HOUSEHOLD ENERGY CONSUMPTION AND DEPENDENCY ON COMMON POOL FOREST RESOURCES: THE CASE OF KAKAMEGA FOREST, WESTERN KENYA

Dissertation
to obtain the Ph. D. degree
in the International Ph. D. Program for Agricultural Sciences in Goettingen (IPAG)
at the Faculty of Agricultural Sciences,
Georg-August-University Göttingen, Germany

Presented by

Stephen Mutie Wambua

From Machakos, Kenya

Göttingen, December 2011

D7

1. Name of supervisor: Prof. Dr. Meike Wollni

2. Name of co-supervisor: Prof. Dr. Xiaohua Yu

Date of dissertation: 9th February 2012

Dedication

To my family, your love and support makes many things possible

Summary

Biomass is still the dominant source of energy used by most rural households in the developing world. Current use patterns have been linked to adverse effects on forest resources. Alternative fuels such as kerosene could mitigate these negative effects. In order to design policies that enhance the use of alternative fuels, a first step is to understand the household fuel use dynamics in terms of quantity, types and sources. This research looks into the consumption of different fuels by rural households living next to a common property resource forest in western Kenya. There are three focuses. First, it examines the determinants of the choice of fuel consumed by rural households through a multivariate probit approach. Second, it estimates a complete demand system for household fuel consumption using the two-stage Linear Expenditure System -Almost Ideal Demand System (LES- AIDS) model. Third, it analyses charcoal trade, with a focus on the trader involvement in Kakamega town, situated on the edge of the public forest. Empirical results are based on a quantitative study of 285 households randomly selected from the community living in villages within 5km from the edge of Kakamega forest, western Kenya. This is incorporated with an analysis of the charcoal supply chain focusing on charcoal traders operating within the Kakamega municipality. Primary data collection was carried out between July 2009 and February 2010. The data collected include details of the quantities and values of different energy types used as well as household and demographic attributes.

Results show that the public forest is an important source of biomass fuel supplying firewood to 50% and charcoal to 15% of sampled households as well as 21% of the charcoal sold in Kakamega town. The poverty level is an important determinant of the type of fuel combination consumed by the household as well as the source of biomass fuel. Poorer households depend

more on the forest for their biomass fuels that the better off households. Households with the higher land holdings tend to rely more on biomass fuels produced form their farms. Household income is an important, but not the only determining factor for the type and level of fuel consumption. The household attributes and prices of different fuel types also play an essential role. The results of this study confirm biomass fuels are used alongside modern fuels without displacing them, evidence of fuel stacking as opposed to fuel switching, a phenomenon also observed in urban households. There is evidence of continued forest degradation from legal and illegal use of the forest for firewood and charcoal, despite the protection of the forest. The demand for charcoal, the most forest destroying fuel, is most responsive to changes in its own price, changes in the price of firewood and liquefied petroleum gas. This offers a potential for a change to a more forest conserving fuel with increasing scarcity of charcoal and increased access to the other more forest conserving fuels. However, as household incomes increase, there is a disproportionately high increase in the demand for charcoal with negative impacts on forest conservation.

Charcoal trade in Kakamega town is dominated by charcoal sourced from outside the Kakamega region with a significant contribution from the public forest. The town offers a ready market for charcoal from the forest due to its growth and proximity to the forest. Therefore charcoal use and trade in the Kakamega municipality has an impact on the conservation of the Kakamega forest. Despite the fact that charcoaling in the forest is banned, it is a thriving business. The results of this study show that charcoal from the forest enters the supply chain only through the hawkers. They therefore act as an important link between charcoal trade and deforestation and forest degradation. Charcoal producers only cut some specific indigenous trees from the forest. This selective felling of the preferred hardwood trees for charcoal may lead to biodiversity disturbance. Every time a hawker sells a bag of charcoal, they earn an equivalent to two man-days of farm wages in the region, although it takes only about three hours to dispose the charcoal. The high profitability of charcoal hawking is a great incentive for the continued deforestation and degradation. The share of Kakamega forest in the charcoal trade in the region is relatively small and tends to benefit mainly the hawkers and charcoal burners who come from the local community. Effective conservation measures therefore should target this group but also consider development of income alternatives for this group as part of the forest stakeholders.

Overall, there is a strong link between the conservation of the public forest and the energy consumption of the community living on its edge. Successful forest conservation policies have also to take into consideration the needs of the local community so as not to make the poor households poorer.

Zussamenfassung

In den ländlichen Haushalten der sich entwickelnden Welt Biomasse die dominante Energiequelle. Die derzeitige Nutzung wird mit negativen Auswirkungen auf Waldressourcen in Verbindung gebracht. Alternative Energiequellen wie Kerosin oder Gas könnten diesen negativen Effekt mildern. Ein besseres Verständnis für die Dynamik der Energienutzung innerhalb von Haushalten ist ein erster Schritt für die Entwicklung von Strategien, welche Nutzung alternativer Energiequellen fördern. Diese Studie untersucht die Nutzung unterschiedlicher Energieträger in ländlichen Haushalten, die sich in der Nähe eines öffentlichen Waldes im Westen Kenias befinden. Die Arbeit hat drei Schwerpunkte. Erstens werden die bestimmenden Faktoren für die Wahl bestimmter Energieträger in ländlichen Haushalten mit Hilfe einer multivariaten Probit Analyse untersucht. Zweitens wird ein ganzheitliches Nachfragemodell für Haushaltsenergieträger auf der Basis eines zweistufigen Linear Expenditure System – Almost Ideal Demand System (LES-AIDS) geschätzt. Die empirischen Ergebnisse beider Schwerpunkte basieren auf quantitativen Umfragewerten mit 285 Haushalten. Die Haushalte wurden nach dem Zufallsprinzip aus Gemeinden selektiert, die zum Kakamega Waldrand eine maximale Distanz von 5km haben. Drittens wurde der Handel mit Holzkohle in Kakamega Stadt näher untersucht. Primärdaten wurden zwischen Juli 2009 und Februar 2010 gesammelt.

Die Ergebnisse zeigen, dass der öffentliche Wald eine wichtige Quelle für Biomasse basierte Energieträger ist. In der Stichprobe haben 38% der Haushalte Holzkohle und 15% der Haushalte Feuerholz aus dem Wald bezogen. Armut ist eine wichtige Determinante für die Verwendung von Brennstoffen. Außerdem spielt die Lokalität der Biomassequelle für die Nutzung eine Rolle. Ärmere Haushalte hängen stärker vom Wald als Energiequelle ab als die etwas besser gestellten

Haushalte. Haushalte mit mehr Land tendieren dazu ihre eigenen Biomasse basierten Brennstoffe zu produzieren. Die Biomassebrennstoffe werden neben den ‚modernen' Brennstoffen parallel in identischen Haushalten genutzt, ohne dass die Biomassebrennstoffe verdrängt werden. Dies ist ein Anzeichen für das sogenannte ‚fuel stacking', also die parallele Nutzung mehrerer Energieträger. Es gibt außerdem Anzeichen für die fortschreitende Degradierung des Waldes durch legale sowie illegale Waldnutzung für Feuerholz und Holzkohle, trotz des praktizierten Waldschutzes. Die Nachfrage für Holzkohle, die für den Wald schädlichste Form der Energiegewinnung, reagiert am stärksten auf Änderungen des eigenen Preises sowie auf Änderungen der Preise von Feuerholz und Gas. Dieser Sachverhalt birgt Potential für Veränderungen hin zu waldschonenderen Energieträgern sofern die Knappheit von Holzkohle erhöht werden kann, beziehungsweise der Zugang zu anderen, schonenden Energieträgern verbessert werden kann. Mit steigenden Einkommen steigt die Nachfrage nach Holzkohle jedoch überproportional and - mit entsprechenden Folgen für den Waldschutz.

Der Holzkohlehandel in Kakamega Stadt wird von außerhalb der Kakamega Region produzierter Holzkohle dominiert. Ungefähr 21% der gehandelten Holzkohle wird jedoch im Kakamega Wald gewonnen. Die wachsende Stadt stellt durch ihre Nähe zum Kakamega Wald einen guten Markt für Holzkohle dar. Deren Nutzung hat Auswirkungen auf den Erhalt des Kakamega Waldes. Trotz des bestehenden Verbots für Holzkohlegewinnung in Kakamega Wald ist dessen Produktion ein blühendes Geschäft. Die Ergebnisse dieser Arbeit zeigen, dass die Holzkohle ausschließlich durch kleine mobile Straßenhändler in den Markt gebracht wird. Sie bilden daher eine wichtige Verbindung zwischen dem Holzkohlehandel und der Degradation von Kakamega Wald. Holzkohleproduzenten konzentrieren sich auf ganz bestimmte heimische Baumarten. Dieser selektive Einschlag von bevorzugten Harthölzern kann Störungen im Gefüge der biologischen Vielfalt verursachen. Jedesmal wenn ein Straßenhändler einen Holzkohlensack verkauft verdient er das Äquivalent von zwei Tageslöhnen eines Landarbeiters der Region, obwohl der Verkauf nur drei Stunden in Anspruch nimmt. Die hohen Gewinnmargen des Holzkohlehandels stellen einen bedeutenden Anreiz für weiteren Holzeinschlag dar. Der Anteil von Kakamega Wald am Holzkohlehandel der Region ist relativ gering. Gewinne entstehen vor allem den Produzenten und Straßenhändlern der lokalen Gemeinde. Effektive Schutzmaßnahmen sollten daher auf diese Gruppen abzielen und die Entwicklung alternativer Einkommensmöglichkeiten dieser Gruppe in Erwägung ziehen.

Im Großen und ganzen zeigt die Arbeit eine starke Verbindung zwischen Waldschutz und Energieverbrauch der in der Nähe des Waldrands lebenden Gemeinde. Erfolgreiche Waldschutzmaßnahmen sollten die Bedürfnisse der lokalen Gemeinden in Erwägung ziehen um zu verhindern, dass die armen Haushalte noch ärmer werden.

Table of Contents

List of Tables

List of Figures

Acknowledgement

I am highly indebted to Prof. Dr. Meike Wollni and Prof. Dr. Xiaohau Yu my first and second supervisors respectively for their guidance and commendable mentoring during the whole period of my study. I am indebted to Dr. Tobias Wünscher for his tutoring, guidance and logistical support during all phases of the study. This work would not have been possible without your valued advice and suggestions. I am grateful to KAAD for providing me with a study scholarship and the German Ministry of Education and Research (BMBF) through the Biodiversity Monitoring Transect Analysis (BIOTA-East Africa) project for providing research funds and the Center for Development Research (ZEF) for offering me office space, logistical support and a partial scholarship to bridge a funding gap during my stay in Germany. Special thanks to Prof. Dr. J. von Braun for the fatherly advice and support.

My sincere gratitude goes to my wife Joyce for her support and encouragement throughout the period of study and especially for being the mother and father to our children in my study absence. My special regards to our children Nduku, Ndunda, Mwikali and Mutheu for bearing with Daddy's absence gracefully. My special thanks to my parents, brothers, sisters and friends for their encouragement and prayers.

Finally I thank the staff and fellow colleagues at the Bonn International Graduate School for Development Research (BIGS-DR), Center for Development Research (ZEF) and at the department of Agricultural Economics and Rural Development, University of Göttingen for their special support.

The support accorded to me during my field research from the KFS headquarters and Kakamega office is highly appreciated. My special thanks to the KFS Assistant Zonal Manager, Kakamega for answering many questions and providing useful data. The good work done by the enumerators Elisha, Josky and Mike is highly appreciated. Special thanks also to all our respondents for patiently answering all questions and the local provincial administration officers for their security and logistical support.

Acronyms

AIDS------------------------------Almost Ideal Demand System

BIOTA-------------------------- Biodiversity Monitoring Transect Analysis in Africa

CPI--------------------------------Consumer Price Index

FD---------------------------------Forest Department

GoK------------------------------Government of Kenya

GTZ---------------------------- Gesellschaft für Technische Zusammenarbeit

IEA-------------------------------International Energy Agency

IIA--------------------------------Independence of Irrelevant Alternatives

IMR------------------------------Inverse Mill’s ratio

KES------------------------------Kenya Shilling

KFMP---------------------------Kenya Forestry Master Plan

KFS------------------------------Kenya Forest Service

KIPPRA-------------------------Kenya Institute of Policy Research and Analysis

KNBS---------------------------Kenya National Bureau of Statistics

KWS--------------------------- Kenya Wildlife Services

LES------------------------------Linear Expenditure System

LPG------------------------------Liquefied Petroleum Gas

MDG----------------------------Millennium Development Goals

MENR--------------------------Ministry of Environment and Natural Resources

MLE----------------------------Maximum Likelihood Estimation

QC------------------------------Quakers Church

SML----------------------------Simulated Maximum Likelihood

WRI----------------------------World Resources Institute

1. Introduction

1-1 Background

Forests and other tree systems in Africa constitute an important component of household livelihood (Sene, 2000). Forests are also important in the conservation of biodiversity, regulation of the hydrological cycle, wildlife habitat, carbon sequestration and climate regulation among others. The indigenous forests, particularly, provide a wide range of goods and services to the local communities, including food (vegetables, fruits and roots), medicinal plants, honey, thatching grass, fodder, firewood, charcoal, construction materials as well as offering cultural, spiritual and ceremonial sites (Wandago, 2002). Forests therefore play an important role in rural household economies. Africa has the highest annual per capita fuel wood consumption in the world at 0.83 m^3 (Sene, 2000). Most of this is used for cooking and therefore, by providing cooking energy, forests and tree systems also contribute to household food security. The contribution of forests to food security also includes the provision of household employment and income. Forests are also known to provide other non-use values which include existence, altruistic and bequest values to different stakeholders (Kolstad, 2000).

Kenya is a forest poor country with only 5.9% of its area covered by different types of forests, 41% of which are closed canopy indigenous, plantation or mangrove forests (KFS, 2009). The indigenous forests are important reservoirs of plant biodiversity as well as providing habitat to almost 40% of the large mammals, 30% of the bird species and 35% of butterfly species (KFMP, 1994). Despite their recognized importance, Kenya has lost almost 8% of its indigenous forest in the last twenty years (Guthiga et al, 2008). These forests are also found in the medium to high potential agricultural lands where most of the population also lives. Indeed, villages on the forest edge have the highest rural population densities in Kenya (Schaab et al., 2010). Therefore, these forests are under pressure from exploitation by local communities. Although national governments are concerned with the value of timber in forests, studies have shown that forests offer important livelihood options for local communities (Emerton, 1996) through the provision of fuel wood and other non timber products. As noted by Fisher (2004), forests and other natural resources offer viable opportunities for lowering the income gap between the poor and rich households in rural areas through consumption and sale of various non-timber products. In spite of the government recognizing the local communities' dependency on forests, and acknowledging their role in forest conservation and protection (MENR, 2007) it has instituted stringent forest management and protection measures to limit forest loss. This has resulted in the loss of some of the benefits enjoyed by the local communities.

There is evidence of a growing gap between the production and consumption of biomass fuels in Kenya under the current wood production and energy use conditions. Biomass consumption and sustainable supply projections in 2000 indicated an increasing deficit from 57.2% in the year 2000 to an estimated 63.4% by 2020 (Ministry of Energy, 2002). Coupled with the growth in population, this may push more households to rely more on common pool forests for their fuel needs.

1-1.1 Problem Statement

Biomass fuels account for 80% of Kenya's energy use (GoK, 2007; Ministry of Energy, 2002). The dependency on biomass fuels is even higher for rural households. As noted by KIPPRA (2010) the increasing gap between the sustainable supply and demand on fuel-wood is exerting pressure on public forests and other tree systems. Kakamega forest in Western Kenya is a high global, national and local value forest in Kenya. The area surrounding this forest also has a population density of almost 700 persons per square kilometer (Schaab, et al., 2010), one of the highest in the country. Since the turn of the twentieth century, the forest has faced constant threats, initially from mining, then logging, excision and of late, from local use. With improved management, the mining and illegal logging has been contained in the indigenous part of the forest. Only permitted logging is carried out in the plantation forest. These management efforts coupled with better forest protection have led to the recovery of the forest in the last ten years, the highest changes being in the parts where extractive use is outlawed (Mitchell, 2004; Schaab, 2010). In spite of this success, there is evidence of forest degradation and deforestation especially as a result of the interaction of the local community with the forest (Lambrechts et al., 2007; Guthiga, et al., 2008). One of the most important uses to the local community is the provision of fuel wood. With the increasing population in both the area surrounding the forest and Kakamega town on the edge of the forest, this reliance will lead to more forest degradation. Even with improved management, illegal forest extraction can be a particular problem in the fuel-wood sector as disperse and small scale activities are difficult to monitor and control. Records at the Kakamega forest office show that between 2007 and 2009, arrests for charcoal burning and cutting of trees have increased by almost 50% (personal communication with Assistant Zonal Manager, Kakamega).

With reduced access to forest fuel wood due to more protection measures, households relying on the forest for fuel may have to change their energy consumption patterns. Studies have indicated that the household’s response to reduced supplies of biomass fuels is determined by the household income and general level of economic development (Masera et al, 2000; Heltberg, 2004; Macht et al., 2007; Schlag and Zuzarte, 2008). Most studies on household fuel consumption have been carried out either in urban settings or general rural areas and fail to consider the source of biomass and any substitution is between fuels and not sources of the same fuel. Their results are not directly applicable to rural area where the common pool forest resources are the most important source of fuel wood. However, studies have pointed to different conclusions on the actual relationship between poverty and dependency on natural resources (Reardon and Vosti, 1995; Fisher, 2004; Khan and Khan, 2009).

1-1.2. Research Objectives

The overall objective of this study is to analyze the energy use by the households living next to the Kakamega forest in western Kenya and its link to the conservation of the common pool forest. The specific objectives of the study are

1. Assess the determinants of the energy choice for cooking by the rural households living next to the Kakamega forest.
2. Explore the options for fuel transition from the current use patterns to more forest conserving fuels and sources.
3. By estimating the complete demand system for fuels used by the rural households for cooking and space heating, calculate the income and price elasticities.
4. Study and document the charcoal supply chain for Kakamega town with special emphasis on the role of traders in charcoal trade.

1-2. Historical development of the forestry sector in Kenya

Government forest reserves have been established since the early 1900's and are managed by the government, originally to supply industrial forest products and to generate income (Broekhoven and Gathaara, 1995). At the beginning of the 20th Century, there was a deliberate move to change the indigenous forests with forest plantations initially for the railway system. These forests were seen as very slow growing compared to the fast growing exotic plantations that were tested in earlier trials. Therefore, the early colonial forestry management introduced an emphasis on exotic plantation development into the country. In around 1945, Kenya started the first systematic program of replacing indigenous forests with plantations of exotic species and replanting of clear-felled industrial plantation areas. Through the *shamba* system (a form of *taungya*), workers were allowed to cultivate food crops in newly planted forest plantations as they took care of the young trees. The inter-cropping of food and tree crops ideally lasted until the tree seedlings were so big that they would prevent a decent harvest of food crops. This practice was important in the early establishment and expansion of the forest plantations as the trees in these forest plantations were well-tended at basically no cost to the Forestry Department (FD)[1]. Under this system, the FD was able to establish a basic national network of industrial forest plantations. The main species planted were exotic conifers (cypress and pines) for timber along with a significant area of Eucalyptus species for fuel (Mitchell, 2004). In the early 1970s, in an effort to solve the problem of increased wood demand, the Government decided to seek external capital to finance a forest development program. This program was designed to increase the production of industrial round-wood as a raw material base for a domestic forest industry. With donor funding, the Forest Department was able to establish about 170,000 Ha of forest plantations.

From the mid-1980s, there was a steady decline in the strength of the FD as a public body responsible for the management of forest plantations (KFMP, 1994). This decline was largely attributed to a lack of political support, inadequate budgetary allocations and changes in staff attitudes, skills and motivation leading to inefficiency and deterioration of the forestry sector.

[1] With the enactment of the Forest Act, 2005, the Forest Department changed to the Kenya Forest Service (KFS)

Currently, there is a large and growing backlog in the implementation of necessary planting and silvicultural operations and the standard of forest plantation establishment work were generally quite poor. The results of these problems can be seen clearly in supply and demand projections for forest products. For example, according to the Kenya Forestry Master Plan (KFMP) of 1994, it was estimated that future increases in wood supply would not be able to keep pace with the projected increase in demand beyond the year 2000. The total national deficit in wood products was projected to rise to 997,000 m^3 by 2005 and 6,841,000 m^3 by 2020 under the current forest management scenario (KFMP, 1994).

The continued loss of forests and associated resources has had a negative impact on the country's economy and welfare. Some of the consequences of forest loss include reduced domestic supply of timber and other wood products, loss of employment, forest biodiversity and destruction of water catchments function with a resultant reduced supply of water for domestic and industrial use. To reverse the declining forest resources, the government responded by two main policies; a presidential decree in 1985 that banned commercial exploitation of natural forests and a ban in 1999 on logging from government forest plantations. Since the ban on logging, the country has been importing timber and other wood products especially form Tanzania, Uganda, Democratic Republic of Congo and Congo Brazaville (KFS, 2003). In 2006, imports included 85,106m^3 of softwood, 21,277m^3 of hardwood and 150 000 power transmission poles, valued at a total of KES 3.6 billion (Geller et. al., 2007). On a positive note, the ban has allowed the KFS to determine the stock available to maintain sustainable harvest levels and time to replant the logged areas. It also made farmers aware of the benefits of investing in tree planting as industry looked to farms for the supply of logs with a resultant increase in the price of trees. It has also led to more efficient use of timber by-products by creating markets for saw dust, for example. When the Presidential ban came into force in 1999, the planting backlog was at 46 000 hectares but replanting efforts have since reduced it to 15000 hectares by 2006. An important effect of the ban on logging was the increase in the price of wood products, for example, the price of construction timber increased by about 92% by 2005 (Kagombe et al., 2006).

1-3. Current status of the forestry sector in Kenya

Kenya is internationally considered to be a low forest cover country as it has less than 10% of its total land area classified as forest (GoK, 2007). By following the FAO definition of a forest as 'land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than10% of trees able to reach these thresholds in situ' Kenya has 5.9% of its area designated as forest (KFS, 2009). Of this, 2.4% is indigenous closed canopy, mangrove and plantation forests in both public and private land (Table 1-1). The public forests account for 93.6% of the closed canopy forests, and are managed by the Kenya Forest Service (KFS) or the Kenya Wildlife Service (KWS) where national reserves or parks also encompass forests. Most of the closed canopy forests are located in the high to medium potential areas of Kenya where the human population and agricultural production is also concentrated. This creates a potential conflict between forest, agriculture and household needs and has led to deforestation and forest degradation.

