007	2.11	0.035	.0416193	1.156842
rural	.4589977	.6953419	0.66	0.509	-.9038474	1.821843
lndistance	-.0834783	.2285056	-0.37	0.715	-.5313412	.3643845
hdprims	.7226032	.6154165	1.17	0.240	-.4835909	1.928797
hdsecs	1.556223	.9019968	1.73	0.084	-.211658	3.324104
gender_male	.1433622	.6326494	0.23	0.821	-1.096608	1.383332
elecworking	2.943533	1.068364	2.76	0.006	.8495768	5.037488
pipdwater	.6880472	.9611567	0.72	0.474	-1.195785	2.57188
_cons	-8.350161	1.895388	-4.41	0.000	-12.06505	-4.635269

(mfuel==2 is the base outcome)

Simultaneous results for all, partial

Number of obs = 440

(Std. Err. adjusted for 187 clusters in id_clust)

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf. Interval]	
all_2						
lnincome	.3134458	.1930589	1.62	0.104	-.0649427	.6918344
lnprice	-.1497066	.1524197	-0.98	0.326	-.4484438	.1490306
rural	-.0565216	.3937832	-0.14	0.886	-.8283225	.7152794
lndistance	.1976436	.1148313	1.72 0.	085	-.0274217	.4227088
hdprims	-.593458	.2979732	-1.99	0.046	-1.177475	-.0094414
hdsecs	-1.574441	.5076132	-3.10	0.002	-2.569345	-.579538
gender_male	.1348589	.29811	0.45	0.651	-.4494259	.7191437
elecworking	4.384121	.6713816	6.53	0.000	3.068237	5.700004
pipdwater	-.6517133	.5887479	-1.11	0.268	-1.805638	.5022115
_cons	-1.190654	.664238	-1.79	0.073	-2.492537	.111228
all_3						
lnincome	1.226343	.3150147	3.89	0.000	.6089257	1.843761
lnprice	.4128142	.2315832	1.78	0.075	-.0410805	.8667088
rural	.2707714	.7602433	0.36	0.722	-1.219278	1.760821
lndistance	.0823814	.2460169	0.33	0.738	-.3998028	.5645657
hdprims	.2453159	.662623	0.37	0.711	-1.053401	1.544033
hdsecs	.1717089	.8890958	0.19	0.847	-1.570887	1.914305
gender_male	.2565102	.671841	0.38	0.703	-1.060274	1.573294
elecworking	7.465595	1.19757	6.23	0.000	5.1184	9.81279
pipdwater	-.193502	1.16842	-0.17	0.868	-2.483563	2.096559
_cons	-9.379323	2.154141	-4.35	0.000	-13.60136	-5.157284
partial_3						
lnincome	.9636326	.2753156	3.50	0.000	.4240241	1.503241
lnprice	.5992304	.1858861	3.22	0.001	.2349004	.9635605
rural	.4589977	.6983377	0.66	0.511	-.909719	1.827714
lndistance	-.0834783	.2267487	-0.37	0.713	-.5278976	.3609409
hdprims	.7226032	.5858727	1.23	0.217	-.4256862	1.870893
hdsecs	1.556223	.7155043	2.18	0.030	.1538606	2.958586
gender_male	.1433622	.5966606	0.24	0.810	-1.026071	1.312795
elecworking	2.943533	1.023497	2.88	0.004	.937516	4.949549
pipdwater	.6880472	1.106855	0.62	0.534	-1.481349	2.857443
_cons	-8.350161	1.884083	-4.43	0.000	-12.0429	-4.657426

```
———————————————————————————————————————
. test [all_3=partial_3]

 ( 1) [all_3]lnincome - [partial_3]lnincome = 0
 ( 2) [all_3]lnprice - [partial_3]lnprice = 0
 ( 3) [all_3]rural - [partial_3]rural = 0
 ( 4) [all_3]lndistance - [partial_3]lndistance = 0
 ( 5) [all_3]hdprims - [partial_3]hdprims = 0
 ( 6) [all_3]hdsecs - [partial_3]hdsecs = 0
 ( 7) [all_3]gender_male - [partial_3]gender_male = 0
 ( 8) [all_3]elecworking - [partial_3]elecworking = 0
 ( 9) [all_3]pipdwater - [partial_3]pipdwater = 0

chi2( 9)        = 101.97
Prob > chi2     =  0.0000
```