Table 1-1: Forest Cover Analysis for Kenya

Category of forest Cover	Area ('000 Ha)			
	1990	2000	2005	2008
Indigenous closed canopy	1240	1190	1165	1165
Mangrove	54	54	54	54
Industrial plantation forest	170	134	119	107
Private Plantation Forest	68	78	83	90
Sub-total (closed canopy forest)	1532	1456	1421	1406
Woodlands	2150	2100	2075	2050
Total Forest cover	3682	3556	3496	3456

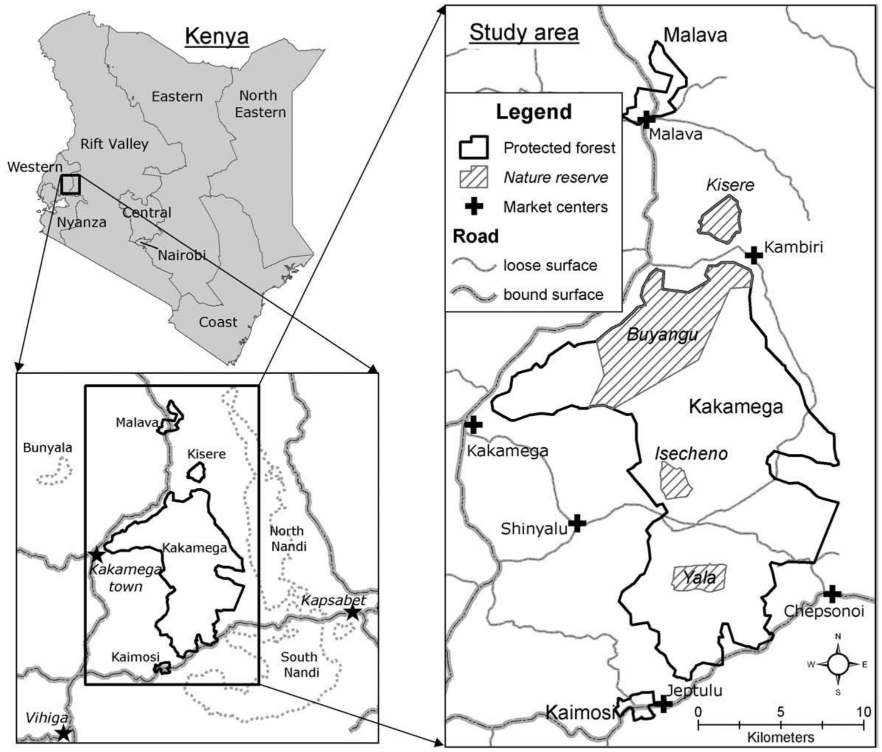
Source: KFS, 2009

Between 1990 and 2008, about 8% of the closed canopy forest areas have been lost through forest excision by the government and invasion by local communities. At the same time, the area under private forestry has expanded, but this increase has not compensated for the loss of public forest land. The rate of forest area loss has slowed over the years from 3.4% in 1990-2000 to only 1.1% during the period 2005-2008. This is attributed to the change in government policy especially the ban on logging from all indigenous forest and better management of public plantation forests by the KFS. In spite of this apparent stabilization of the areas designated as closed canopy forests, research has established that the loss of trees within these areas still continues, for example, only 43% of the Kakamega and Nandi forests which are classified as closed canopy forests is totally covered by the tree canopy (Schaab et al., 2010). Aerial photographs in all major water catchment forests in the country show similar deforestation and degradation (Gathaara, 1999; Lambrechts et al., 2003; 2007). In addition to the 1.4 million ha of closed canopy forests, there are approximately 2.05 million ha of other woodlands spread over the arid and semi arid areas of the country. These are supplemented by trees on farmlands in meeting the wood demand in Kenya.

Historically, the KFS has been both the national forestry authority and the manager of the state-owned forest resource. Since only about 5.4% of forests are privately owned, KFS is the main producer of forest products in Kenya. The KFS is financed mainly by the government although it receives some external funding for specific projects. It is mandated to lead in policy formulation to ensure a growth in the area under forests and an adequate supply of forest products. It has set out plans that target an increase of closed canopy forests from the current 2.4% to about 4% by the year 2012 and 10% by 2030 (GoK, 2007). To achieve this, the KFS is developing programs that ensure better management of the plantation forests, by involving the private sector in the management of industrial plantations and also promote community participation in forest management and conservation. To ease pressure on the public forest, KFS is also promoting farm forestry and dry-land forest management specifically to meet the household needs (GoK, 2007).

1.4. Description of the study area

The study was carried out within the communities living around Kakamega forest. Charcoal traders operating in Kakamega town which is situated on the eastern edge of the forest were also included (Fig 1-1) in the study. This forest and its associated forest fragments of Kisere, Malava and Kaimosi are located mainly in the larger Kakamega district with a small portion in Vihiga district, western Kenya. It covers an area of about 240^2 km (Mitchell, 2004, Börner et al., 2007). It is the eastern most extent of the Guneo-Congolian rainforest and the only kind in Kenya (Fig 1-1).



Source: Müller and Mburu, 2009

Figure 1-1 : Location of Kakamega forest

Due to its location and nature, the forest is one of the species richest forests in Kenya and home to a special mix of flora and fauna, some of which are endemic. Apart from its rich biodiversity value, the forest is an important water catchment area for the lake basin with two important rivers, Isiukhu and Yala flowing through it. The forest is surrounded by a densely populated agricultural land, with over 700 inhabitants per square kilometer in the first 2km ring around the forest (Table 1-2), one of the highest in the country. This is projected to increase to about 1000 persons per km^2 by 2019 (Schaab et al., 2010). It is estimated that about 90% of the people living in the rural areas of Kakamega directly or indirectly depend on agriculture for food and income despite the low levels of household land holding (Guthiga, 2007). At the same time the incidence of poverty is high and the population living below the rural poverty line in Kakamega district ranges between 50-60% (KNBS, 2003). These conditions create a high potential conflict between forest conservation and the needs of the local community.

Table 1-2: Population density around Kakamega forest

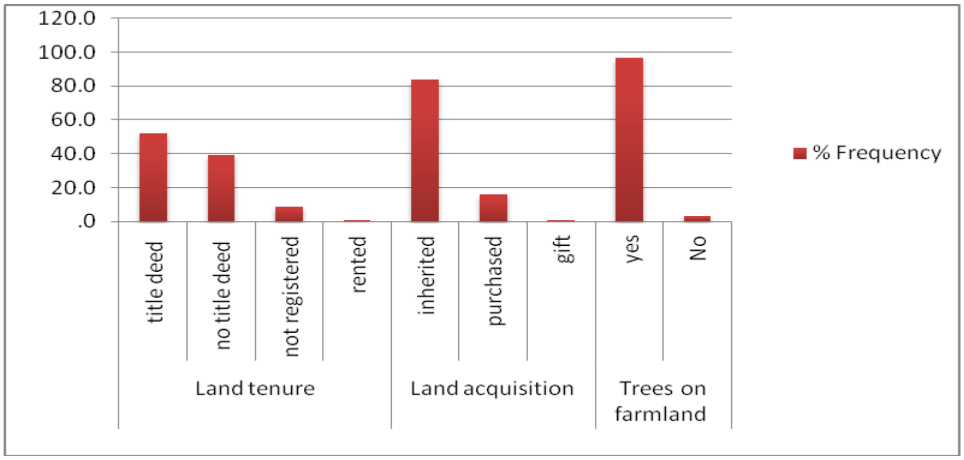
Area around forest	Population (persons/sq.km)				
	1979	1989	1999	2009	2019[a]
2Km Buffer zone	300	450	525	710	975
5km Buffer zone	270	400	470	670	900
Kakamega District	250	300	425	570	750

Source: Schaab, et al., 2010
[a] predicted population

In the pre-colonial days, the forest was part of the community land. The first boundary was physically established at around 1908-1910, revised in 1912-1913 and later in 1929-1932 (Mitchell, 2004; Schaab et al., 2010). The current forest boundaries were gazetted in 1933 as a trust land forest. The forest remained the property of the local people but the government would manage it on their behalf. The customary rights of the local people on the forest were reinstated by special rules issued by the government in 1959 and 1964. At this time the forest was managed by the local people through their village elders (Mitchell, 2004). The forest was declared a central government forest in 1964, but the local people were allowed to extract products from the forest. Because of this, the local communities still consider themselves the *de facto* owners of the forest. Due to government sanctioned logging and also extraction by the local community, high levels of deforestation were recorded. In an effort to preserve the natural forest, the Isecheno and Yala Nature reserves were set up under the Forest department in 1967. The Yala reserve was established to conserve an example of an unexploited riverline forest type (Schaab et al., 2010). In 1985, a portion of the forest near Buyangu and Kisere forest were designated national reserves under the management of KWS. The mall fragment of Kaimosi to the south of the forest is privately managed by the Quakers Church (QC) (Fig.1-1). The National Reserves under KWS are managed as strictly non-extractive use area with restricted access where visitors are charged to enter (Guthiga, 2007). The KFS manages the southern part of the main block as well as the Malava forest (Fig. 1-1). Both the KFS and QC allow free access to the forest under their care, but control the extractive use of permitted products by charging access fees and policing. After purchasing the appropriate licenses, the locals are allowed to collected fallen dead branches for firewood, cut grass from the forest grades and also graze their animals in the forest. Despite these efforts, almost 20% the forest was lost between 1970 and 2000 (Lung and Schaab, 2004). Increased conservation efforts in the last ten years coupled with the ban on logging from the indigenous forest has resulted in forest recovery in most parts of the forest (Mitchell, 2004, Schaab et al., 2010). The KWS managed part has shown the highest levels of recovery. Given the prevailing levels of poverty and livelihood options, the current patterns of dependence on the forest by the local community are unlikely to change in the near future. The local community continues to rely on the forest for specific products especially firewood, charcoal, building poles, traditional medicines and grass (for both thatch-grass and grazing). The forest therefore is likely to remain under constant threat of degradation from these activities. Illegal forest extraction continues to be reported in all forest areas including the well protected nature and national reserves, managed by the KFS and KWS respectively (Lambrechts et al., 2007).

1.5. General characteristics of sampled households

The mean values of the main characteristics of the sampled households living next to Kakamega forest are summarized in Table 1-3 and Figures 1-2a and b. Although there is a link between charcoal trade in Kakamega town and the conservation of the forest, only a small proportion of the traders interact with the forest. Contrary to this, most rural households living next to the forest depend directly or indirectly on the forest for their energy needs. Therefore, this summary is based on the primary data collected on 390 rural households living in villages within five kilometers from the edge of the forest. In general, households in Kakamega can be classified as small scale land owners given the average land ownership of 2.25 acres (0.91 ha) (Table 1-3). This agrees with findings of other studies in the area; for example, 0.97 ha by Guthiga (2007) and about 1.2ha by Sikei et al., (2008). Given this low land holding, the average land set aside for trees is on average only 0.12 acres. Despite this, almost 97% of the households have planted trees either on land set aside for pasture or along the edges of farm land. Inheritance was given as the main method of acquiring land. Over 83% of the respondents indicated that they inherited the main farm from their parents (Figure 1-2a). There is security of land tenure as about 91% of household heads have registered their land ownership with the government and more than half of them have acquired title deeds. Most of the households (75%) are involved in farming as their main source of livelihood (Figure 1-2a).



Source: Author's calculations based on collected data

Figure 1-2: Frequency distribution for some selected land ownership variables of sample respondents

Under these conditions, household land holdings are expected to continue declining in the future, thus reducing the ability of the land to meet the needs of the residents. The decreasing land sizes and the accompanying loss in agricultural production may leave forest extraction as the main viable option for most households. This will be detrimental to the forest conservation efforts.

Table 1-3: General characteristics of the sampled households

Variable	Mean	Std. Deviation
Total household farm holding in acres	2.25	2.57
Total area in acres under crops	1.77	2.08
Total grazing area in acres for the household	.34	.52
Total area in acres under trees	.12	.25
Age of the household head in years	51.19	14.34
Years of formal education of household head	6.80	3.94
Average husehold size	5.50	1.78
Per capita annual expenditure (KES)	25183	13557
Average number of trees per acre of farmland	13.02	11.24
Distance to the nearest forest edge in Km	2.12	3.46

Source: Author's calculations based on collected data

The average household head is male (83%) (Figure 1-2b), is 51 years old and has gone through about 7 years of formal education. This implies that most residents have very limited options of getting employed in the non-farm sector or to successfully set up and run their own commercial enterprises. Indeed, only 16% of household heads are employed in formal employment and another 9% are self-employed (Figure 1.2b).The average annual per capita expenditure of KES 25 183 (Table 1-3) calculated for the sample households gives a per capita monthly income equivalent to KES 2 098, which is slightly higher than the rural poverty line. The calculated standard deviation of 13 557 (see Table 1-3) indicates that the household expenditure has a high variance of distribution. This is better shown by the level of poverty where about 58% of the residents are classified as poor, with per capita expenditures below the current rural poverty line of KES 1988, which is derived from the national poverty line (KNBS, 2007) adjusted for inflation over the years (KNBS, 2011). On average, the sampled households are within a 2 km radius of the forest edge, which is a walking distance to the forest. Therefore, it is easy for the local community to access the forest and legally or illegally extract from it. The high poverty levels, low land holdings and short distance to the forest may push many households to rely on the forest for their fuel requirements.

Table 1-4: Frequency distribution of selected characteristics of sample households

Variable		Frequency (%)
Gender of household head		
	Male	82.8
	Female	17.2
Marital Status of household head		
	Maried	82.5
	Divorced/separated	0.7
	Widow/Widower	16
	Single	0.4
Occupation of Household head		
	Farming	75.1
	Salaried Worker	15.8
	Self employed	9.1
Membership in social group (household head or spouse)		
	Yes	59
	No	41
Poverty level (Expenditure above poverty line)		
	Poor	57.9
	Non Poor	42.1
Collects firewood from forest		
	Yes	37.9
	No	62.1
Participates in forest conservation		
	Yes	58.8
	No	41.2
Source of forest charcaol		
	Burns forest trees	4.9
	Buys from forest burners	9.5

Source: Author's calculations based on collected data

The average household has about 6 members. This creates a demand for forest products. Almost 38% of the sampled households obtain firewood from the forest. Of these, 43.5% do so without obtaining the relevant permits for firewood collection. A number of households (4.9%) also admitted to burning charcoal using trees obtained from the forest while another 9.5% buy charcoal from burners who get their trees from the forest (Table 1-4). Despite this, all respondents agreed on that the forest is of great importance to the region and should be conserved. Indeed, about 58.8% of the household heads or their spouses (see Table 1-4) indicated that they had participated in forest conservation activities within 12 months before data collection for this study. Some of these activities included; unpaid planting of trees in the forest and other public land, helping protect the forest areas near them and attending forest conservation awareness meetings. Therefore, it is possible to involve the residents in the conservation of the forest as they are aware of its importance and know who among themselves abuse the forest. It would be possible to reach the local community if conservation agencies worked through the already existing social networks since about 59% of the household heads or their spouses are members of at least one social group.

1.6. Organization of the Dissertation

This dissertation is organized in five chapters: In chapter 2, the determinants of household choice of different fuels are analyzed and the opportunities for transition from the current fuel use pattern to more forest conserving fuels and/or fuel sources explored. In Chapter 3 a LES-AIDS model is used to derive a complete demand system for fuel consumption for the rural households living next to the Kakamega forest. The expenditure and price elasticities for the various fuels are also estimated. Chapter 4 looks at the charcoal supply chain in Kakamega town. It specifically studies the role of charcoal trade on forest degradation and deforestation. Lastly chapter 5 summarizes the major findings of the study and discusses their policy implications and further highlights insights for future research.

2. Determinants of Household Fuel Choice in Rural Western Kenya: Implications for Forest Conservation

2-1. Introduction

The global use of biomass based fuels is widespread and almost 2.5 billion people, about 52% of the population in developing countries, rely on these fuels for cooking and heating. This is expected to increase to about 2.7 billion by 2030 mainly fueled by population growth (IEA, 2006). The proportion of the population dependent on biomass fuels is highest in Sub-Saharan Africa, where 76% of households depend on them as their primary cooking fuels (IEA, 2006). In the rural areas, the use of biomass is even higher and about 90% of households use firewood, charcoal, crop residues and cow dung as their primary cooking fuel (IEA, 2006; Mekonnen and Köhlin, 2008). The use of biomass in itself is only of concern when resources are harvested unsustainably and energy conversion technologies are inefficient, thus leading to deforestation and forest degradation while causing adverse consequences for health, the environment and economic development (Schlag and Zuzarte, 2008).

In Kenya, about 70% of households use different combinations of biomass fuels as their primary energy source. A closer breakdown for rural households indicates that 89% use firewood, 34% use charcoal, and 34% use animal waste and crop residues. These biomass fuels are used together with kerosene, liquefied petroleum gas (LPG) and electricity (Ministry of Energy, 2002). There is evidence of a growing gap between the production and consumption of biomass fuels in Kenya under the current wood production and energy use conditions. Biomass consumption and sustainable supply projections in 2000 indicated an increasing deficit from 57.2% in the year 2000 to an estimated 63.4% by 2020 (Ministry of Energy, 2002). This is attributed mainly to the increase in the population relying on firewood and charcoal in both rural and urban areas, decreasing reforestation efforts, and opening up more land for agriculture and grazing (KFS, 2009). Severe fuel wood shortage is localized especially around areas of high population densities (KIPPRA, 2010) due to increased demand and reduced supply. This has a potential of increasing the pressure on public forests and other tree systems.

Faced with decreasing biomass availability and the accompanying expenses, households respond differently, depending on their socio-economic and demographic attributes (Schlag and Zuzarte, 2008). Where feasible, households may start incorporating other non-biomass fuels in their use alongside the use of the primary fuels. The decision on the choice of fuels to be used is determined by their availability and the household's capacity to acquire and use these fuels. The share of non biomass fuels in household energy consumption varies widely across countries and regions, primarily reflecting their resource endowments but also their levels of economic development (IEA, 2006).

In household energy consumption, the role of household income and the general level of economic development have been emphasized (Masera et al, 2000; Heltberg, 2005; Macht et al, 2007; Schlag and Zuzarte, 2008). It has been argued that, poorer households rely entirely on biomass energy and the poorer the household, the lower in the category of the biomass it falls. In a study on energy use in Ethiopia, Mekonnen and Köhlin (2009) found that the poorest rural households use cow dung and crop residues for cooking more than any other category of the population. As household income increases, households start incorporating other cleaner and more expensive fuels, moving from biomass fuels (crop residues, animal waste and firewood), through transitional fuels (charcoal and kerosene) to more advanced fuels (electricity and liquefied petroleum gas) (Heltberg, 2004; Schlag and Zuzarte, 2008).

Some studies on the determinants of household fuel choice and use in developing countries have been carried out (Masera et al. 2000; Heltberg 2004; Heltberg 2005, Mekonnen and Köhlin, 2009). Through an in-depth study of energy use in rural villages in Mexico, Masera, et al. (2000) evaluate the energy ladder model by using longitudinal data collected from a large-scale survey on four states over a four-year period. The result of their study shows that a multiple fuel stacking model and not a simple progression as depicted in the traditional energy ladder scenario more accurately describes the pattern of fuels choice and use in the rural areas. In addition to the importance of income as a factor in household decision making, Masera et al. (2000) observe that it is also influenced by (1) the prices and availability of different fuels coupled with the stove types owned by the household; (2) matching of the technical characteristics of cooking stoves and the desired cooking practices; (3) cultural preferences; and (4) health considerations. In a study of seven cities in Ethiopia, Mekonnen and Köhlin (2009) use a multinomial logit analysis on four years panel data to study the determinants of household fuel choice. For ease of analysis, they group all fuels into two groups; the solid fuels (firewood and charcoal) and the non-solid fuels (kerosene and electricity). On the other hand, Heltberg (2005) employs the probit model to investigate the factors that determine the household's choice of non biomass fuels using country level household data in eight developing countries. The fuels are purchased from the market and there is no consideration of the impact of their use on the environment. Therefore, the results cannot be applied directly to a rural setting where there are multiple sources of the biomass energy with different environmental conservation implications.

A study that incorporates the use of biomass fuel and their source could be important in rural western Kenya because households there also have the public forest as a source of firewood and charcoal. The use biomass of fuels therefore, has affect on the conservation of Kakamega forest, one of the most biodiversity rich forests in Kenya (Mitchell, 2004). The fuel stacking model assumes that as household incomes improve; there is a shift to the use of non biomass fuels which are cleaner and more expensive. The link between poverty and dependence on natural resources has been studied. However, there is no consensus on the actual relationship. In a study on forest dependency and well being in Malawi, Fisher (2004) concludes that asset poor households are more reliant on natural resources and that forests are important in improving the living standards of the poor, thus reducing income inequality. Khan and Khan (2009) observe that in the rural areas, all income groups depend on natural resources and resource degradation is not caused by poverty but failures in management and corruption. This dependency on natural resources is not only determined by the level of household poverty but also by its nature; whether its asset or food or income poverty (Reardon and Vosti, 1995).

In Kenya, the poverty head count has reduced from 53% in 1997 to 37.6% in 2007 (KNBS 2007). At the same time, the population growth rate is about 2.5% per year, exerting pressure on natural resources. Although the link between poverty and dependency on natural resources has been established, the exact nature of this relationship is area specific (Fischer, 2004). As their incomes improve, households tend to incorporate more advanced fuels in their fuel mix. The problem is that the nature of this fuel transition is not clear, especially where there is an option of collecting biomass energy from the common pool forest resources, and this transition may also involve the substitution between different sources of biomass fuels. A study of the determinants of fuel choice for households living next to Kakamega forest is therefore important in the understanding of how household fuel consumption changes as incomes improve and how this affects the conservation of the common pools forest resource.

Under this background, the main objective of this chapter is to examine the patterns of household energy use in rural western Kenya and assess the determinants of households' choice of the use of non biomass fuels (kerosene and LPG) alongside firewood and charcoal. Understanding the dynamics of household fuel choice is vital in the development of policies for the reduction of the undesirable environmental impacts of unsustainable use of some biomass fuels. For successful adoption and sustainable use of the resources in the rural areas, it is necessary to understand the nature of household fuel use and fuel stacking. Therefore, this study of the factors that influence the household choice of fuels in a rural area bordering a public forest is important in informing policy, especially in relation to the conservation of common pool forest resources. This is done through a study of the different fuels that households use for cooking. A further analysis is carried out on the source of consumed biomass fuels, linking fuel use to forest conservation. A general conceptual framework guiding the analysis of the determinants of household fuel use for the community living next to the Kakamega forest is discussed in section 2-2. Section 2-3 discusses the research methodology while the research area and empirical data are discussed in section 2-4. A description of the household characteristics is done in section 2-5. Sections 2-6 and 2-7 discuss the determinants of fuel choice and determinants of the sources of biomass fuels respectively. Some concluding remarks, limitations of the study and suggested areas for future research are presented in the last section.

2-2. Conceptual framework

The household choice of the fuel combination is not only dependent on their income but also on other economic, social, technical and cultural factors. This study follows the concept of the energy 'ladder' described by Schlag and Zuzarte (2008) (Figure 2-1). As income increases, households move from the basic, more polluting fuels to more advanced fuels likened to climbing a ladder where the different fuels form the 'rungs' of the ladder. This model looks at the development of energy use in three stages of fuel choice. In the first and lowest stage, households depend entirely on biomass fuels for cooking. As their income improves, households transit to fuels that burn more efficiently but still have notable emissions, including charcoal, kerosene and coal.

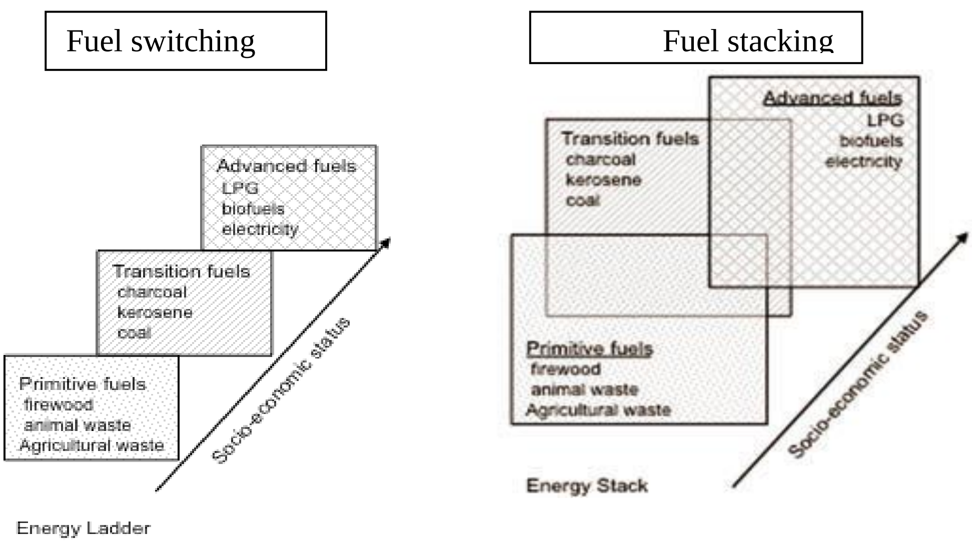


Figure 2-1 : Fuel stacking as compared to fuel switching

Source: Schlag and Zuzarte, 2008

After this intermediate stage, households move to a level where they depend on the cleanest forms of energy, usually LPG, electricity or biogas. As described by Schlag and Zuzarte (2000) two concepts are used to explain this transition movement up the energy ladder; fuel switching and fuel stacking. Fuel switching proposes that the introduction of cleaner fuels leads to a phasing out of the traditional fuels as households switch to the former. It assumes a perfect substitution of one fuel for another as households move up the energy ladder by choosing only the fuel that best fits their socioeconomic position, and that they totally abandon the inefficient, more polluting lower tier energy as they move to more advanced ones. This simple linear relationship between income, household fuel choice and demand, though plausible has been criticized as being too simplistic as fuel preferences could be explained by other factors (Mekonnen and Köhlin, 2009). The fuel switching model has been challenged by empirical research that has shown that households choose to integrate modern fuels slowly into their fuel mix without necessarily abandoning the initial fuels. This was described by Masera et al. (2000) as fuel stacking. It recognizes that there are many factors beside income that determine household fuel choice. Social, economic and technological barriers may prevent the linear progression towards clean cooking fuels represented by the energy ladder (Schlag and Zuzarte, 2008). As economies develop and the household situation changes, the process of fuel stacking takes place naturally. But where the trend in the consumption of biomass energy is undesirable or unsustainable, policy intervention may speed up the uptake of non biomass fuels. The most frequently applied interventions support inter-fuel switching and the uptake of improved stoves (Heltberg, 2005). In the first option, governments have introduced subsidies to motivate the consumption of target fuels, for example, Ethiopia's kerosene subsidy (Mekonnen and Köhlin, 2009). In urban areas where all fuels are purchased, the trend in fuel stacking is more certain than in rural areas with easy access to free biomass and therefore where households may not see the sense in switching to more expensive fuels or investing in wood saving stoves (Heltberg, 2005). The type of fuel combination and source of biomass chosen by a household have different impacts on the conservation of the public forest. This study hypothesizes that the development of fuel use by the rural households in western Kenya follows the fuel stacking model.

2-3. Methodology

The unconditional correlation between the decision to use different fuel combinations (an aspect of fuel stacking behavior), on one hand, and the household socio-economic and demographic factors on the other is studied. To understand fuel choice, both descriptive and more rigorous regression analyses are used. The households living next to Kakamega forest have the option of choosing different fuel combinations for cooking from the available fuels. Each household is faced with a binary decision as to which particular fuel mix to adopt, given their particular circumstances. The consideration of what combination to pick from among the possible fuel mixes potentially available to the household is done simultaneously and the decisions are therefore correlated with each other. In dealing with simultaneous binary decisions, previous studies have used either multinomial logit models (Gensch and Recker, 1979; Heltberg, 2005; Mekonnen and Köhlin, 2009) or multivariate probit models (Song and Lee, 2005). The multinomial logit model relies on the assumption of the independence of irrelevant alternatives (IIA). The IIA states that the odds of choice do not depend on alternatives that are not relevant. As explained by Tabet (2005), this assumption implies that if a choice A is preferred to choice B out of a choice set A, B, then adding a third choice C, and expanding the choice set to A,B,C, must not make B preferred to A. It is however difficult to enforce the IIA in a study using cross-sectional data. The multivariate probit model relaxes this property of the multinomial logit model. Therefore, the determinants of fuel choice were analyzed using the multivariate probit model.

As shown by Greene (2003) and used by Cappellari and Jenkins (2003), if a household *i* is faced with J different choices, then the multivariate probit model can be constructed as:

$$y_{ij}* = \beta_j'X_{ij} + \varepsilon_{ij},\ j= 1,\dots,J \qquad (1)$$

$$y_{ij} = 1 \text{ if } y_{ij}* > 0 \text{ and } 0 \text{ otherwise}$$

where,

ε_{ij}, = error terms distributed as multivariate normal, each with a mean of zero, and variance–covariance matrix **Σ** , where **Σ** has values of 1 on the leading diagonal and correlations $\rho jk = \rho kj$ as off-diagonal elements

J = the number of different choices available

y_{ij} = outcomes for J different choices

The multivariate probit model can be used to fit a probit model for cross-sectional data allowing for a free correlation structure (Cappellari and Jenkins, 2003). The equations need not have the same set or number of explanatory variables. This allows for the most appropriate explanatory variables to be used in each equation. The multivariate probit model is estimated through the simulated maximum likelihood method (SML) using a smooth recursive simulator, the Geweke-Hajivassiliou-Keane (GHK) simulator, to evaluate the multivariate normal probabilities described by Cappellari and Jenkins (2003). This ensures that the simulated probabilities are unbiased and bound within the (0, 1) interval.

2-4. Research area and empirical data

The research was carried out within the communities living around Kakamega forest in western Kenya (Figure 2-2). This forest and its associated fragments of Malava, Kisere and Kaimosi cover an area of about 240 km2 (Börner et al., 2007). The area around the forest has one of the highest population densities in Kenya, with up to 700 inhabitants per square kilometer (Schaab, et al., 2010). It is a closed canopy equatorial tropical rainforest, the indigenous part of which is one of the richest biodiversity areas in Kenya. Since the turn of the 20th century, severe forest disturbance has been recorded; fueled by conversion of the forest for settlement and agriculture as well as logging (Mitchell, 2004). Studies have shown that the forest cover has been improving in some parts of the forest in the last twenty years after many years of deterioration (Guthiga, 2007; Schaab et al., 2010) This can be attributed to the ban on the logging of indigenous forest in Kenya (Gathaara, 1999) and improved management of the forest (Guthiga, 2007). However, the forest is still under threat of degradation since the local communities rely on it for fuel wood, charcoal, building poles, medicinal plants and grazing (Guthiga et al., 2008). Incidents of charcoal burning, which is illegal, have been reported even in the parts managed as strictly no extraction zones of the forest as shown by Lung and Schaab (2004) and Lambrechts et al. (2007). It is estimated that about 90% of the people living in the rural areas of Kakamega directly or indirectly depend on agriculture for food and income despite the low levels of household land holding (Guthiga, 2007). At the same time the incidence of poverty is high and the population living below the rural poverty line in Kakamega district ranges between 50-60% (KNBS, 2003). These conditions create a potential for conflict between forest conservation and the needs of the local community.

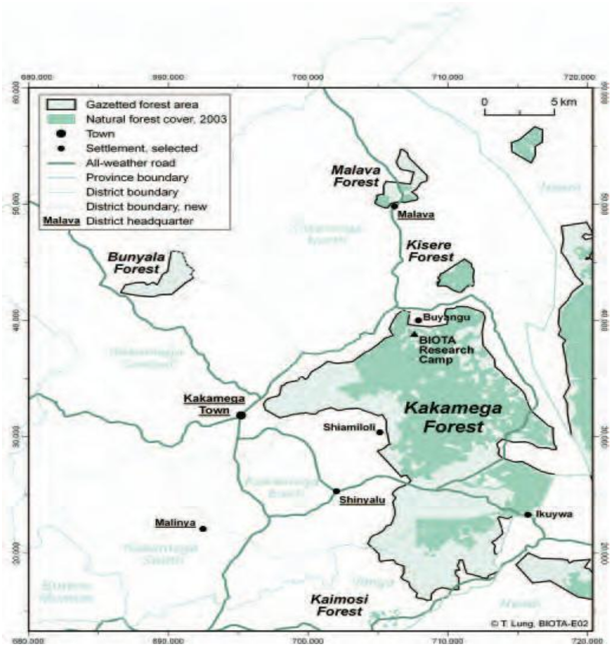


Figure 2-2: Map of the study area (Kakamega forest and its associated forests)

Data collection for this study was carried out between July 2009 and February 2010. A sample was drawn from a list of households living in villages within 5km of the forest edge assembled in 2005 (Guthiga, 2007). The unit of observation was the household, where it was defined as the number of people including resident employees who share in the use of energy for cooking and lighting. A two stage stratified random sampling was carried out. At the first stage, 64 villages were randomly selected from a list of 250 villages around the edge of the forest. Within these villages, 290 households were randomly selected from a list of resident households proportional to the village population. A semi-structured questionnaire was administered to the household head/spouse or adult sibling to collect information on the households' use of different fuels in quantities, sources and the prices paid if bought in the market or as valued by the household based on how much they would have paid for the fuel had they purchased it from the market. Further information on household attributes and their interaction with the local public forest management was also collected. Local enumerators were used for data collection. They were trained and continuously supervised during data collection in the field. A major challenge of the data collection process though was the reliance on memory in the absence of households' energy consumption records.

2-5. Household Income and Patterns of Fuel Use

Household income has been cited as a main determinant of the choice and source of fuels used for cooking. In this study, an estimated annual household expenditure was used as a measure of household income. To understand the relationships between poverty and fuel use, the sampled households were grouped into four quartiles based on their per capita expenditure on goods and services. To further explore the link between extreme poverty and the household choice of fuels, the poor households (per capita expenditure below the Kenya rural poverty line) are grouped into two; the 'ultra poor', households, living below the food poverty line and the 'poor' households with per capita incomes above the food poverty line but below the national rural poverty line. Households with incomes above the poverty line are again grouped into two quartiles; the 'non-poor' households have per capita income of up to 50% above the poverty line while the better off have incomes above 50% of the poverty line. Based on this classification, 58.6% of the sampled households are below the national rural poverty line, which compares well with the poverty incidence in western Kenya (KNBS, 2003). Household expenditure was estimated from data collected on the monthly household expenditure on health, education, energy, food, clothing, transport and communication. Household expenditure on food also included own produced food which was valued at the prevailing market prices. Since the focus of this study is on household energy consumption, data on the amounts and expenditures on specific fuel types and their sources were also collected. Table 2-1 shows the distribution of the poverty quartiles within the sampled households. The food and rural poverty lines used in this study were obtained by adjusting the respective poverty lines estimated by KNBS (2007) for inflation by applying the average consumer price index for 2008 and 2009 (KNBS, 2011). The KNBS (2007) food and poverty line adjusted for inflation and used in this study are KES 1257 and KES 1988 respectively (Table2-1). The incidence of extreme poverty in the study area is 20% while the moderately poor households comprise 38.6%. The households living above the poverty line were comprised of the non poor (25.6% in the sample), who have per capita expenditures of up to 50% above the poverty line and the well off category (15.8%) with expenditures above 50% of the rural poverty line (Table 2-1).

Table 2-1 : Household distribution in the sample based on their per capita monthly expenditure

Income Quartile	Monthly per capita Income (KES)	Frequency	Percent
Ultra poor	below 1257	57	20.0
Poor	1258-1988	110	38.6
Non poor	1989-2984	73	25.6
Well off	above 2984	45	15.8
TOTAL		285	100

Source: Author's calculations based on collected data

Table 2-2 shows some of the household characteristics, comparing them across the income quartiles. The average age of the household head is similar in all income quartiles. The 'well off' households are endowed with more resources. They have access to larger farms; an average of 3.86 acres as compared to 2.55 for the 'non-poor', 1.85 and 1.28 for the poor and ultra poor respectively. The household head of 'ultra poor' households has had only an average of 5 years of formal education as compared to 6 year for the 'poor', 7 years for the 'non poor' and 9 years for the well off. The 'well-off' households on average spend KES 13 549 on energy per year, which is more than double the expenditure by the 'ultra poor'. It is expected that the 'well off' may afford the more expensive modern fuels and the required technology, which may be difficult for the extremely poor households. The absolute household expenditure on energy increases with income, but the proportion of income spent on energy falls with increasing income, from 8% for the poorest to about 6% for the richest categories. The household size drops across the income quartiles from 6.4 for the 'ultra poor' to 4.5 for the well off category. Based on the their small land sizes, larger families to feed and low incomes, the 'ultra poor' may depend more on collected fuels from the public resources and as opposed to either own farm production or purchased fuels.

Table 2-2: Household characteristics according to income quartiles

	Ultra Poor	Poor	Non Poor	Well off	All
Household size	6.4	5.8	5	4.5	5.5
Annual Household expenditure ('000 KES)	76.7	111.8	144.0	219.8	130.8
Land holding (acres)	1.3	1.95	2.6	3.9	2.3
Household head's years of education	5.1	6.2	7.4	9.2	6.8
Household's annual energy budget ('000 KES)	5.2	7.5	8.5	13.5	7.7
Household's energy share of budget (%)	8.0	6.8	6.0	6.1	6.9

Source: Author's calculations based on collected data

2-5.1 Household Choice of Fuels

The household characteristics discussed in section 2-5 help to define the household energy consumption situation, where several major features can be mentioned. The first was that all households use firewood for cooking, but there are differences in the rate of use between the income quartiles (Table 2-3) Firewood is in combination with charcoal, kerosene or LPG. All households use kerosene for lighting and only 3.2% use it for cooking. The use of solar energy or electricity was insignificant in the study area. Therefore, electricity and solar energy sources were dropped from further household energy analysis.

Table 2-3: Proportion in percent of households using different cooking fuels by income quartile

	Income Quartile				
	Ultra poor	Poor	Non poor	Well off	All
LPG	0.0	0.0	0.0	13.3	2.1
Kerosene (Cooking)	1.8	2.7	1.4	8.9	3.2
Kerosene (Cooking and lighting)	100.0	100.0	100.0	100.0	100.0
Charcoal	31.6	40.9	50.7	66.7	45.6
Firewood	100.0	100.0	100.0	100.0	100.0

Source: Author's calculations based on collected data

The use of LPG was reported only by the 'well off' households where 13.3% of them (2.1% of the sampled households) combine it with other fuels. The rate of use of charcoal increases with increasing incomes. Only 31.6% of the ultra poor households use charcoal as compared to 40.9% of the poor, 50.7% of the non poor and 66.7% of the well off. The proportion of households using various combinations of fuel for cooking and heating is presented in Table 2-4. Almost 54% of all sampled households exclusively use firewood to meet their cooking needs. This reliance on firewood reduces with increasing incomes. About 70% of the 'ultra poor' households use only firewood, reducing to about 35% of the 'well off' households. These results confer with the observations by Masera et al. (2000) and Heltberg (2005), that increasing incomes improves the household's access to other more advanced fuels into their fuel mix. Firewood- charcoal mix is the most common fuel combination used by 43% of sampled households, but the rate of use increases from 28% in the ‘ultra poor’ category to about 50% for both the ‘non poor’ and the ‘well off ‘categories. These observations show that biomass (firewood and charcoal) is the most important source of cooking fuel for the households living on the edge of the Kakamega forest. Only 3.2% of the sampled households spread over all income quartiles use kerosene for cooking. This makes any fuel combination that includes kerosene to be also poorly used. This leaves charcoal as the most widely used transition fuel in this region.

Table 2-4: Household use of various combinations of fuels for cooking by income quartile

	Income Quartile				
Fuel combination	Ultra poor	Poor	Non poor	Well off	All households
Firewood only	69.8	58	48.6	34.8	54.0
Firewood + Charcoal	28.3	39.3	50	50	41.8
Firewood + Kerosene	0	0.9	0	0	0.4
Firewood + Charcoal +Kerosene	1.9	1.8	1.4	2.2	1.8
Firewood +Charcoal +LPG	0	0	0	6.5	1.1
Firewood +Charcoal +kerosene +LPG	0	0	0	6.5	1.1

Source: Author’s calculations based on collected data

In the absence of electricity use for cooking, LPG was the only advanced and most modern fuel in the rural area adjacent to Kakamega forest. The use of LPG was only reported within the ‘well off’ category although only 6.5% used it in combination with firewood and charcoal and another 6.5% used LPG in combination with the three other fuels. As households adopted the use of other more advanced fuels in cooking, they did not stop using the more basic biomass energy (firewood) Table 2-4). Since the modern fuels are always used in combination with the more traditional fuels, fuel stacking explains the fuel transition in the rural community in western Kenya.

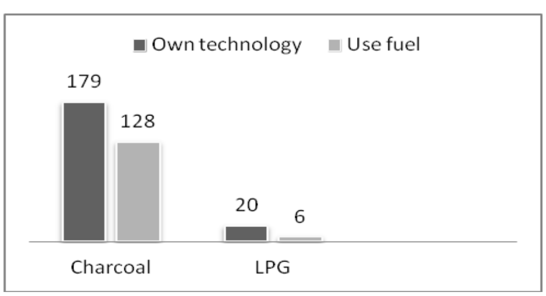
In addition to the household access to fuels, the availability and use of the appropriate technology by the households is a prerequisite to the adoption of specific fuels. The household ownership of cooking stoves and other appliances necessary in the use of different fuel types was explored and is reported in Table 2-5. Generally, the ownership of different appliances across all income quartiles was higher than the reported rates of use of the relevant fuels.

Table 2-5: Household ownership of energy appliances (percent along income quartiles)

	Income Quartile				
	Ultra poor	Poor	Non poor	Well Off	All
Charcoal Stove	52.6	57.3	71.2	75.6	62.8
Gas Stove	1.8	5.5	4.1	20.0	7.0
Pressing hot iron (charcoal)	38.6	48.2	54.8	68.9	51.2

Source: Author's calculations based on collected data

For example, although no households reported using LPG in the 'ultra poor', 'poor' and 'non poor' income quartiles, the gas stove ownership among these groups was 1.8%, 5.5% and 4.1% respectively. As shown in Figure 2-3, only 30% of households who own gas stoves reported using LPG for cooking within the study period. The same is true for charcoal; 71.5% of charcoal stove owners reported using charcoal.



Source: Author's calculations based on collected data

Figure 2-3: A comparison between the number of households owning of a particular technology and use of the relevant fuel

Even after overcoming the initial investment cost of acquiring the necessary technology for using a particular fuel, it is observed that some of these households are not using some of the fuels that they were using before. Therefore access to the necessary technology may not be the limiting factor in the use of more advanced fuels in Kakamega. Households may stop using marketed fuels following a drop in their incomes or an increase in the relative prices of these fuels. In addition to this, Masera et al (2000) notes that the change from biomass to modern fuels is bi-directional and over time households may drop the use of some of the more advanced fuels due to changes in some non-income factors. Makonnen, (1999) notes that changes in household composition, for example, children finishing school or moving out of home, may lead to a discontinuation of the fuels used specifically in the morning to save time in preparing them for school. Apart from economic factors, social and cultural considerations also play an important role in the process of adopting and continued use of modern fuels. To better understand this, a further analysis of the determinants of household fuel choice and use is analyzed in section 2-7 and 2-8.

2-5.2. The source of biomass fuel

All kerosene and LPG used by the households is purchased from the market. The case is different for the biomass fuels (charcoal and firewood). For firewood and charcoal, households have the option of growing their own trees, buying from the market or obtaining the fuels from the common pool forest. Each of these sources of wood has different implications on the conservation of the forest. Generally, the collection of fallen dead branches for firewood is allowed after paying an access fee in forest areas managed by the KFS and the Quakers church. As shown in Table 2-6, the poorest households depend most on the forest for their firewood needs. When harvested sustainably, firewood use has no adverse effect on the environment.

Table 2-6: Source of firewood (per cent share of households in quartile)

	Income quartile				
	Ultra poor	poor	Non poor	Well Off	All
Purchased	26	31	44	42	35
Collected from Forest	51	44	34	13	38
Own trees	40	40	55	62	47

Note: For all quartiles, the total proportions add to more than 100% indicating that some households have multiple sources of firewood
Source: Author's calculations based on collected data

Even with the low land holding in these communities, own farm trees are an important source of firewood in all income quartiles Indeed, this was the most important single source of firewood for the 'non-poor' (55%) and 'well off' (62%) quartiles (Table 2-6). Almost half of the 'ultra poor' households collect firewood form the public forest. This decreases to 44% for the 'poor', 34% for the 'non poor' and only 13% for the 'well off'. These results confirm that the household dependency on the common pool forest resources for basic biomass energy decreases with increasing incomes. This is expected since the 'ultra poor', with larger household size have more labor for collecting firewood from the forest, lower incomes to purchase, and smaller parcels of land for growing own firewood. Any policy that cuts off this source of firewood would adversely affect the 'ultra poor' more than any other group. The market was the second important source of firewood for both 'non poor' and well off households'. As expected, higher incomes increase the household access to the firewood markets.

Among the biomass fuels used in this region, charcoal has the highest potential of causing forest degradation and deforestation. As shown in Table 2-7, the sampled households across all income groups depend more on the market for charcoal than from their own production. All forest management agencies have outlawed charcoaling from the public forest. Despite this ban, the households still manage to obtain charcoal from the forest. Some households cut trees and burned charcoal themselves, either in the forest or on their land. This method was least popular with the 'ultra poor' where only 5.6% of households that use charcoal confirmed producing their own charcoal as compared to about 11% of the 'poor', 13.5% of the 'non poor' and 10% of the 'well off' (Table 2-7). Being an illegal activity, it was felt that not all households using charcoal from the forest would confess to cutting forest trees for fear of victimization.

Table 2-7: Source of charcoal (share of households in quartile per cent for consuming households)

	Income Quartile			
Source of charcoal	Ultra poor	Poor	Non poor	Well off
Burns from own trees	22.2	8.9	2.7	10.0
Burns from purchased trees	0.0	6.7	8.1	3.3
Burns from forest trees	5.6	11.1	13.5	10.0
Purchases from forest burners	22.2	11.1	21.6	10.0
Purchases from other burners	7.0	16.4	21.9	26.7
Purchases from market	8.8	10.0	5.5	15.6

Source: Author's calculations based on collected data

Therefore, households were also asked about the charcoal they purchased knowing that it was from the forest, as this is an illegal source. In all income quartiles, the proportion of households buying charcoal from forest burners was either higher (ultra poor, 22%; non poor, 21.6%) or the same as those burning the charcoal themselves (Table 2-7). The forest is therefore an important source of charcoal for the local community.

2-6. Variables used in the fuel choice and source of biomass fuel analysis

The decision on the variables to include in the analysis of the choice of fuel type and the source of biomass fuel is informed by the findings of previous studies and confirmed by some of the observations from the descriptive statistics of this study (Table 2-5). Studies by Masera et al., 2000; Fisher, 2004 and Mekonned and Köhlin, 2009 have shown that the adoption of modern fuels increases with improvement in household income, therefore poor households depend more on biomass energy for their cooking needs. It is hypothesized that increasing household income (lower household poverty) increases the chance of households using more advanced fuels. As observed by Guthiga (2007) and Wambua (2008), poor households are more likely to rely on collected fuel wood as opposed to obtaining it from either their own farms or from the market. The choice of fuel and source of biomass fuel used by any household is also influenced by the specific attributes of the household. The education level of the household head is expected to increase working opportunities and hence household income, leading to less reliance on primary fuels (Mekonnen and Köhlin, 2009). At the same time, it increases the exposure and access to new technology which positively influences the adoption of more advanced fuels since households can only use a particular fuel after acquiring the necessary cook stoves (Masera et al, 2000). Access to the relevant technology can be an important barrier to the adoption of modern fuels especially where the cost of the stoves is high. Other important household attributes include; farm holding and household size. Households with access to larger farms are not only richer (with higher household income) but have the potential to grow trees for firewood and charcoal, thus relying less on the common pool forest for these biomass fuels. In a study of the Kakamega forest, Guthiga (2007) concludes that the interaction between the public forest and local communities depends on the distance to the forest the rules of adopted by the forest management agencies. Households living nearest to sections of the forest where the management agency allows controlled collection of firewood are expected to also rely more on biomass fuels. This may have an inverse relationship with the use of other non-forest acquired fuels. Local cultures also influence the choice and source of fuels at the household level (Masera et al, 2000). In the study area, firewood collection is the responsibility of women. Therefore, the time the adult female of the household spends within the homestead determines the type of fuels used and the source of these fuels used by the household.

2-7. Determinants of fuel choice

All sampled households use firewood as their main fuel. They however can choose to combine this with charcoal, kerosene or LPG. For each fuel, the household is faced with a binary decision on whether to use this particular fuel or not. There are four fuel types to be considered and the decision on multiple fuel use is made simultaneously. Therefore, the multivariate probit model is used for this analysis of the joint decision on fuel use. All households use firewood, therefore, firewood was dropped from this analysis as there is no variability in the household choice of its use.

2-7.1. Estimation of the multivariate probit (MVP)

The analysis of fuel choice was done on the other fuels that households combine with firewood. Charcoal and Kerosene for cooking are the transitional fuels while LPG represents the advanced fuels category. Previous studies suggest that household attributes, demographic factors and access to fuels are important determinants of the household choice of fuels used. This was clearly seen in the patterns identified from the simple descriptive statistics discussed in section 2-5 and discussed in section 2-6.

Table 2-8: A summary of variables used in the multivariate estimation of the determinants of fuel choice

Variable	Mean	Std. Dev.
Age household head (years)	51.2	14.3
Years of formal education HHH	6.8	3.9
Land ownership (acres)	2.5	2.6
Household size	5.5	1.8
Distance to the nearest forest edge (Km)	2.0	2.6
	% Frequency	
Households living below poverty line	57.9	
Forest extraction allowed	84.6	
Adult woman works away from home	14.0	

Source: Author's calculations based on collected data

2-7.2. Results of the multivariate probit on the determinants of fuel use

The likelihood ratio test that ρ12 = ρ31= ρ32 = 0 is rejected as significantly different from zero (chi2 (3) = 18.39) (Table 2-9). This implies that there is a correlation between the errors of the three equations and therefore the multivariate probit model was correctly used instead of estimating each equation separately. The correlation between the probability of a household using of charcoal and kerosene; charcoal and LPG and kerosene and LPG is significant at 1%. The correlation between the household decision to use charcoal or kerosene for cooking is 0.7 and 0.71 for the choice of kerosene or LPG (Table 2-9). This suggests that the unobservable factors that increase the probability that a household chooses to use charcoal for cooking will also increase the probability of using kerosene and LPG for cooking. The same can be said about the choice of charcoal and LPG as cooking fuels.

Table 2-9: Multivariate probit model results for household choice of fuel

Multivariate probit (MSL, # draws = 13) Number of obs = 285

Wald chi2(20) = 181.3; Prob >

Log likelihood = -224.6 chi2= 0

	Coef.	Std.Err	z	P>z	[95% Conf.	Interval]
Charcoal use cooking (Yes=1)						
Years of formal education HHH	0.065	0.023	2.870	0.004	0.021	0.109
Poverty (Poor =1, 0 otherwise)	-0.504	0.174	-2.900	0.004	-0.845	-0.164
Adult female works away from home (Yes=1)	0.114	0.178	0.640	0.522	-0.234	0.462
Forest extraction permitted(Yes=1)	0.651	0.215	-3.020	0.003	-1.073	-0.229
Farmholding (acres)	0.026	0.033	0.780	0.435	-0.039	0.092
Household size	0.058	0.041	1.400	0.161	-0.023	0.138
Fuel wood use per capita	-0.005	0.007	-0.730	0.465	-0.020	0.009
Owncharcoalstove	2.440	0.278	8.770	0.000	1.895	2.985
Kerosene use for cooking (1=Yes)						
Years of formal education HHH	0.000	0.046	0.000	0.997	-0.091	0.090
Poverty (Poor =1, 0 otherwise)	-0.322	0.390	-0.830	0.409	-1.086	0.442
Adult female works away from home (Yes=1)	-0.281	0.369	-0.760	0.446	-1.004	0.442
Forest extraction permitted (Yes =1)	-0.486	0.519	-0.940	0.349	-1.504	0.531
Farmholding (acres)	0.164	0.052	3.180	0.001	0.063	0.266
Household size	-0.063	0.087	-0.730	0.466	-0.233	0.106
Fuelwood use per capita	-0.056	0.019	-2.890	0.004	-0.094	-0.018
LPG use for cooking (1=Yes)						
Years of formal education HHH	0.121	0.062	1.970	0.049	0.000	0.242
Poverty (Poor =1, 0 otherwise)	-2.754	97.445	-0.030	0.977	-193.74	188.23
Adult female works away from home (Yes=1)	-0.251	0.412	-0.610	0.542	-1.059	0.556
Forest extraction permitted (Yes =1)	-5.837	2.921	-2.000	0.046	-11.562	-0.112
Farmholding (acres)	0.165	0.068	2.440	0.015	0.032	0.298
Household size	-0.406	0.120	-3.380	0.001	-0.641	-0.171
Fuel wood use per capita	-0.051	0.021	-2.460	0.014	-0.092	-0.010
Own gasstove (Yes=1)	2.617	1.965	1.330	0.183	-1.235	6.469
/atrho21	0.536	0.257	2.080	0.037	0.031	1.040
/atrho31	0.440	0.343	1.280	0.200	-0.233	1.112
/atrho32	1.277	0.633	2.020	0.044	0.036	2.518
rho21	0.490	0.196	2.500	0.012	0.031	0.778
rho31	0.413	0.285	1.450	0.146	-0.229	0.805
rho32	0.856	0.170	5.050	0.000	0.036	0.987

Likelihood ratio test of rho21 =rho31 = rho32=0: chi2(3) = 12.1859; Prob > chi2 = 0.0068

Source: Author's calculations based on collected data

As expected, the level of household poverty is an important predictor of the choice of fuel consumed. As a household moves from extreme poverty (‘ultra poor’ quartile), the probability of using charcoal. Therefore, household expenditure is positively related to the probability that a household will opt for other non biomass fuels. Households with larger farms had a lower probability of using charcoal. The probability of the use of charcoal, kerosene and LPG is negatively influenced by the household size. The ownership of the relevant cooking stoves positively influences the probability of use of that particular fuel. Owners of charcoal stoves are more likely to use charcoal than non owners. The same is applicable to LPG. The adoption of policies that make different fuel technologies accessible to the households will increase the choice of these fuels in the household fuel mix and may help in the conservation of the forest. There is admittedly a risk of endogeneity between the ownership of technology and use of a particular fuel as households will only invest in technologies that they intend to use.

A somewhat surprising result is the positive relationship (0.651) between the probability of using charcoal and the permission to collect firewood from the forest. This may be explained by the fact that when households pay access fees for firewood collection, they not only collect fallen tree branches for firewood but also cut trees for charcoaling, an illegal activity. Therefore, although controlled firewood collection has no adverse effect on the conservation of the forest, the permission for forest use by the local community is an entry point for charcoaling, a major cause of forest degradation. As expected, the education level of the household head is positively related to the probability of using charcoal and LPG for cooking. At the same time, increasing household expenditure on goods and services (proxy for household income) and the ownership of a charcoal stove increases the probability of the household’s in Kakamega to use charcoal for cooking although it has no significant influence on the use of kerosene and LPG. The probability of using kerosene or LPG for cooking increases with increasing household's land ownership while it decreases with increasing use of fuel wood.

2-8. Determinants of sources of biomass fuels

The local community living around Kakamega town relies more on biomass fuels for cooking and heating than non-biomass fuels. Households obtain wood for fuel from three main sources; their own farm production; collecting from the public forest or purchasing from the market. The source of wood has different implications on the conservation of Kakamega forest. Generally, wood produced from farmlands for own use or the market reduces pressure on the public forest. Collecting firewood from the forest if done sustainably and within the guidelines of the managing agencies has no negative effect on the forest. However, as already discussed in section 2-7.2, allowing firewood collection also increases the cutting of trees either for charcoal or firewood, a practice that causes deforestation and forest degradation.

2-8.1. Multivariate probit estimation of source of biomass fuel

The joint decision on whether to collect fuel wood from the forest, purchase from the market or obtain from the farm was analyzed using a multivariate probit analysis. The dependent variable for the three sources is a binary choice which dependents on the household's socio-economic and demographic attributes (income, size, land holdings, education level and occupation of the female decision maker) as well as the interaction with the common forest (whether extraction is permitted and distance to the forest) see Table 2-8.

2-8.2. Results

The likelihood ratio test that $\rho21 = \rho31 = \rho32 = 0$ is rejected as significantly different from zero (chi2 (3) = 164.61) (Table 2-10). This implies that the individual decisions on each source of biomass fuel are correlated. Therefore the multivariate probit model was correctly used instead of estimating each equation separately. The correlation between the probability of using own or forest biomass ($\rho21 = -0.77$) and between forest and market biomass ($\rho32 = -0.67$) are significant at 1% while the decision to use own or market biomass ($\rho31 = 0.24$) was significant at 5% (Table 2-10). This implies that the unobservable factors that increase the probability that a household chooses to obtain their firewood and charcoal from the forest reduces the probability of obtaining the same from their own farm. The same can be said about the choice between market and own farm. However, the factors that increase the probability of obtaining biomass from the market also increase the chance of obtaining the same from the farm.

The opportunity given by the forest management agency to collect firewood legally from the forest increases the probability of the household to collect firewood from the forest while reducing the use of own biomass. Therefore, the households living next to KFS and Quakers church managed forest parts have a higher probability of getting the firewood and charcoal from the forest than the households living next to KWS managed parts, where any extractive use of the forest is illegal. The distance from the homestead to the nearest forest edge had no significant effect on the probability of the choice of the source of biomass fuels. This may be because all sampled households were on average 2 km from the forest edge (Table 2-8). This short distance from the forest edge may have provided only a small variability in the impact of distance to the source of biomass used.

Table 2-10: Multivariate results on the source of biomass fuels

Multivariate probit (MSL, # draws = 13) ; Number of obs = 285
Wald chi2(24)= 84.44; Prob > chi2 = 0; Log likelihood = -457.514

	Coef.	Std. Err	z	P>z	[95% Conf.	Interval]
Ownbiomass						
Forest extraction permitted(Yes=1)	-0.587	0.189	-3.110	0.002	-0.957	-0.218
Poverty (ultrapoor= 1)	0.063	0.215	0.290	0.770	-0.358	0.484
Shortest distance to the forest (km)	-0.001	0.035	-0.030	0.976	-0.070	0.068
Household size	-0.023	0.038	-0.600	0.548	-0.097	0.052
Years of formal education HHH	0.025	0.021	1.190	0.234	-0.016	0.067
Adult female works away from home (Yes=1)	-0.359	0.235	-1.530	0.127	-0.819	0.102
Farmholding (acres)	0.255	0.049	5.220	0.000	0.159	0.351
Participation in forest conservation (1 = Yes)	-0.320	0.197	-1.620	0.105	-0.707	0.067
Forestbiomass						
Forest extraction permitted(Yes=1)	0.313	0.175	1.780	0.075	-0.031	0.656
Poverty (ultrapoor= 1)	0.004	0.206	0.020	0.986	-0.401	0.408
Shortest distance to the forest (km)	-0.026	0.029	-0.910	0.364	-0.083	0.030
Household size	0.034	0.035	0.980	0.327	-0.034	0.103
Years of formal education HHH	-0.053	0.020	-2.610	0.009	-0.092	-0.013
Adult female works away from home (Yes=1)	-0.385	0.241	-1.600	0.111	-0.858	0.088
Farmholding (acres)	-0.120	0.035	-3.450	0.001	-0.188	-0.052
Participation in forest conservation (1 = Yes)	0.104	0.189	0.550	0.583	-0.266	0.473
Purchasebiomass						
Forest extraction permitted(Yes=1)	-0.040	0.174	-0.230	0.818	-0.382	0.302
Poverty (ultrapoor= 1)	-0.410	0.206	-1.990	0.046	-0.813	-0.007
Shortest distance to the forest (km)	-0.010	0.037	-0.280	0.779	-0.082	0.061
Household size	0.001	0.035	0.040	0.969	-0.066	0.069
Years of formal education HHH	0.026	0.019	1.360	0.173	-0.012	0.064
Adult female works away from home (Yes=1)	0.334	0.221	1.520	0.130	-0.098	0.767
Farmholding (acres)	-0.050	0.025	-1.960	0.050	-0.100	0.000
Participation in forest conservation (1 = Yes)	0.086	0.182	0.470	0.635	-0.270	0.442
/atrho21	-1.019	0.125	-8.130	0.000	-1.265	-0.774
/atrho31	0.245	0.100	2.440	0.015	0.048	0.441
/atrho32	-0.817	0.119	-6.850	0.000	-1.051	-0.583
rho21	-0.770	0.051	-15.050	0.000	-0.852	-0.649
rho31	0.240	0.094	2.540	0.011	0.048	0.415
rho32	-0.674	0.065	-10.330	0.000	-0.782	-0.525

Likelihood ratio test of rho 21= rho 31 = rho 32 = 0.00; chi2(3)= 164.612 Prob > chi2 = 0
Source: Author’s calculations based on collected data

Households with larger farm holdings rely less on the forest and more on their farms for biomass. Larger farms give households the opportunity to either set aside land for trees or to plant more trees along the boundaries, a practice common in the research area. The attributes of the household head as the main decision maker also affect the choice of the source of firewood and charcoal. The education level of the household head measured in the number of completed years of formal education reduces the dependence of the household on the forest for biomass fuels while increasing the probability of the purchase of the same from the market. Education, however, has no significant effect on the probability that a household will use own-farm biomass. The household participation in forest conservation activities (proxy for conservation awareness) household size, the occupation of the adult female member of the household and have no significant effect on the source of firewood and charcoal.

2-9. Conclusion

This chapter examined the determinants of household choice of fuel used for cooking and space heating. It also analyzes the determinants of the choice of the source of biomass fuel. Analysis was based on a cross-section survey from 285 rural households living in villages within 5 km from the edge of Kakamega forest in western Kenya. Results indicate that the rural households living next to the forest have use firewood as the basic biomass fuel. They have the option of combining this with other more advanced fuels for cooking. There is evidence of fuel stacking as households do not abandon firewood as they adopt other fuels, especially LPG.

The reliance on the common pool forest for firewood is highest for the poor, but the relatively better off use more charcoal which goes hand in hand with cutting of trees. Indeed increasing poverty levels decreases the probability of households to meet their biomass energy needs from the market leaving the forest and own production as the possible sources for the poor. Therefore, although the poor depend more on the forest, they degrade less assuming that they do not cut trees for firewood which may, however, also occur. At the same time, the larger the size of land available to the household, the higher the probability of relying on own produced biomass and the lower the reliance on purchased or collected fuel wood. The poor also have smaller land holdings. Cutting the forest supply of biomass energy from the forest will therefore affect the poor much more than the better-off. The probability of charcoal use increases with increasing household income. But increasing household income is positively related to the purchase of biomass fuel including charcoal. Policies that create poverty reduction opportunities will benefit the forest by increasing the use of purchased biomass. To improve conservation of the forest, the purchased charcoal should be obtained from outside the forest.

The dependence on the forest for biomass fuels is also influenced by the management regimes. Households living next to parts of the forest where controlled extractive use is allowed have a higher probability of using charcoal. They are also more likely to collect firewood from the forest while they have a lower probability of purchasing or obtaining biomass fuels from their farms. Allowing people to collect firewood is an avenue for charcoaling using trees from the forest. A ban by the KFS and QC on collecting firewood from the forest will help in reducing forest degradation. However, this will also adversely affect the poor who depend more on the forest for firewood, and who have small farms reducing the opportunity for on-farm fuel production potential. Such a ban therefore, must be accompanied by alternative livelihood options for the poor in Kakamega.

Results show that some households owning a particular stove were not using the corresponding fuel over the time of data collection. This rather surprising finding confirms Masera at al. (2000) assertion that fuel stacking is not unidirectional and households keep changing their fuel mix depending on the household needs and situation at any given time. The use of non biomass fuels is however low. Only 4.2 % of the sampled households incorporate either kerosene or LPG (or both) into their fuel mix. Therefore, the use of more advanced fuels to reduce pressure on the common pool forest resource is not a viable option in the short run. In the long run, policies that increase the household access to the advanced fuels, for example, the lowering of the price of LPG will increase the use of the gas stoves already owned by households, thus reducing reliance on biomass energy.

In summary, the conservation of Kakamega forest will in the long term benefit from policies that lead to an increase in the use of non biomass fuels or reduce the reliance on the forest for firewood. Some long term strategies include a reduction of the household sizes in the local communities, creating opportunities for nonfarm jobs for women and income generating opportunities that reduce poverty.

3. Estimation of a Two-Stage LES-AIDS Energy Demand System for Rural Households and Its Link to Forest Degradation, Kakamega Forest, Western Kenya

3-1. Introduction

Biomass based fuels are still the dominant form of energy used by many rural households in developing countries to meet their cooking and heating needs (Davis, 1998; KIPPRA, 2010). This is because biomass is an easily accessible energy option for rural households. In addition to the common biomass fuels, firewood and charcoal, rural households also use liquefied petroleum gas (LPG) for cooking, kerosene and electricity for lighting and sparingly for cooking, where available. The use of LPG for cooking is spreading in rural Kenya and is now available in different sizes in most rural towns and shopping centers (Murphy 2001; Ministry of Energy. 2002; KIPPRA, 2010). Although there have been efforts in rural electrification, access to the electricity grid in rural Kenya is still limited to those villages near towns or along major roads. Even where the grid is available, it is only the wealthy rural households who can afford the connections (Murphy, 2001). Electricity is mainly used for lighting and running of a few electrical appliances especially radios, TVs and refrigerators (Ministry of Energy, 2002; KIPPRA, 2010). Renewable energy technologies such as solar systems, biogas and wind-power are being promoted but their use is still insignificant (Murphy 2001).

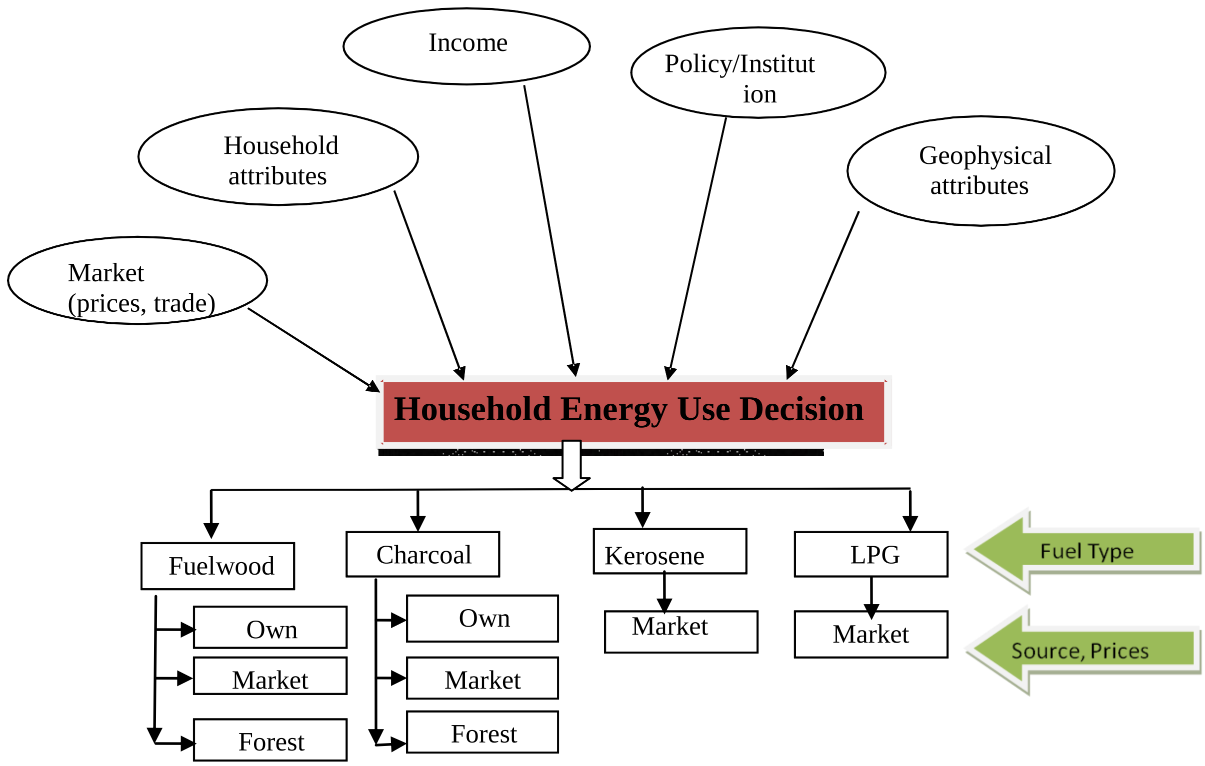
According to Schlag and Zuzarte (2008), the proportion of rural population using firewood across sub Saharan Africa has remained fairly constant as a result of its low cost and few available viable alternatives. Apart from own production and purchase from the market, households can obtain fuel wood at no cost other than the time they spend in collecting from public forests and woodlands and requires no specialized technology for its use (Mander and Quinn, 1995). Associated with this high reliance on fuel wood is the potential risk of deforestation and forest degradation of common property forest resources (Heltberg, 2004) and/or where private property rights are not well enforced. The use of biomass energy under poor ventilation also causes health problems from indoor air pollution (Heltberg, 2005). According to Arnold et al. (2006), the household's reliance on forests depends on the household socioeconomic attributes and the nature of the prevailing local fuel markets. Forest degradation may occur when fuel wood collection exceeds the forest sustainable yield. Degraded forests have less biomass for collection, leading to fuel wood scarcity (Heltberg et al., 2000) and increased opportunity costs for collecting households (Palmer and MacGregor, 2009). Due to the bulky nature of fuel wood, the impact of firewood collection on forests is highly localized (Heltberg, 2005) and is especially common in areas of high rural population density or around cities (Heltberg, 2001, Mutimba, 2004, Gebreegziabher 2007). High fuel wood costs (in the form of market prices or opportunity costs of fuel wood collection) may exacerbate natural resource degradation (Heltberg et al 2000) and induce substitution to alternative energy sources and/or adoption of technologies that require less firewood or charcoal for cooking or space heating by households (Heltberg, 2005; Palmer and MacGregor, 2009). However, this transition depends on the household's access to modern energy types such as kerosene and liquefied petroleum gas (LPG) (Mishra, 2008). The use of these alternative energy sources is determined by the household specific economic, demographic and social attributes (Heltberg et al 2000; Mishra, 2008; Palmer and MacGregor, 2009). Some households may still remain reliant on fuel wood because of a lack of access to alternative cleaner energy options while others result in using crop residues and dung, competing with their use as manure with adverse effects on soil fertility (Mekonnen, 1999). The switch to higher level fuels is dynamic and may however be reversed by the unavailability of fuel alternatives as well as the household economic ability to purchase them (Mishra, 2008). Although fuel transition may take place eventually, it is accelerated by targeted policy instruments (Heltberg, 2005). Such policy measures include subsidies on specific fuels (Schlag and Zuzarte, 2008); provision of subsidized technologies (Manibog, 1984) or the expansion of the electricity grid (Arnold et al., 2006). Unlike the urban areas with less access to biomass, fuel switching uptake in the rural areas faces specific challenges. One of the main challenges is cost; the cleaner fuels are not only more expensive than biomass fuels but also require specific technologies for their adoption (Schlag and Zuzarte, 2008). This is worsened by the general poor infrastructure which makes these fuels unavailable in most rural markets. The transition to modern fuels is encouraged due to the strong correlation between their use and the improvements in the quality of life (Ministry of Energy, 2002). The improved access to non- traditional energy in the rural areas is associated with better socio economic development and conservation of the environment. Though desired, the nature of the transition to better fuels is area and household specific.

Given this background, the main objective of this paper is to investigate the household energy use by the rural community living next to the Kakamega forest in western Kenya. This is done through the estimation of a total demand function for each of the fuels used for cooking and/or space heating. The derived demand elasticities help in coming up with policy suggestions on fuel transition taking into consideration the conservation of the public forest. In order to investigate these issues, the general conceptual framework guiding the analysis of household fuels demand for the community living next to the Kakamega forest, is discussed in section 2. Section 3 describes the econometric methodology used. The study area, sample selection and the data used in the analysis are discussed in Section 4 while the results are discussed in section 5. Some concluding remarks, limitations of the study and suggested areas for future research are presented in the last section.

3-2. Conceptual framework

To meet their energy needs, the rural households in Kenya depend on biomass, transitional or advanced fuels for cooking and space heating (Ministry of Energy, 2002; KIPPRA, 2010). According to the Ministry of Energy (2002), of all firewood used in the country, 89% is used by rural households, making it the most important fuel in rural Kenya. Among the transition fuels, charcoal which is also biomass based is used by 46% of rural households. Other fuels used together with these are kerosene, LPG, biogas and electricity where households are connected to the national grid. The access to electricity and biogas in rural Kenya is insignificant. Biogas penetration is only 0.2% (KIPPRA, 2010) while access to electricity is heavily dependent on the extension of the national grid to the villages by the government and not primarily subject to household decision making. Therefore, electricity and biogas were not considered in this demand analysis. Households in the same area use different fuel mixes (Mishra, 2008; KIPPRA, 2010) and may obtain their particular fuel from different sources. Whereas kerosene and LPG are only purchased from the market, consumers have several options of obtaining firewood and charcoal. These two fuels may be produced by the household, collected from the common pool forests and other tree systems where available or purchased from the market (Figure 3-1). As noted by Guthiga et al. (2008), collection of fallen dead wood for firewood is permitted by the management agencies in some parts of the Kakamega forest, after the payment of an access fee, but any cutting down of trees is outlawed. Therefore, charcoaling using forest trees is illegal in all parts of the forest. Despite this ban, there is evidence that the local community obtains charcoal from the forest (Guthiga et al., 2008). Generally, collecting dead wood for firewood has no negative impacts on the conservation of the forest unlike charcoal which involves the illegal and therefore unmanaged cutting of forest trees.

The choice of the fuel types and the level of consumption is household specific. It is therefore influenced by household demographic and socio-economic attributes as well as the availability of the different fuels (Figure 3-1). The household attributes used in this study were based on consumer theory and from other previous studies on household energy use. Household expenditure is expected to influence the access to different marketed fuels including the required technology to use these fuels. Poorer households are expected to rely more on the basic fuels (Gupta and Köhlin, 2006; Gundimeda and Köhlin, 2008). The household size is also directly related to energy requirements through the actual demand and available labor for collection, although larger households may have a lower per capita consumption due to their better economies of scale (Mishra, 2008; Peng et al., 2010). According to Köhlin (1998), the kinds of foods cooked and hence their energy demand is influenced by the time that the adult female household member spends at home. Whether the oldest female member of the household spends her day away from home is used as a proxy for the opportunity cost of time and lifestyle.



Source; Authors conceptualization

Figure 3-1: Conceptual framework for household fuel use in rural Kakamega

The household head is assumed to be the main decision-maker within the household. Their specific attributes are therefore important. Education has an influence on the household income, wealth, and therefore access to different fuel choices. It also increases the exposure to technology that is a prerequisite to the use of some energy sources like cooking appliances and may therefore be negatively related to household dependency on the forest.

3-3. Methodology

Due to the absence of time series data on household energy use in Kakamega, this study makes use of cross-sectional data collected on individual households, selected from the community next to the public forest. The demand analysis relies on the price variations between simultaneous observations to explain variations in the household consumption of different energy sources as used by Mackenzie and Weaver (1986). For the analysis of fuel consumption, we estimate a total demand function for cooking and heating fuels, where we estimate quantities of the consumed fuels as a function of the unit value of all consumed fuel types as well as household socio-economic and demographic factors including the household size, household income and other household attributes including occupation of the wife (or oldest female household member). The interaction of the household with the common pool forest resource is also included. The market prices of all purchased fuels are used in the analysis. For collected or own produced firewood and charcoal, a shadow unit value is estimated based on how much the household would have paid for the same fuel had they purchased it from the market.

The analysis of energy consumption is based on the method followed by Fan et al. (1995) in their study of food demand in China. The household's decision on energy consumption is analyzed at two levels; first, a household allocates its total expenditure onto the broad group of goods (e.g. energy, food, health etc.); then in the second stage, group expenditures are allocated over individual commodities (in the case of energy e.g., fuel wood, charcoal, kerosene and LPG). This procedure assumes that the consumer's utility maximization decision can be decomposed first into the broad consumption groups like energy (the focus of this study) and then into the specific subgroups (firewood, charcoal, etc.)

The function chosen for the first stage is the linear expenditure system (LES) of the functional form

$$P_IQ_I = P_IR_I + B_I (E- \Sigma_J P_JR_J) \qquad (1)$$

Where, P_IQ_I is the household expenditure allocated to consumption group I, which is given by the aggregated price (P) and quantities (Q) in group I. E is the total household expenditure and R_I and B_I are parameters to be estimated. First, the household purchases the minimum quantity, $R_{I,}$ of each commodity group required costing P_IQ_I, then allocates the remaining expenditures (E- Σ_J P_JR_J) over all commodities in fixed proportions B_I, the marginal budget share of commodity group *I* (Fan et al, 1995). The two expenditures can be considered as the subsistence and supernumerary expenditures respectively (Michalek and Keyzer, 1992; Pyo et al., 1991 and Fan et al, 1995). The underlying utility function makes the following assumptions necessary:

$$Q_I > R_I$$

The model satisfies homogeneity and symmetry automatically. For adding-up, it is necessary to implement

$$\sum_i^N Bi = 1 \text{ and } B_i > 0, \qquad (2)$$

such that the sum of all group expenditures is equal to the total household expenditure (Pyo et al., 1991)

The expenditure elasticity of demand is given by

$$\varepsilon_I = B_IE / (P_IQ_I) \qquad (3)$$

where $E / (P_IQ_I)$ is the share of budget by the commodity group *I*

The uncompensated (Hicksian) price elasticities associated with equation (1) as used by Pyo et al. (1991), which indicate the effect of a 1% price change in the quantity demanded of that good and all other goods, on the assumption that the other prices and the level of utility are held constant, is given by

$$(P_J/Q_I)\ (\delta Q_I/\delta P_J) = -\delta_{IJ} + (\delta_{IJ} - B_I)\ \mathbf{\{}(P_J R_J) / P_I Q_I)\mathbf{\}} \qquad (4)$$

The compensated (Marshallian) price elasticities, which give a measure of the effect of a price change on quantity demanded under the assumption that real expenditure is held constant is given by

$$(P_J/Q_I)\ S_{IJ} = (B_I - \delta_{IJ})\ \mathbf{\{}((P_J Q_J - P_I R_I) / (P_J Q_J) / (P_I Q_I)\mathbf{\}} \qquad (5)$$

where $\delta_{IJ} = 1$ if $I = J$, $\delta_{IJ} = 0$ if $I \neq J$ and S_{IJ} is the share of household budget spent on the commodity group *I*.

The LES is appealing because it is the only demand system in expenditure relative to price, which fulfils the regularity conditions of demand theory. In this model, only five broad commodity groups are considered and therefore demand elasticities estimated only have implications for those broad commodity groups; in this case food, energy, farming, education and ‘others’ (health, communication and miscellaneous expenses).

The Almost Ideal Demand System (AIDS) of Deaton and Muellbauer (1980) used by Heien and Wessells (1990) and modified by Shonkwiler and Yen (1999) was selected as the specification for the demand system of the second stage. The technique used in AIDS is attractive as in principle it can be applied to any demand system (Heien and Wessells, 1990). The AIDS was chosen because of its flexibility and linearity and because it is a complete system, that is, it can be restricted to satisfy the conditions of adding up, homogeneity and symmetry.

The demand system is specified with the shares of expenditure as the dependent variables (Poi, 2002)

$$w_i \equiv p_i q_i /m$$

where, p_i is the price paid for good *i*, q_i is the quantity of good *i* consumed and *m* is the total expenditure on all goods in the demand system such that

$$\Sigma\, w_i = 1$$

As used by Heien and Wessells (1990), the AIDS demand relations, in budget-share form, are given by

$$w_i = \alpha_i + \sum_{i=1}^{n} \gamma_{ij} \ln p_j + \beta_i \ln (m/P), \quad i = 1, \ldots\ldots, \text{n.} \qquad (6)$$

where *w* is the budget share of *i*th item in the budget category, *m* is total expenditure, p_j is the price of the *j*th good, γ and β are parameters to be estimated and P is a price index given by

$$\ln P = \alpha_0 + \Sigma\, \alpha_i \ln p_i + ½ \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j \qquad (7)$$

Equation 6 is estimated after imposing the adding up, symmetry and homogeneity restrictions (Deaton and Muellbauer, 1980; Fan et al., 1995; Poi, 2002)

i) $\Sigma_j\, \alpha_i = 1$, $\Sigma_j\, \beta_i = 0$ $\Sigma\, \gamma_{ij} = 0$ and (adding up restriction)

ii) $\Sigma\, \gamma_{ij} = 0$ (homogeneity restriction) and

iii) $\gamma_{ij} = \gamma_{ji}$ (symmetry restriction)

Various studies have shown that the household use of different fuels is not only influenced by the household income and prices but also by household specific demographic and socio-economic factors. The AIDS model (6) is therefore modified to include these factors by specifying

$$\alpha_i = \rho_{io} + \Sigma\, \rho_{ik}\, d_k, \qquad i = 1, \ldots, \text{n.} \qquad (8)$$

where ρ_{io} and ρ_{ik} are parameters to be estimated and the d_k are the demographic and socio-economic variables.

This model however encounters one main problem; not all households consume something of every fuel type and the minimum that any household can consume is zero. The observed budget shares cannot take any negative values and so are left censored at zero as there is no possibility of negative consumption (Deaton and Irish, 1984; Keen, 1986; Ransom, 1987; Heien and Wesselles, 1990). The decision to consume and how much of any fuel to use are made simultaneously by the household. Therefore the demand relations are inter-related through the error structure and any cross-equation restrictions. Any single equation demand estimation would therefore not be reliable. To correct this, Heien and Wessells (1990) use a two-step estimation model as developed by Amemiya (1974) and used by Lee (1978). The estimators resulting from this are more efficient than those obtained through the Olsen and Heckman selection model. The estimation first corrects the selection bias since the budget share is only observed in the households reporting some consumption of that particular fuel type. Following Heien and Wessells (1990), a probit regression is computed that determines the probability that a given household will consume a particular commodity, and the inverse Mills ratio (IMR) for each household and for each fuel type is computed. This IMR is then used as an additional regressor that incorporates the censoring latent variables in the second stage estimation of the system of demand equations.

The estimation procedure is undertaken in two stages. In the first steps, the decision to consume is modeled as a dichotomous choice problem,

$$Y_{ih} = f\,(p_{ih}, \ldots , p_{nh}, m_h, d_{1h}, \ldots , d_{sh}), \qquad (9)$$

Where

Y_{ih} = 1 if the *h*th household consumes the ith fuel type

and 0 otherwise.

Based on this estimation, the IMR for the household consuming a particular fuel type is computed as

$$R_{ih} = \phi\ (\mathbf{p}_h, \mathbf{d}_h, m_h) / \Phi\ (\mathbf{p}_h, \mathbf{d}_h, m_h) \qquad (10.1)$$

For the households not consuming the specific energy,

$$R_{ih} = \phi\ (\mathbf{p}_h, \mathbf{d}_h, m_h) / (1\text{-}\Phi\ (\mathbf{p}_h, \mathbf{d}_h, m_h) \qquad (10.2)$$

Where $\mathbf{p}_h$ is a vector of prices for the hth household, $\mathbf{d}_h$ is a vector of the demographic variables for the hth household and ϕ and $\mathbf{\Phi}$ are the standard normal density and standard normal cumulative distribution functions respectively.

The IMR for each fuel type is then incorporated in (8) as a regressor and then into (7) in the second-stage regression

$$w_{ih} = \rho_{io} + \Sigma\ \rho_{ik}\ d_k + \Sigma\ \gamma_{ij}\ ln\ p_j j + \beta_i \ln\ (m_h/Z_h) + \delta_i\ R_{ih} \qquad (11)$$

where following Deaton and Muellbauer (1980)

$$Z_h = \Sigma\ w_i \ln\ p_{ih} \qquad (12)$$

To estimate a complete system of equations, prices must be available for all households including those who do not consume that particular item. Some households reported no consumption of some of the fuels in the survey, and therefore had a missing price for that fuel. The treatment of zero consumption in cross-section demand estimation has been addressed in literature. This study used the approach by Heien and Wessells (1990) and replaced the missing prices with the average prices in each village as households in a particular geographical cluster are assumed to face similar prices. This study assumed that all fuels consumed were of the same quality.

The two stage LES-AIDS demand system is theoretically plausible and consistent while satisfying the demand properties of additivity, homogeneity, symmetry and concavity (Michalek and Keyzer, 1992). This two-stage system is superior to the LES as it generates elasticities which do not rise with expenditure and also allows for a drop in budget shares and admits negative marginal expenditures. At the same time, the LES-AIDS system is better than the AIDS system in that it allows for the own-price and cross-price substitution without requiring an intractable number of parameters (Michalek and Keyzer, 1992).

As shown by Michalek and Keyzer (1992) and Fan et al. (1995), the estimates of the elasticity of demand for the group of commodities with respect to a change in the uncommitted expenditure, M, in the LES-AIDS demand system is given by

$$\eta_I = (M/Q_I)\ (\delta Q_I/\delta M)$$

which can be also written as

$$\eta_I = 1 + (B_I/W_I) \qquad (13.1)$$

where W_I is the uncommitted expenditure share of group I.

On the other hand, the elasticity of demand for an individual commodity in group I with respect to a change in total household expenditure $m = M + P_I R_I$ (both subsistence and supernumerary expenditures) is given by:

$$\eta_i = (m/q_i)\ (\delta q_i/\delta m)$$

$$= \theta i\ (m/M)\ (P_I Q_I) / (p_i q_i)\ \eta_I \qquad (13.2)$$

The uncompensated price elasticities within the same group is given by

$$\eta_{ij} = \eta_{ijI} + \varepsilon_{iI}\ w_{jI}\ (1 + \eta_{IJ}) \qquad (14.1)$$

and the unconditional expenditure elasticity is calculated as

$$\varepsilon_i = \varepsilon_{iI} \varepsilon_I \qquad (14.2)$$

Equations 14.1 and 14.2 are used to calculate the complete demand system elasticities from the estimated LES and AIDS elasticities. From the estimated uncompensated elasticities the compensated price elasticities are derived using equation 14.3 (Michalek and Keyzer (1992):

$$\varepsilon^{c}_{ij} = \varepsilon^{uc}_{ij} + w_j\eta_i \qquad (14.3)$$

where, ε^{c} is the price compensated elasticity and ε^{uc} is the uncompensated elasticity.

3-4. Research area and data elicitation

Kakamega forest, the most easternmost edge of the Guineo-Congolean rainforest is Kenya's only remaining tropical rain forest (Kokwaro, 1988). This forest has an important indigenous part, rich in biodiversity, hosting numerous animals and plants, some of which are endemic. The forest has been undergoing recorded disturbances leading to a loss of about 20% of the forest area since the late 1970s (Lung and Schaab, 2004). According to Wandago (2002), this forest loss has been due to deforestation and fragmentation. The high population density around the forest and high incidence of poverty increases the rate of resource extraction from the forest (Takasaki et al., 2001; Peggy et al., 2004; Ouma, 2005). Currently the forest and its fragments are under two management regimes. The Kenya forest service (KFS) manages the bigger part of Kakamega forest main block and Malava fragment, while the Quakers Church (QC) manages the smaller Kaimosi fragment. Both KFS and QC allow controlled collection of dead wood by the local communities after the payment of an access fee. Furthermore, part of the forest was designated a Nature reserve and is administered by the Kenya Wildlife Service (KWS), which strictly outlaws any extractive use of the forest (Guthiga et al, 2008). Following a ban on timber harvesting from indigenous forests and a more thorough management of the plantation forests by the government, records at the KFS office in Kakamega indicate that state permitted deforestation has largely been controlled in all areas of the forest. However, the forest is still under a threat of degradation since the local communities still rely on it for fuel wood, charcoal, building poles, medicinal plants and grazing (Guthiga et al 2008). Incidents of charcoal burning, which is illegal, have been reported even in the KWS managed part of the forest as shown by Lung and Schaab (2004). Data collection for this study was carried out between July 2009 and February 2010. A sampling frame assembled by the BIOTA[2] study team in 2005 targeting households living in villages within 5 km from the forest edge was utilized. A two stage stratified random sampling was carried out. At the first stage, we randomly selected 64 villages from a list of 250 villages to equally represent the north and south. Within these villages, 290 households were randomly selected from a list of resident households proportional to the village population. Households in our sample are located around the forest covering all four administrative districts that border with the forest and all forest management regimes. The unit of observation was the household, where it was defined as the number of people including resident employees who share in the use of energy for cooking and lighting. A semi-structured questionnaire was administered to the household head/spouse or adult sibling to collect information on the households' use of different fuels in quantities, sources and the prices paid if bought in the market or as valued by the household based on how much they would have paid for the fuel had they purchased it from the market. We also collected information on household attributes and their interaction with the local public forest management. A major challenge of the data collection process was the illiteracy of some of the respondents and the reliance on memory in the absence of households' energy

[2] Biodiversity Monitoring Transect Analysis in Africa (BIOTA) is joint research on sustainable use and conservation of biodiversity in Africa jointly funded by the German Federal Ministry of Education and Research (BMBF) and several African countries and institutions. In East Africa, BIOTA East had research interests in Kakamega forest (Kenya), Mabira and Budongo forests in (Uganda). www.biota-africa.org

consumption records. Only locals were used in data collection, after training and were continuously supervised in the field.

3-5. Results

3-5.1 Household characteristics and energy use

Agriculture is the main economic activity in the research area being the major occupation of 74% of the households in our sample. Furthermore, 16% are salaried employees, and 11% are self employed in a non-farming business. Agriculture is primarily for the subsistence production of food, but any excess production is marketed. Land holding is generally low with an average of 2.26 acres (Table 3-1) but varying substantially among households in our sample as shown by the standard deviation of 2.58. Land size is expected to continually decrease in the future due to land sub-division as each son inherits a portion of his father's land, a practice accounting for 84% of land ownership in the area. Although only 34% of the residents have set aside a specific area for trees, 97% of households have planted trees other than fruit trees on their land, especially along the land boundaries. Continued land sub-division will, however, also limit the potential of households to meet their firewood needs from this source. The declining size of land holdings is expected to decrease the earning potential of households relying on agriculture as their main economic activity, thus exerting even more pressure on the common forest both as a source of energy and livelihood.

Table 3-1: Basic statistics of the rural households in Kakamega

	Mean	Std Deviation
Farm Holding in acres	2.26	2.58
Private wood lot in acres	0.1227	0.254
Age HHH in years	51.19	14.31
Formal Education HHH in years	6.8	3.94
Household size	5.5	1.8
Annual HH expenditure ‘000 KES	131.95	71.64

* 1US Dollar = KES 80, average for 2009

Source: Author’s calculations based on collected data

The average household in our sample has 5.5 members. For the purposes of this study, the household members considered were all persons sharing in the use of cooking and lighting fuel. The household head has on average gone through seven years of education, which is equivalent to a primary level education. This limits the options for non-agricultural employment for most household heads, hence the reliance on agriculture as the main occupation.

The analysis of the survey data indicates that rural Kakamega households allocate about 59% of their annual expenditure to food. Any own produced food consumed by the household was valued at the buying market price in the region. Valuing food at the buying price included the transaction costs normally associated with marketing the food. Since households did not bear any transaction costs in consuming their own food, this inflated the food expenditure. It was believed to be more reliable than either the production costs or selling price. Other important expenditure items include; transport and communication (9.9%) education (8.9%); farming (6.7%) and on average 6.8% of their annual expenditure is devoted to the provision of cooking and lighting energy (Table 3- 2).

Table 3-2: Average household expenditure on various consumption groups for the rural households living next to Kakamega forest (Kenya Shillings (KES) per household per year)

HH expenses in KES/HH/yr on different items	Mean	Std. Deviation	Percentage of total expenditure
Food	72315	30257	59.3
Clothing	3955	3676	3.2
Farming activities	8212	10286	6.7
School expenses	10792	22752	8.9
Transport and communication	12121	13386	9.9
Health	6191	7876	5.1
Cooking and lighting energy	8347	7647	6.8
Total household expenditure	121 933	59259	100

* 1US Dollar = KES 80, average for 2009
Source: Author's calculations based on collected data

As shown in Table 3-3, all households in our sample use fuel wood (firewood) for cooking. This is substantially higher than the national average of 70% for rural households estimated by the Ministry of Energy (2002). Firewood is used alongside charcoal, kerosene and liquefied petroleum gas (LPG). The household access to these fuels gives multiple options for fuel combinations. As shown in Table 3, 45.8% of the households combine fuel wood with charcoal, 98.6% use kerosene and only 2.1% use LPG. Unlike firewood, charcoal, and LPG, which are exclusively used for cooking, kerosene is the main lighting fuel but is sometimes also used for cooking.

Table 3-3: Household Fuel use

Fuel Type	HHs Reporting *	Av. consumption Per HH/yr	Average unit price (KES)
Fuel wood	285 (100%)	97.9 Head loads	76KES/Head load
Charcoal	131 (45.8%)	9.11 Bags	465KES/Bag
Kerosene	282 (98.6%)	37.3 Litres	80.2KES/Litre
LPG	6 (2.1%)	34 Kg	146KES/Kg

* Total exceeds 100% indicating multiple fuels use
Source: Author's calculations based on collected data

Households obtained firewood from three main sources; own trees, purchased from other producers (either as ready-to-use firewood or in the form of trees from which they obtain firewood) or collected from the public forest. Some of the households have multiple sources of firewood. The common pool forest is the most important source of firewood for the local community, accounting for 46.7% of all firewood used by the sampled households (Table 3-4). This is either through direct collection from the forest or purchase from forest collectors. Each household depending on forest firewood consumes on average 91 head loads per year, which is more than the 77 and 72 head loads obtained from their own farms or purchased from the market, respectively. Firewood collection, when done according to the guidelines of the management agencies has no adverse effects on the conservation of the forest. However, 53% of households collecting firewood admitted to occasionally also cut down young trees when they fail to get fallen dead branches. Therefore, when not well managed, lawful firewood collection may form the avenue for forest degradation.

Table 3-4: Analysis of firewood use

Source	Number of HH s Reporting	Average annual consumption (Head load /HH/yr)	Average value per head load	Proportion of total consumption
Own trees	135 (47.4%)	77	72	37.30%
Purchased from private trees	62 (21.8%)	72	82	16%
Public forest	147 (51.6)	91	78	46.70%
Overall	285	98	76	100%
Public Forest fuel wood				
Purchased from forest collectors	108 (37.9%)	96	77	37.70%
Own collection from public forest	39 (13.7)	64	79	9%

Source: Author’s calculations based on collected data

All households have at least some trees planted along the farm boundaries or on land reserved for grazing. Therefore, although most households do not set aside part of their land for trees, farm trees provide firewood for 47.4% of the households. There is an active firewood market in the research area. The public forest still accounts for the bulk of the traded firewood, accounting for 37.7% of firewood consumption (Table 3- 4). Therefore, forest not only provides fuel but is an important source of income for the local residents.

Charcoal is the second most frequently used fuel: 48.9% of the households reported consuming an average of 437 kg per year. This is higher than the reported national average consumption of 34%, but these households consume less than the reported national average of 717 kg per rural household annually (Ministry of Energy, 2002). The rural households obtained charcoal either by charcoaling themselves or buying ready to use charcoal. As shown in Table 3-5, about 72.8% of the charcoal used in this area is purchased: 18.2% from charcoal traders in the shopping centers, 15.3% from charcoal burners using trees from the forest, and 39.3% from burners using other trees. The rest of the charcoal is burned by the households themselves from farm tress (8.8%), purchased trees (3.8%) or forest trees (14.1%).

Table 3-5: Analysis of charcoal consumption

Source	HHs reporting	Average annual consumption bags/hh/yr	Average price per bag* KES/bag	Proportion of total
Own Charcoaling				
Farm trees	12	8.76	430	8.80%
Forest trees	15	11.21	415	14.10%
Purchased trees	7	6.39	469	3.80%
Purchased charcoal				
Market	27	8.07	604	18.20%
Forest tree burners	20	9.45	405	15.30%
Other burners	50	9.39	449	39.30%

*1 bag weighs approximately 48Kg
Source: Author's calculations based on collected data

Although charcoaling from Kakamega forest is prohibited, 29.4% of all charcoal consumed by the sampled community comes from the forest. Since charcoaling involves cutting down of whole trees or mature branches, it is a major cause of deforestation and degradation of the forest.

The community living next to the Kakamega forest depends on firewood for cooking. This is usually combined with charcoal, the next most frequently used fuel. There is a high dependency on the common pool forest for fuel, which has led to forest degradation. The use of advanced fuels in rural Kakamega is low with only 2.1% of households surveyed reporting the use of the most advanced fuel (LPG) in their energy use combinations. Given their low uptake, the use of advanced fuels to reduce pressure on the forest is not a viable option in the short term. To safe guard the forest, a focus should be on sustainable sources of firewood and charcoal, especially the encouragement of own tree plantings to obtain firewood.

3-5.2 Demand estimation and calculation of elasticities

A complete demand system was estimated using the LES-AIDS model. There are five groups of commodities for this first stage of the demand system; food, energy, education and services. The services group was comprised of the household expenditure on traveling and communication. The linear expenditure system, equation (1) was estimated using a seemingly unrelated regression model. A summary of the results of this estimation extracted from the complete results (Appendix 1) is presented in Table 3-6. All estimated marginal budget shares of each commodity group (B_I) are significant at the 1% level.

Table 3-6: Linear Expenditure System Estimation Results

	Mean of Total Expenditure on group I (P_IQ_I)	Marginal Budget share (B_I)	Minimum Expenditure on (KES) (R_IP_I)	R^2	Minimum Expenditure (R_IP_I) as % of P_IQ_I
Food	72315	0.412**	20152	0.556	65.1
Energy	8347	0.071**	6569	0.257	64.7
Education	10792	0.274**	8019	0.475	64.2
Health	6191	0.045**	4963	0.110	63.3
Services	16077	0.193**	10758	0.491	60.3

** 1% significant
Source: Author's calculations based on collected data

The estimated compensated own price elasticities for food, energy, education and services are very similar and range from -0.226 for the food to -0.325 for energy (Table 3- 7). The cross price elasticities are not estimated here as the focus of this study is on the specific items within the energy group and not on the household demand for all commodities. Household demand is least elastic for food and health as compared to the other three groups.

Table 3-7: LES expenditure, uncompensated and compensated own price elasticities

	Expenditure Elasticities	Uncompensated Elasticities	Compensated Elasticities
Food	0.649	-0.836	-0.226
Energy	0.964	-0.269	-0.325
Education	2.936	-0.464	-0.323
Health	0.824	-0.234	-0.272
Services	1.368	-0.460	-0.314

Source: Author's calculations based on collected data

The expenditure elasticity for food (0.649), health (0.824) and energy (0.964) is less than one; therefore these consumption groups can be classified as necessities. A 1% decline in household expenditure will result in a less than 1% drop in the household expenditure on these groups.

However, the expenditure elasticities for education (2.936) and services (1.368), which are above one, can be classified as luxuries, and a 1% decline in household expenditure will result in a more than 1% drop in the expenditure allocated to each of these groups.

In the second stage, the AIDS model was estimated where the proportion of the energy expenditure used by the household for each particular fuel type was regressed on the natural logarithm (log) of its own price, the log of the prices of the other fuels, the log household expenditure on energy and some household attributes (see Appendix 2). To account for the selection bias, the IMR generated in a probit estimation for the household choice of each fuel was used as a regressor. This was only done for charcoal, kerosene and LPG which are not consumed by all households. A summary of the variable statistics is presented in Table 3-8.

Table 3-8: Summary of variables used in the demand estimation

Variable	Mean	Std. Dev.	Min	Max
Energy expenditure share on firewood (w1)	0.612	0.185	0.087	0.969
Energy expenditure share on charcoal (w2)	0.127	0.168	0.000	0.633
Energy expenditure share on kerosene(w3)	0.257	0.120	0.000	0.800
Energy expenditure share on LPG (w4)	0.005	0.040	0.000	0.532
Log of price of firewood (lnp1)	4.317	0.281	3.219	4.942
Log of price of charcoal (lnp2)	2.259	0.238	1.427	2.931
Log of price of kerosene (lnp3)	4.387	0.189	3.912	5.768
Log of price of LPG (lnp4)	5.015	0.089	4.738	5.339
Log of expenditure on energy(lnexpenergy)	9.030	0.797	6.804	10.897
Household size	5.502	1.781	2.000	10.000
Education household head (yrs)	6.796	3.942	0.000	16.000
	%Households			
Forest firewood collection allowed	84.56			
Adult woman works away from home	12.68			

Source: Author's calculations based on collected data

The regression results including the price and expenditure elasticities of the second stage AIDS system are presented in Appendix 2. By applying equation (14), the complete demand system expenditure, compensated and uncompensated price elasticities were calculated from the elasticities estimated for the LES (Table 3-7) and AIDS (Appendix 2) models, respectively and the results presented in table 3- 9a and 3-9b.

The complete system expenditure elasticities were positive for firewood (0.804), charcoal (1.787), kerosene (0.937) and LPG (1.007) (Table 3-9a), suggesting that all the fuels are normal goods and an increase in household energy expenditure will generally lead to a higher consumption, though at different rates. The high expenditure elasticity for charcoal implies that an increase in expenditure on fuel will lead to a more than proportionate increase in the expenditure shares of this fuel type in Kakamega. As household incomes increase, the demand for charcoal will also increase, thus putting additional pressure on the forest. The inverse is true for firewood which is more expenditure inelastic, and an increase in household expenditure will have a lower impact on the demand for firewood. This is as expected, since firewood is the only cooking fuel used by all households and currently has no viable substitutes. However, with an increase in household expenditure, more households may meet their firewood needs from the forest, the cheapest source of firewood, thus putting more pressure on its conservation.

Table 3-9a: Uncompensated Complete System Demand Elasticities

Energy budget share	Log of price				Expenditure Elasticity
	Firewood	Charcoal	Kerosene	LPG	
Firewood	-0.539	0.494	0.467	0.476	0.804
Charcoal	0.157	-1.037	0.123	0.012	1.787
Kerosene	0.172	0.219	-0.818	0.186	0.937
LPG	0.187	-1.290	-0.178	-0.288	1.007

Source: Author's calculations based on collected data

The complete demand system compensated and uncompensated own price elasticities for all fuels are negative (Table 3-9a and 3-9b) and are consistent with economic theory, an increase in own price would lead to a lower consumption of that particular fuel type. The compensated own price elasticities for firewood, and LPG are less than one (Table 3-9b); hence the demand for these energy types is relatively own-price inelastic or less responsive to own-price changes. A one percent change in the prices of each of these fuels will lead to a less than one percent change in its demand. It is assumed that the relative price changes within fuel categories would not affect the real expenditure on fuel (Gundimeda and Köhlin, 2008) and substitution is within the energy sub-group in household expenditure.

Table 3-9b: Compensated Complete Demand System Elasticities

	Log of price			
Energy budget share	Firewood	Charcoal	Kerosene	LPG
Firewood	-0.785	0.880	0.837	0.851
Charcoal	0.185	-1.161	0.147	0.022
Kerosene	0.233	0.293	-1.011	0.251
LPG	0.188	-1.296	-0.179	-0.290

Source: Author's calculations based on collected data

The compensated own price elasticity for LPG is the least in magnitude (-0.290) and its demand is the most inelastic among the different energy types, implying that the percentage change in the consumption of LPG would be lower than the change in price. Charcoal and kerosene have the relatively most elastic demand and households are more likely to increase or reduce the consumption of these fuels following a change in own price. A decline in the consumption of charcoal from the forest is beneficial for forest conservation since charcoal is the most forest destroying fuel among the fuel types used by the households. Households are allowed to collect fallen dead tree branches from the forest for firewood after paying an access fee, but charcoaling involves the cutting down of either whole trees or branches from mature trees, contributing to deforestation and forest degradation. Although firewood and charcoal are both biomass fuels, the use of charcoal is more detrimental to the forest. A change from the use of charcoal to firewood would therefore have a beneficial effect on forest resources.

The complete system cross price elasticities can be used to analyze the impact of changes in the price of one fuel type on the demand of another (Tables 3-9a and 3-9b). The absolute magnitude of the elasticities indicate whether a given fuel is a complementary fuel (cross price elasticity less than one) or a substitute fuel (cross price elasticity greater than one) to the other fuel. The compensated demand elasticities for charcoal with respect to changes in the prices of the other fuel types are 0.185 for firewood, 0.147 for kerosene, and 0.022 for LPG (Table 3- 9b). The demand for charcoal is therefore not very responsive to changes in the price of the other alternative fuels. The demand for firewood is also inelastic to changes in the prices of all other fuel types given the cross price elasticities for charcoal (0.88), kerosene (0.837) and LPG (0.851), confirming its importance to the households living next to the forest. Any substitution may therefore be between the sources of biomass. The demand for LPG, which is the most advanced cooking fuel accessible to the households, is very elastic to changes in the price of charcoal (-1.296) but relatively inelastic to changes in the price of firewood (0.188) and kerosene (-0.179). Therefore, policies that increase the household access to LPG will relieve pressure on charcoal consumption but will have a much lower impact on the use of firewood and kerosene.

3-6 Conclusion and recommendations

This article analyzed the household demand for different fuel types used for cooking and space heating. Analysis was based on a cross-section survey from 285 rural households living in villages within 5 km from the edge of Kakamega forest in western Kenya. Results indicate that as household expenditure increases, the allocation for energy use will also increase. However, this increase in consumption is least in firewood and highest in LPG. Furthermore, the demand for firewood is neither responsive to changes in its own price and nor the prices of the other fuels. Given that over 60% of all energy expenditure is used on firewood, households in Kakamega have no real alternatives to the use of firewood, and substitution may be within the sources of firewood. The highly negative own compensated price elasticity for charcoal (-1.161) suggests that increasing charcoal prices will reduce demand appreciably, an action that may benefit forest conservation. Better protection of the forest against charcoaling may reduce the supply to the local residents and increase its price, thus acting as an incentive for households to use other energy sources which are more forest conserving. The use of LPG, the most advanced fuel in Kakamega is still low, and is currently not a viable alternative to charcoal. However, as household incomes improve, the demand for LPG will increase, given its complete system expenditure elasticity of 1.007 (Table 3-9a).

Deforestation of Kakamega has been fairly controlled since the banning of logging of indigenous forests in Kenya. However, limiting forest degradation is still an important issue in the conservation of the forest as the local residents still rely on the forest for legally collected firewood and some illegally obtained charcoal. The current forest protection policy of imposing coercive measures on local residents by restricting access to forest resources seems not to be effective as 30% of the charcoal consumed by the local residents is from the forest. Also 53% of individuals collecting firewood from the forest occasionally cut down young trees. Other management options especially those that involve the local community may increase compliance with extraction rules and thus achieve better forest conservation.

4. Charcoal Trade in Kakamega Town: The Role of Traders and the Implications for the Conservation of Kakamega Forest

4-1 Introduction

The seventh millennium development goal (MDG) aims at ensuring environmental sustainability through incorporating the principles of sustainable development into country policies and programs in an effort to reverse the loss of environmental resources (UN, 2008) and reduce biodiversity loss. Moderate success has been achieved on this goal although deforestation continues to pose serious challenges even when the global net loss of forest area is slowing down. Forests not only play an important role in mitigating climate change but also conserve biodiversity and water resources when sustainably managed (UN, 2008). Despite the efforts being put in forest conservation in developing countries, Mugo and Ong (2006) observe that the increasing population in both rural and urban areas, unemployment and the nature of land tenure regimes remain key drivers of deforestation and degradation.

In developing countries, the use of biomass based fuels for cooking and heating is still wide spread accounting for almost 90% of household energy consumption. Under the current energy policies and consumption pattern, the use of biomass fuels is expected to keep increasing at an annual average rate of 1.6% and by 2030 about a third of the world population will still rely on biomass energy (IEA, 2006). In sub Sahara Africa, charcoal is the most used biomass fuel for the urban households while firewood is the main fuel for the rural households and cottage industries. Recent case studies in East Africa show an increasing use of charcoal for both rural and urban households (Malimbwi et. al., 2001; Mutimba and Barasa, 2005; Sepp, 2008). This increasing use of charcoal results from a combination of a number of factors that include the rising population, urbanization and shifts in the patterns of household fuel use fuelled by changes in living standards (Mugo and Ong, 2006). Some attributes of charcoal make it the fuel of choice for many urban dwellers. It is convenient to use indoors as it does not smoke; it is easily packaged and transported over long distances and has a high calorific value per weight (Ministry of Energy, 2002). Over the years, the proportion of households relying on biomass for their energy needs in Kenya has slightly increased from 68% in 2001 (Ministry of Energy, 2002) to about 70% in 2009 (KIPPRA, 2010). Although firewood is the most used biomass fuel, charcoal is more important in the urban centers. Nationally, 47% of households use charcoal, with slightly higher per capita consumption in the rural areas at 156 kg as compared to 152 kg in the urban areas. However, 82% of households in urban areas use charcoal as opposed to only 34% in the rural areas (Ministry of Energy, 2002).

Various stages of the charcoal supply chain impact in multiple ways on the economic, social, and environmental aspects of developing countries. In Kenya, 92% of consumers purchase charcoal, 1% purchase but sometimes produce their own while 7% produce their own charcoal (Ministry of Energy, 2002). This consumption pattern makes charcoal an important traded biomass fuel. Charcoal trade contributes positively to livelihoods support through job creation directly for the burners, transporters and traders and indirectly to the support industries. Despite the importance of charcoal use in Kenya, the energy policy has paid little attention to the ways in which charcoal is produced and sold including the need for having the wood used for charcoaling produced and harvested sustainably (Ludeki et al., 2006; Mugo and Ong, 2006). According to the World Resources Institute (2005) lack of coherent policies in charcoal production, transportation and distribution has rendered this sector informal in most of the tropical countries thus making it an inefficient and a risky enterprise for investors. This situation is made worse by the unregulated and sometimes illegal setting in the charcoal sector and corruption within the forestry sector in most of these countries (Sepp, 2008). Thus the charcoal production rarely attracts the capital investment required for improved charcoaling technology (Seidel, 2008). The development of unregulated charcoal trade with high profits for some of the players has led to the exploitation of forest and woodlots that are far from urban centers, the main charcoal markets (Mugo and Ong, 2006; Sepp, 2008). In recognition of the importance of the production and trade in charcoal in Kenya and its potential impact on the forestry resources, the current forest policy also addresses the need for the development and promotion of efficient wood technologies and use of alternative forms of energy (Forest Act, 2005). However, to date, except for the ban of charcoaling from public forests, no specific laws have been enacted that specifically address the charcoal sector.

4-1.1 Charcoal use and its link to deforestation and forest degradation

The clearance of forests and other tree systems to support agriculture and settlement is a major cause of deforestation in the tropics (Bajracharya, 1983). However, commercial charcoal production has been linked to forest deforestation and degradation (Modi et. al, 2006). This is especially so where the depletion of forests has already taken place due to other forces like commercial logging. There is a definite link between wood fuel use and deforestation (Dewees, 1989). Studies by Hofstad (1997), Malimbwi et al. (2001), CHAPOSA (2002), Ministry of Energy (2002) and Mwampamba (2007) on different cities in Kenya, Tanzania, Mozambique and Zambia have concluded that forests and woodlands near thriving cities suffer deforestation and degradation directly attributable to charcoal production. In an effort to reduce the damage caused by unplanned charcoal production, Mugo and Ong (2006) observe that most countries in the region have imposed restrictions on production and transportation of charcoal while maintaining charcoal trade and use in the urban areas legal. Restricting or banning charcoal production has only resulted in pushing production secret and therefore slowing the adoption of better production technologies without significantly affecting its use (Mutimba and Barasa, 2005). This has resulted in increasing charcoal prices which remain high even after such restrictions or bans are relaxed (Seidel, 2008).

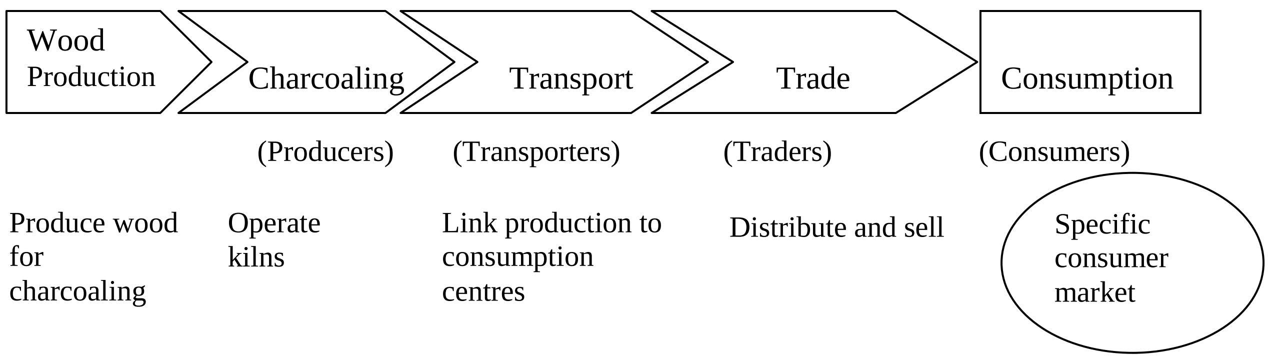
In Kenya, about 40% of the charcoal used in the urban centers is obtained from the drier savanna also referred to as rangelands, another 40% from private farmlands and 20% from government forests (Ministry of Energy, 2002). This is despite a ban on logging of both indigenous and plantation public forests in Kenya since 1989 and 1999 respectively. Most of the trees for charcoal are sourced from the rangelands, but also occasionally from government forests; are harvested unsustainably (Mugo and Ong, 2006). Even where charcoal is harvested from private forests and woodlots, the process of charcoaling is inefficient and associated with a lot of waste thus exacerbating deforestation and degradation of large areas (Republic of Uganda, 2002, Ministry of Energy, 2002). Under the current techniques, charcoal burning is a wasteful use of natural resources and leads to massive land degradation and deforestation (Malimbwi et al, 2001; CHAPOSA, 2002; Mugo and Poulstrup, 2003). For example, the conversion efficiency reported for the earth mold kiln, the charcoaling technology most used in Africa, is quite low; 9-12% in Kenya (Theuri, 2003), 11-15% in Tanzania (CHAPOSA, 2002) and about 15% in Mozambique (Pereira, et. al., 2001). Although the use of improved kilns has the potential of achieving better efficiencies, they are not widely used (CHAPOSA, 2002).

For charcoal production and use to contribute to sustainable development and poverty alleviation while ensuring a sustainable use of forest resources, a different approach to the charcoal sector has to be taken. The needed changes in the decision making processes and planning of policies and actions to tackle problems related to this sector cannot be done without a clear understanding of the current situation and the severity of the associated problems. The main objective of this study is to investigate the link between charcoal trade in Kakamega town and the deforestation and degradation of the Kakamega forest. To achieve this objective, a charcoal supply chain map for Kakamega town is developed. This forms the basis of understanding the structure and role of the different traders involved in the charcoal trade through the analysis of the source and volumes of traded charcoal. The results of this study support the development of conservation policies for Kakamega forest while offering insights that can inform policy-makers and the other stakeholders in both the energy and forest sector in the country. For the western Kenya region, this study helps in the understanding of the charcoal trade through an analysis of the structure and involvement of the main stakeholders and their roles in the charcoal flow and trends in the deforestation of Kakamega forest due to charcoal production and use. Through an analysis of trade volumes and margins, a general understanding of the incomes generated at different stages of the supply chain is achieved. This is important in addressing some of the problems caused by charcoal production as a contribution to reducing deforestation and forest degradation of the public forest. As charcoal production and trade occurs all over Kenya and the other developing countries, the results of this study may be relevant to other regions in the country and other countries in the region.

The use of firewood and charcoal by the community living around Kakamega forest and its contribution to deforestation and forest degradation has been the subject of previous studies. Guthiga et al. (2008) in a study on the interaction between the management agencies and the rural community concludes that although the community rates the agencies that allow controlled extractive use of the forest poorly, they still accept them due to the benefits that they obtain including access to charcoal from the forest even though this is outlawed. Wambua (2008) values the non-timber wood forest products including charcoal obtained by the community from the forest for their own consumption. This study adds an analysis of the charcoal trade between the forest and Kakamega town to the existing literature. The contribution to deforestation and forest degradation of adjacent forests and tree systems by charcoal use in thriving urban areas has been documented by other authors (Hofstad, 1997: Malimbwi et al 2001; CHAPOSA, 2002). In these studies the contribution of rural communities to charcoal trade with the urban areas is only through their role as charcoal producers from their private land. Our study specifically looks at the local community's role in the trade of charcoal obtained from the public forest. By studying the structure and trend of charcoal trade in Kakamega town, this study contributes to the literature on the conservation of common pool forest resources by exploring the link between charcoal trade in the town and conservation of the forest. In order to investigate these issues, the general conceptual framework guiding the analysis of supply chains in general is discussed in section 4-2. Section 4-3 describes the study area, sample selection and data collection procedures used in this study. The study results that explore the linkages in charcoal trade in Kakamega municipality and the conservation of Kakamega forest is discussed in section 4-4 while some concluding remarks are presented in the last section.

4-2 Conceptual Framework of Supply Chains

A first step in reducing forest destruction and degradation from charcoal burning is to understand how charcoal from the forest enters the supply chain. A visualization of the charcoal flows within this supply chain results in a chain map, which identifies and describes the roles of the various actors within the supply process. An analysis of the supply chain forms a basis for better understanding of the dimensions of the charcoal sector, the production and trade processes, the volumes involved and the incomes generated at the different stages of the chain. This has the potential to facilitate the understanding of the problems that need to be addressed and the areas where different actions can be performed. As described in GTZ (2007) and used by Seidel (2008), the construction of the value chain involves four related steps that are carried out concurrently. The first step is the identification and mapping of the elements and stages of the supply process and the corresponding stakeholders involved as presented in Figure 4-1.



Source; Adapted from GTZ, 2007; Seidel, 2008

Figure 4-1: A general chain map for charcoal production and trade.

Once the chain links are mapped, the number of players in each category, the product volume and their market share, the amounts of product accruing at each level of the supply chain is estimated. This process is the quantification of the supply chain. In the third step, the quantities estimated in step two are used to quantify the flow of revenues accruing at various stages in regards to income and profit, prices and the distribution of the profits within and among the groups along the value chain.The last step involves an in-depth analyis of selected factors to gain a deeper understanding of the underlying issues and the institutions involved. Some of these issues may be regulatory constraints (land tenure, property rights, trade licencing and reguation, taxes/ duties, management rights etc.), or operational constraints, especially infrastructure and information availability and sharing. However, due to limited data availability, this study does not include this last step.

4-3 Study area and data collection procedure

Kakamega town is on the edge of the Kakamega forest and therefore has a direct interaction with the forest through the rural population living in the villages around the forest. This forest is the only remaining part of the Guinea-Congolean rainforest in Kenya and also one of the few remaining indigenous forests in Kenya with a unique diversity of flora and fauna, some of which are endemic. The forest has been undergoing recorded disturbances leading to a loss of about 20% of the forest since the late 1970s (Lung and Schaab, 2004). According to Wandago (2002), this forest loss has been due to deforestation and fragmentation. The high human population density around the forest and high incidence of poverty increase the rate of resource extraction from the forest (Peggy et al., 2004, Ouma, 2005). The proximity of Kakamega town to the forest creates an avenue for the interaction between the energy needs of the town residents and the conservation of the forest.

Kakamega town is an important trade centre for western Kenya and also hosts the provincial offices of headquarters of the Western Province of Kenya and Kakamega District. It is also home to Masinde Muliro University of Science and Technology. The government is promoting tourism to this forest as part of the 'western tourism circuit'. These factors have contributed to the growth of this town. The population of Kakamega town has been steadily increasing from 6,244 individuals in 1969 to 74,115 in 1999 (GoK, 2009). This represents an average annual population growth rate of 6.6% between 1979 and 1999. With the continued expansion of the town, the rate of population growth is expected to be even higher than 6.6%. According to Ministry of Energy (2002), 82% of households living in cities and towns and 86% of small scale industries (especially restaurants and food kiosks) use charcoal as their primary cooking fuel. The increase in population therefore has a double effect on the demand for charcoal in Kakamega; firstly, through the increase in the number of households using charcoal and secondly, through the accompanying growth in small-scale businesses especially hotels and food kiosks, which are estimated to grow at a rate of 3.5% annually (Ministry of Energy, 2002). The increase in the demand for charcoal has the potential of increasing deforestation and forest degradation of the Kakamega forest.

To capture the different categories of traders, all market areas where charcoal dealers operate in the Kakamega Municipality were first identified in a pre-survey. Stratified random sampling as described by Mugenda and Mugenda (2003) was chosen as the most appropriate sampling strategy. For this study, the trader category was used as the basis for stratification. Three strata (trader categories) were identified, the wholesalers; the retailers and the hawkers. In the absence of a readily available sampling frame of all charcoal traders operating in Kakamega town, a systematic random sampling within each stratum was used. Normally in Kakamega town, charcoal traders operate near the residential areas, and set up their businesses near each other in the small trading areas, in this study referred to as charcoal selling points. Once a selling point was identified, a clear arrangement of all traders was mapped from an identified starting point. Of the three categories, only the retailers and wholesalers operate from the charcoal selling points. The retailers purchase their charcoal from mainly the wholesalers in bulk (bags), break the bulk and sell charcoal directly to consumers in smaller units. The first four traders in each category were indentified, then one of them randomly picked as the starting point and subsequently every fourth trader was interviewed. In any charcoal selling point, the different categories of traders were therefore first identified and then a random sample picked to achieve a sample of 25% representation of each trader category within a selling point. The third category of traders is the charcoal vendors or hawkers. These traders have no defined operating base but carry charcoal from the rural villages and hawk within the residential areas of Kakamega town. The routes which they normally use to town were identified and for a week, every fourth person passing by and carrying charcoal was interviewed. Data collection for this study was carried out in October 2009. In total, 16 wholesalers, 26 retailers and 19 hawkers were interviewed. Semi-structured questionnaires were administered to the selected traders to elicit information on the source of traded charcoal, prices and quantities sold, any periods of scarcity and sources of charcoal during these periods of scarcity if different form the normal sources.

4-4 Linkages in charcoal trade in Kakamega Municipality

Charcoal transporters deliver charcoal from the forest and private producers directly to the charcoal traders in Kakamega town. For traders in the town, the charcoal buying price is inclusive of the transport costs. Wholesalers purchase charcoal from transporters, who deliver bags of charcoal in trucks. Wholesalers operate charcoal stores from where they sell to other traders or directly to consumers without breaking bulk. The second category, the retailers, operate charcoal kiosks where after buying charcoal in bags they break the bulk and sell charcoal to consumers in smaller volumes, usually in 20, 10, 4 and 2 liter containers. The third category is comprised of vendors, mostly women, from the rural community living next to the Kakamega forest, who carry charcoal on their heads into the town and move around searching for buyers, hence the term ‘hawkers’ used to describe them in this study. The hawkers normally sell directly to consumers but may occasionally sell charcoal to retailers.

In total, 16 wholesalers, 26 retailers and 19 hawkers were interviewed. Semi-structured questionnaires were administered to the selected traders to elicit information on the source of traded charcoal, prices and quantities sold during September, 2009 specifically and generally, any periods of scarcity and sources of charcoal during these periods of scarcity if different form the normal sources. Study results show that the charcoal traded in Kakamega is obtained from different regions and transported to Kakamega usually by trucks. The Rift Valley region, which includes the wattle tree plantations near Eldoret town, some 100km from Kakamega, and the drier rangelands of Narok and Nandi are important sources. Charcoal traded in Kakamega town is also obtained from Busia and private trees near the town or from the Kakamega forest. These sources of charcoal and their relative contribution to the volume of charcoal traded in Kakamega town are shown on Figure 4-2.

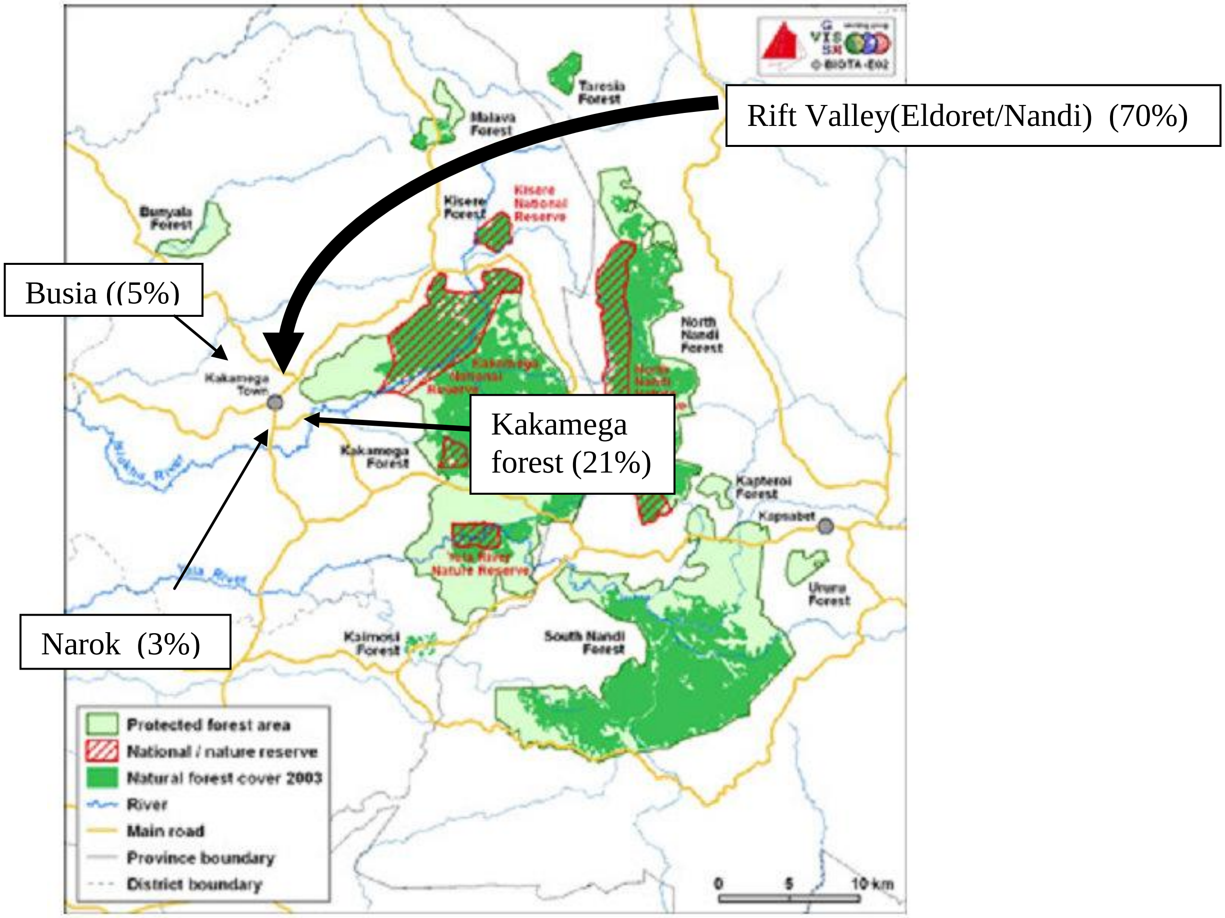


Figure 4-2: Main sources of charcoal traded in Kakamega Municipality
Source; Adapted from BIOTA East Africa (www.biota-africa.org)

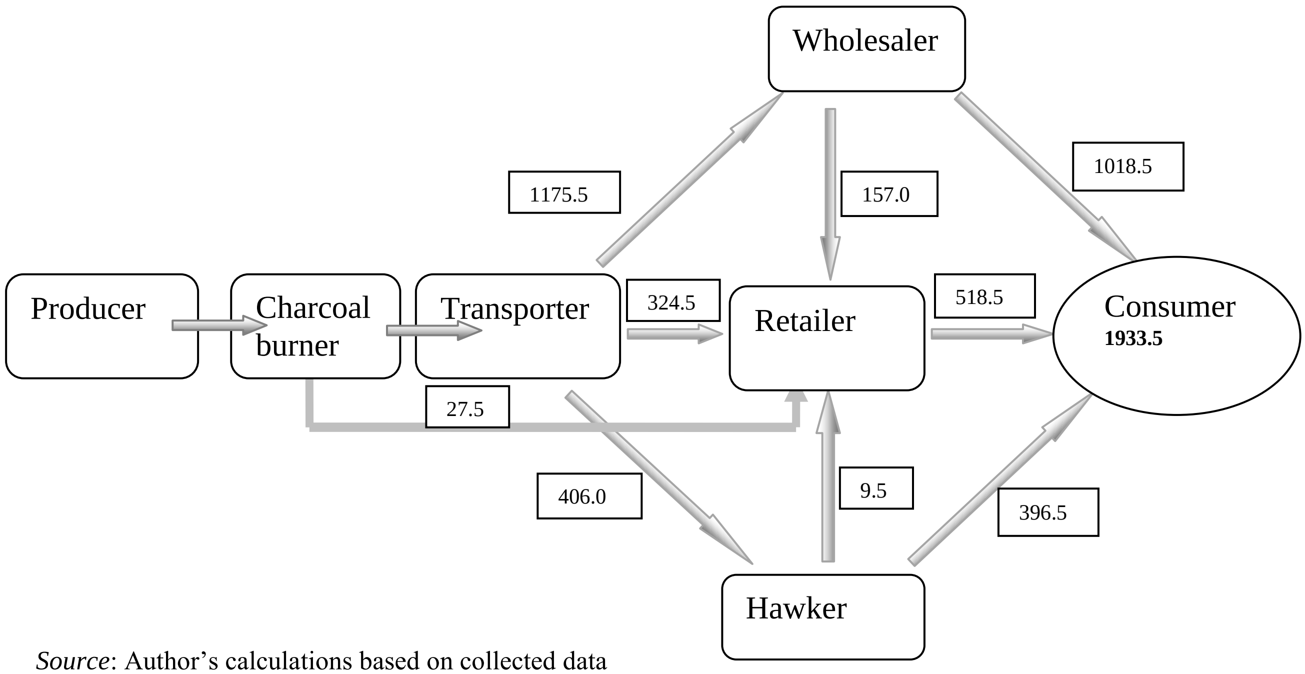
All wholesalers obtain charcoal from the wattle plantations in Eldoret either as their main source (88%) or secondary source (12%). Only two charcoal wholesalers get their primary supplies from Busia and Narok. As shown in Table 1, the retailer category had the most diverse primary source of traded charcoal with 35% buying charcoal delivered from Eldoret, 46% buying from stores operated by wholesalers within Kakamega town, 8% buying charcoal obtained from privately owned trees near Kakamega town, and 11% purchasing their supplies from hawkers. The secondary source of charcoal for each trader refers to where they get their supplies if for any reason they cannot get supplies from their primary sources. All charcoal traded by the hawkers was produced from trees cut in the Kakamega forest.

Table 4-1: Primary and Secondary Source of Charcoal by Sampled Trader Category

	Wholesalers		Retailers		Hawkers
	Main source	Other source	Main Source	Other Sources	Main Sources
Eldoret	14	2	9	3	0
Narok	1	2	0	1	0
Busia	1	0	0	0	0
Stores	0	0	12	3	0
Private trees in Kakamega	0	0	2	2	0
Hawkers	0	0	3	4	0
Nandi	0	3	0	1	0
Kakamega forest	0	0	0	0	19
Total Number of traders reporting	16	7	26	14	19

Source: Author's calculations based on collected data

On average, 1933.5 bags of charcoal are sold to consumers in Kakamega town every month. Of this total, the wholesalers handle 1175.5 bags (60.8%), selling 1175.5 bags directly to consumers and 157 bags to retailers. The retailers sold some 518.5 bags of charcoal of which they purchased 324.5 bags (63%) from the transporters who also sell to the wholesalers, 157 bags (30%) from the stores operated by the wholesalers, 27.5 bags (5%) from charcoal burners from the rural area near Kakamega town and only about 9.5 bags (2%) from the hawkers (Figure 4-3). On average, hawkers carry 406 bags of charcoal per month into Kakamega town, selling 396.5 bags (98%) of this directly to consumers and the rest (9.5 bags) to retailers.



Source: Author's calculations based on collected data

Figure 4-3: Categories of charcoal traders and their linkages in Kakamega town showing number of bags of charcoal traded in one month

All traders were asked the ultimate source of the charcoal that they were selling. To avoid double accounting, the charcoal purchased by retailers from the stores and hawkers was accounted for in the wholesaler and hawkers totals respectively. The average monthly quantity of charcoal in bags obtained from the different sources by each category of traders, either as a primary or secondary source, was estimated from the data collected and presented in Table 4-2. The Rift Valley through Eldoret is the most important source of charcoal for Kakamega town, accounting for about 70% of all traded charcoal (Table 4-2). This charcoal comes mainly from the wattle tree plantations near Eldoret to the north east of Kakamega town and some supplies from the drier Nandi rangelands. This supply is supplemented by charcoal from Busia (4.9%), Narok (2.6 %) and the Kakamega forest. The rural area surrounding Kakamega forest contributes only 1.4% of the charcoal consumed in the town as compared to 21% obtained from the public forest.

Table 4-2: Quantity of charcoal from different sources by trader category

Source	Average number of bags charcoal sold per month by trader category				
	Wholesaler	Retailer	Hawker	Total	% of total
Eldoret	1030.5	324.5	0	1355	70.1
Narok	50	0	0	50	2.6
Busia	95	0	0	95	4.9
Wholesale stores in *Kakamega*	0	157	0	157*	
Private trees Kakamega	0	27.5	0	27.5	1.4
Hawkers	0	9.5	0	9.5*	
Kakamega forest	0	0	406	406	21
Total	1175.5	518.5	406	1933.5**	

** To avoid double counting, this total does not include the amount of charcoal obtained by the retailers from wholesalers and hawkers *

Source: Author's calculations based on collected data

Despite the banning of charcoaling from the Kakamega forest by all management agencies and the deployment of forest guards to enforce the ban (Guthiga, 2007) the forest still remains an important source of traded charcoal for Kakamega town.

To understand the financial gains of charcoal trade to the different trader categories, a gross margin analysis was carried out and the results presented in Table 4-3. For uniformity, the income accruing from charcoal trade for the three categories was based on the bag and not the smaller units. Looking at the gross income from charcoal trade as the difference between the buying price and the selling price per bag, the hawkers make KES 173 per bag as compared to KES 97 and 94 for retailers and wholesalers respectively (Table 4-3). The normal practice of the retailers and hawkers is to break bulk and sell charcoal in smaller units, thus increasing their gross margins. Although the hawkers sell their charcoal at a lower price as compared to the retailers, their gross income per bag is higher since they obtain their charcoal at lower prices (Table 4-3).

Table 4-3: Gross income per bag by trader category

	Hawkers	Retailers	Wholesalers
Buying price/bag	465	591	595
Selling price/bag	638	688	689
Gross income/bag	173	97	94
% Gross margin	37	16	16

Prevailing exchange rate; 1 $ = 80 KES
Source: Author's calculations based on collected data

As earlier indicated, this study did not include the transport costs in the analysis of charcoal trade in Kakamega town since the charcoal is delivered to the traders and the transport costs are included in their purchase price. The gross income for the wholesalers and retailers is therefore net of transport costs. The hawkers however bear the transport costs by carrying charcoal to town and their gross income per bag includes this cost.

4-5 Conclusions

Charcoal trade in Kakamega town is dominated by charcoal sourced from outside the Kakamega region with a significant contribution from the public forest. The town offers a ready market for charcoal from the forest due to its growth and proximity to the forest. Therefore charcoal use and trade in the Kakamega municipality has an impact on the conservation of the Kakamega forest. Despite the fact that charcoaling in the forest is banned, it is a thriving business. The results of this study show that charcoal from the forest enters the supply chain only through the hawkers. They therefore act as an important link between charcoal trade and deforestation and forest degradation. Charcoal producers only cut some specific indigenous trees from the forest (personal discussion with the Assistant Forest Zonal Manager, Kakamega). This selective felling of the preferred hardwood trees for charcoal may lead to biodiversity disturbance. The high profitability of charcoal hawking is a great incentive for the continued deforestation and degradation. Effective conservation measures therefore should involve this group but also consider development of income alternatives for this group as part of the forest stakeholders. From an analysis of the established market flows, cutting off charcoaling from the forest will reduce charcoal supply into Kakamega town by about 21% and will be accompanied by a loss of income to the local community engaged in this trade. Reduced supply may lead to a slight increase in prices, making charcoaling from the forest even more appealing. Under the current trend of charcoal trade, limiting supply from the forest may be compensated by increased supply from the other sources, especially Busia and the Rift Valley through Eldoret if there is enough capacity to meet the increase in demand or through the identification of other charcoal producing areas. Any policy that cuts off supply from the Rift Valley could have detrimental effects on Kakamega forest.

5. Conclusions and Policy Implications

5-1 Recap of the Research Problem and Objectives of the Study

The importance of Kakamega forest in western Kenya in terms of its biodiversity richness and support to rural household livelihoods has been studied and documented. Although deforestation through logging has been largely contained, the high population density of the local communities coupled with high poverty levels has continued to put the forest under a high threat of degradation. This is likely to put the continued realization of the above mentioned benefits at risk of being lost.

Research has also established the importance of the support and participation of local communities in the success forest conservation programs. In order to ensure the continued recovery of the forest and local community benefits, it is important to understand the current households' energy use patterns and their impact on the forest resources. Different studies on household fuel consumption have shown the importance of household socio-economic conditions and other attributes in determining the types and sources of fuels used. The dependency on natural resources has been linked to poverty, and poorer households are expected to rely more on the forest firewood for use and sale. Therefore, understanding the nature of forest dependency by the local communities could provide insights into how forest management policies can be made responsive to the needs of the people living next to the forest, who are important partners in forest conservation.

Against this background, this study set out to investigate the determinants of the choice of fuels by the households living next to Kakamega forest and estimate the demand elasticities for the major fuels used. It further studies the link between the forest and charcoal trade in Kakamega town, found on the edge of the forest; through an analysis of the charcoal supply chain. The major findings are discussed in the section 5-2.

5-2 A discussion of the major findings

5-2.1 Determinants of household choice of fuel use

The households living next to Kakamega forest have the option of exclusively using biomass energy or combining this with other more advanced fuels for cooking. There is evidence of fuel stacking as households do not abandon firewood as they adopt other more advanced fuels. Results show that some household owning a particular stove were not using the corresponding fuel over the time of data collection. This rather surprising finding confirms results of other studies that fuel stacking is not unidirectional and households will keep changing their fuel mix depending on the household needs and situation at any given time. The use of non biomass fuels is however low. Only 4.2 % of the sampled households incorporate either kerosene or LPG in their fuel mix. Therefore, in the short run the use of more advanced fuels to reduce pressure on the common pool forest resource is currently not a viable option.

The public forest is an important source of biomass energy for the local community. Poverty decreases the likelihood of households' adoption of non biomass fuels. At the same time, poor households are more likely to collect firewood from the public forest and rely less on their own production or purchase from the market. Household attributes related to poverty, for example, low human capital (education level of household head related access to salaried employment for both household head and spouse) and low asset ownership (including land and cooking technology) increase the dependency on the forest for energy. Although the poor depend more, on the forest for fuel, their use when done within the rules of the management agencies does not adversely affect the forest because they only collect the fallen dead branches for firewood.

5-2.2 Household energy demand

The current pattern of household expenditure show that energy is an essential good and a 10% increase in household expenditure will result in a 12% increase in the expenditure on energy. However, this allocation will be differential among the different fuel options, with charcoal and LPG likely to receive more allocation than firewood and kerosene. The demand for firewood is neither responsive to changes in its own price and nor the prices of the other fuels. Given that over 60% of all energy expenditure is used on firewood, households in Kakamega have no real alternatives to the use of firewood, and substitution may be within the sources of firewood. The forest supplies about 21% of the charcoal consumed by the local community. Therefore, a higher consumption of charcoal will lead to more forest degradation. On the other hand, policies that lead to an increase in the price of charcoal will lead to a lower consumption thus are beneficial to forest conservation. For example, better protection of the forest against charcoaling may reduce the supply to the local residents and increase the price, thus acting as an incentive for households to use other energy sources which are more forest conserving. This benefit may be lost if more protection is accompanied by increasing corruption by agents of the KFS and KWS. The use of LPG, the most advanced fuel in Kakamega is still low, and is currently not a viable alternative to charcoal. In the short run, a sustainable production of firewood from the different sources to ensure adequate supplies may enhance forest conservation, since the demand for charcoal will fall with a decline in the price of firewood (and a resulting higher consumption of firewood

5-2.3 The role of traders in the charcoal supply chain in Kakamega town and the link to forest conservation

Charcoal trade in Kakamega town is dominated by charcoal sourced from outside the Kakamega. The local production of charcoal is predominantly through burning of forest trees. The short distance to Kakamega town coupled with its fast growth rate offer a ready market for charcoal from the forest. Therefore charcoal use and trade in the Kakamega municipality has an impact on the conservation of the Kakamega forest. In spite of the fact that charcoaling in the forest is banned, it is a thriving business within the local community. Charcoal production from the forest only targets specific hard wood indigenous trees. This selective felling of the preferred hardwood trees for charcoal may lead to biodiversity disturbance. Every time a hawker sells a bag of charcoal, they earn an equivalent to two man-days of farm wages in the region, although it takes only about three hours to dispose the charcoal. The high profitability of charcoal hawking is a great incentive for the continued deforestation and degradation. The share of Kakamega forest in the charcoal trade in the region is relatively small and tends to benefit mainly the hawkers and charcoal burners who come from the local community. Cutting off charcoaling from the forest into Kakamega town will reduce supply by about 20% and will be accompanied by a loss of income to the local community engaged in this trade. In the short run, this shortfall in supply can be compensated by increased supply from the other sources, especially Busia and the Rift Valley through Eldoret if there is enough capacity to meet the increase in demand or through the identification of other charcoal producing areas. Reduced supply may lead to a slight increase in prices, making charcoaling from the forest even more appealing. Any policy that cuts off supply from the Rift Valley could have detrimental effects on Kakamega forest. Effective conservation measures therefore should target this group but also consider development of income alternatives for this group as part of the forest stakeholders

5.3 Policy Recommendations

In order to benefit forest conservation while safe guarding the welfare of the local communities, this study derives the following policy recommendations;

5.3.1 Forest protection

The current forest protection practice is not very effective in conserving the forest given the amount of charcoal obtained from the forest for use by the local community or sale in Kakamega town. Improving the guarding of the forest against illegal extraction can reduce the cutting of trees for charcoal. The effectiveness of this would be reduced by any corruption practices by the management agents. An alternative would be to ban any extractive use of the forest the local community as is practiced by KWS. Indeed, the better recovery of the areas under KWS encourages this recommendation. This would however, have some externalities in the expected higher cost of policing increased and reduced energy access for the poor who depend more on the forest for firewood. Effective protection measures have to go hand in hand with the creation of opportunities for some forest benefit transfers to the local community and especially poor.

5.3.2 Reduction of forest dependency

In the short run, the local communities living next to Kakamega forest are expected to continue using biomass fuels. However, the dependency on the forest for firewood can be reduced through

The development and encouragement of on farm tree production systems in the area around the forest. Given the generally low farm holdings in Kakamega, it may not be viable for households to set aside part of their farm land exclusively for trees. Production systems that incorporate trees with crops can be extended to the farmers. Although this would directly benefit the households with larger land holdings, an increase in the supply of firewood in the region would lead to a fall in the prices, thus making it more affordable to all.

5.3.3. Increasing access to non biomass fuels

- Poverty is a major driver to forest reliance for fuel wood and poor adoption of non biomass fuels. Developing strategies that offer alternative livelihood options for the poor would increase their access to non biomass fuels. In the long term, investments in education and employment opportunities for especially for women in Kakamega will lead to more use of LPG and charcoal. Unlike firewood, charcoal can also be obtained from other regions and therefore an increase in its use may not necessarily be detrimental to the forest.
- The government can use market instruments targeting specific marketed fuels. This can be achieved through the lowering of taxes on LPG and kerosene. An alternative would be to subsidize the non biomass energy (including the relevant technology) to make charcoal non competitive.

5.4 Study limitations and implications for further study

Household energy use in this study was based on collected cross section data thus relying on the memory of the respondents in estimating monthly energy use levels and prices. This has the potential of having errors in the estimation of historical consumption levels since the respondents do not keep records on their energy use. A related limitation was the risk that households reported no consumption of some fuels that they had temporary suspended using. It is therefore recommended that future research be carried out using panel data to collect energy use information on the same households over a longer period of time.

This study managed to develop a part of the charcoal supply chain for Kakamega forest. This was due to the absence of detailed data on all stakeholders along the supply chain from tree production to charcoal consumption. The study of the link between charcoal trade and forest conservation will benefit from future research that includes all levels of the supply chain including the socioeconomic attributes of producers (especially the forest charcoal producers), traders and consumers.

References

Amemiya. T. (1974), 'Multivariate Regression and Simultaneous Equation Models When the Dependent Variables Are Truncated Normal', *Econometrica,* 42, 999-1012.

Arnold, J.E.M., Köhlin, G. and Persson, R., (2006) 'Woodfuels, livelihoods, and policy interventions: changing perspectives', *World Development*. 34(3): 596-611.

Bajracharya, D. (1983) 'Deforestation in the Food/fuel Context: Historical and Political Perspectives for Nepal.' Mountain Research and Development vol.3, No.3 (1983), pp 227-240

Börner, J., Mburu, J., Guthiga, P. and Wambua, S. (2009), 'Assessing opportunity costs of conservation: Ingredients for protected area management in the Kakamega Forest, Western Kenya', *Forest Policy and Economics* 11, 459–467

Capellari, L. and Jenkins,S (2003) 'Multivariate probit regression using simulated maximum likelihood', *The Stata Journal*, Number 3, pp 278-294.

CHAPOSA (2002), 'Charcoal Potential in Southern Africa', Final Report Stockholm Environment Institute

Davis. M., (1998) 'Rural household energy consumption: the effects of access to electricity-evidence from South Africa', *Energy Policy*, Vol 26, (3), Elsevier, 1998, pp 207-217.

Deaton, A,. and Muellbauer. J. (1980), 'An Almost Ideal Demand System', *The American Economic Review*, 70, 312-326.

Deaton, A., and Irish, M. (1984), 'Statistical Models for Zero Expenditures in Households Budgets', *Journal of Public Economics*, 23, 59-80.

Dewees, (1989), 'The Woodfuel Crisis Reconsidered: Observations on the Dynamics of Abundance and Scarcity' World Development, vol.17, No. 8, (1989) pp 1159-1172.

Emerton, L. (1996), 'Valuing the Subsistence Use of Forest Products in Oldony Orok Forest, Kenya', Rural Development Forestry Network Paper19e ODI, London

Fan, S., Wailes, E.J and Cramer, G.L. (1995), 'Household demand in rural China: A two-stage LES- AIDS model', *Amer.J. Agr. Econ*, 77, 1995, pp 54-62.

Fisher, M. (2004), 'Household welfare and forest dependence in Southern Malawi', *Environment and Development Economics* 9: 135–154

Gathaara, N.G. (1999), 'Aerial Survey of the destruction of Mount Kenya, Imenti and Ngare Ndare Forest Reserve'.

Gebreegziabher, Z. (2007), 'Household fuel consumption and resource use in rural-urban Ethiopia', PhD Thesis Wageningen University ISBN: 978-90-8504-745-2.

Geller, S., McConnell, R. and Wanyiri, J. (2007), 'Linking National Forest Programmes and Poverty Reduction Strategies', Forestry Department, FAO, Rome

Gensch, D. H. and Recker, W. (1979), 'The Multinomial, Multiattribute Logit Choice Model', *Journal of Marketing Research*, Vol. 16, No. 1, pp. 124-132.

Government of Kenya (2007), 'Sessional Paper No 1 0f 2007 on forest policy' Government Printer, Nairobi

Gudimenda, H. and Köklin, G. (2008), 'Fuel demand elasticities for energy and environmental policies: Indian sample survey evidence', *Energy Economics* 30 Issue 2 pages 517-546

Greene, W. H. (2003), 'Econometric Analysis', 5th ed. Upper Saddle River, New Jersey: Prentice–Hall.

GTZ (2007), 'Value Links Manual – The Methodology of Value Chain Promotion', Eschborn, Germany

Gupta, G. and Köhlin, G. (2006), 'Preferences for domestic fuel: Analysis with socio-economic factors and rankings in Kolkata, India', *Ecological Economics*, 57/1: 107-121.

Guthiga, P.M., Mburu, J. and Holm-Mueller K. (2008),'Factors Influencing Local Communities' Satisfaction Levels with Different Forest Management Approaches of Kakamega Forest, Kenya', *Environmental Management* (2008) 41:696–706.

Guthiga, Paul (2007), 'Economic Assessment of Different Management Approaches of Kakamega Forest in Kenya: Cost-benefit and Local Community Satisfaction Analysis', PhD Dissertation, University of Bonn, Germany http://hss.ulb.uni-bonn.de/diss_online.

Heinen D. and Cathy R. Wessells (1990), 'Demand Systems with Microdata: A Censored Approach', *Journal of Business and Economics*, vol. 8 No. 3 (July 1990), pp. 365-371.

Heltberg, R. (2001), 'Determinants and impacts of local institutions for common resource management', *Environment and Development Economics* 6: 183-208

Heltberg, R., Arndt, C., Sekhar, N.U., (2000), 'Fuelwood consumption and forest degradation: a household model for domestic energy substitution in rural India', *Land Economics* 76 (2), 213–232.

Heltberg, R., (2004), 'Fuel switching: evidence from eight developing countries', *Energy Economics* 26, 869–887.

Heltberg, R. (2005), 'Factors determining household fuel choice in Guatemala', *Environment and Development Economics* 10: 337-361

Hofstad, O., (1997), 'Woodland deforestation by charcoal supply to Dar es Salaam', *Journal of Environmental Economics and Management*, vol. 33, pp. 17-32

International Energy Agency (IEA) (2006), '*World Energy Outlook 2006',* OECD/IEA, Paris

Kagombe, J.K. and Gitonga, J. (2005), **'**Plantation establishment system in Kenya – the shamba system case study', Kenya Forest Research Institute and Forest Department, September 2005

Keen, M. (1986), 'Zero Expenditures and the Estimation of Engel Curves', *Journal of Applied Econometrics*, 1, 277-286.

Khan S.R., and S.R. Khan (2009), 'Assessing poverty–deforestation links: Evidence from Swat, Pakistan', *Ecological Economics* 68, pp 2607–2618.

KIPPRA (2010), 'A comprehensive Study and Analysis on Energy Consumption Patterns in Kenya', A synopsis of final Report submitted to Energy Regulatory Commission, Nairobi, Kenya.

KFMP, (2004) Kenya Forestry Master Plan, Ministry of Environment and Natural Resources, Nairobi

KFS (2009), 'Kenya Forest Service Strategic Plan 2009/10-2013/14', Kenya Forest Service, Nairobi, Kenya.

Kenya National Bureau of Statistics (2007), 'Basic Report on Well-Being in Kenya, Who and Where are the Poor?' Regal Press Kenya, Nairobi, Kenya

Kenya National Bureau of Statistics (2011), 'Inflation trends from 1961 to present', http://www.knbs.or.ke/consumerpriceindex.php (accessed Sept 3rd 2011).

Kokwaro, J.O., (1988), ‘Conservation Status of the Kakamega Forest in Kenya. The Easternmost Relic of the Equatorial Rain Forests of Africa’, *Monographs in Systematic Botany* (Missouri Botanical Garden), 25, pp. 471-489.

Kolstad, C. D. (2000), ‘Environmental Economics’ Oxford University Press, ISBN 0-19-511954-1

Lambrechts, C., Woodley, B., Church, C., Gachanja, M. (2003), ‘Aerial Survey of the Destruction of the Aberdare Range Forests’, UNEP, KWS, Rhino Ark, KFWG

Lambrechts, C., Woodley, D., Litoroh, M., Kamwara, P. (2007), ‘Aerial Monitoring of Forest Boundaries’, KWS; KFS, Nairobi, Kenya.

Lee. L.-F. (1978), ‘Simultaneous Equations Models with Discrete and Censored Dependent Variables’, in *Structural Analysis of Discrete Data with Econometric Applications,* eds. P. Manski and D. McFadden Cambridge, MA: MIT Press. pp. 346-364.

Ludeki, J.V., G.M. Wamukoya and D. Walubengo (2006), ‘Environmental Management in Kenya: A Framework for Sustainable Forest Management in Kenya – Understanding the New Forest Policy and Forests Act, 2005’

Lung, T. and Schaab, G. (2004), ‘Change –Detection in Western Kenya – The Documentation of fragmentation and disturbance for Kakamega Forest and associated forest areas by means of remotely- sensed imagery’, In ISPRS Archives, Vol. XXXV, Part B (CD Rom), Proceedings of the ISPRS XXth Congress, 12-23 July 2004, Istanbul.

Mackenzie, J. and Weaver, J.F., (1986), ‘A Household Production Analysis of Fuelwood Demand in Rhode Island’, University of Rhode Island Agricultural Experiment Station (AES), Publication No 2264

Malimbwi, R. E., S. Misana, G. Monela, G. Jambiya and J. Nduwamungu (2001), ‘Charcoal potential in southern Africa’, Sokoine University of Agriculture, Morogoro, Tanzania

Mander, J.J., and Quinn N.W., (1995), ‘Biomass Assessment National Overview Report’, Department of Minerals and Energy 1995

Manibog, F.R. (1984), ‘Improved Cooking Stoves in Developing Countries: Problems and Opportunities’, *Ann. Rev. Energy* 1984. 9.' 199-227.

Masera, O.R., Saatkamp, S.D., Kammen, D.M., (2000), ‘From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model’, *World Development* 28 (12), 2083–2103.

Müller, D. and Mburu, J.(2009), ‘Forecasting hotspots of forest clearing in Kakamega Forest, Western Kenya’ *Forest Ecology and Management* 257, 968–977

Mekonnen, A. (1999), ‘Rural Household Biomass Fuel Production and Consumption in Ethiopia: A case study’, *Journal of Forest Economics* 5(1): 69-97.

Mekonnen, A. and G. Köhlin (2008), ‘Biomass Fuel Consumption and Dung Use as Manure Evidence from Rural Households in the Amhara Region of Ethiopia’, Environment for Development discussion Series, EfD DP 08-17.

Mekonnen, A. and G. Köhlin (2009), ‘Determinants of Household Fuel Choice in Major Cities in Ethiopia’, Working Papers in Economics No.399 School of Business, Economics and Law at University of Gothenburg. ISSN 1403-2465

Michalek, J, and Keyzer, M.A., (1991), ‘Estimation of a two-stage LES-AIDS consumer system for eight EC countries’, Euro. *R. Agr. Eco.* 19 (1992) 147-163.

Ministry of Energy, Kenya (2002), ‘Study on Kenya’s energy supply and policy strategy for households, small-scale industries and services establishments, final draft report’, Ministry of Energy, Nairobi, Kenya.

Mishra A., (2008), ‘Determinants of Fuelwood Use in Rural Orissa: Implications for Energy Transition’, (SANDEE Working Papers, ISSN 1893-1891; 2008- WP 37).

Modi, V., McDade, S., Lallement, D. and Saghir, J. (2006), ‘Energy and the Millennium Development Goals’, New York: Energy Sector Management Assistance Programme, United Nations Development Programme, UN Millennium Project, and World Bank.

Mitchell N., (2004), ‘The exploitation and disturbance history of Kakamega forest, Western Kenya’, Bleher, B. & Dalitz, H. (eds) BIOTA East Report No.1.-Biefelder Okologische Betrage 20:1-77

Mugenda, O. and Mugenda, A. (1999), ‘Research Methods: Quantitative and Qualitative Approaches’, Act Press, Nairobi, Kenya ISBN 9966-41-107-0

Mugo, F. and Walubengo, D. (2002), '*Woodfuel policy and legislation in eastern and southern Africa',* Proceedings of a Regional Workshop held at the World Agroforestry Centre, Nairobi, Kenya, March 4-6, 2002. RELMA, ICRAF. p9.

Mugo, F. and Poulstrup, E. (2003), 'Assessment of potential approaches to charcoal as a sustainable source of income in the arid and semi-arid lands of Kenya', Danida and RELMA report

Mugo, F. and C. Ong. (2006), 'Lessons of eastern Africa's unsustainable charcoal trade', ICRAF Working Paper no. 20. Nairobi, Kenya. World Agroforestry Centre

Murphy, J. T. (2001), 'Making the energy transition in rural East Africa: Is leapfrogging an alternative?', *Technological Forecasting & Social Change* 68 (2001) 173–193.

Mutimba, S., and Barasa, M.; (2005), 'National Charcoal Survey: Exploring the potential for a sustainable charcoal industry in Kenya', Energy for Sustainable Development Africa; Nairobi.

Mwampamba, T.H., (2007), 'Has the wood-fuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability', Energy *Policy*, Vol 35, Issue 8, pp. 4221-4234

Ouma Kwamboka O. (2005), 'Environmental Protection, Ecotourism and Rural Livelihoods: The Case of Kakamega Forest Region, Kenya', PhD Dissertation, University Of Salzburg, Austria

Palmer, C. and MacGregor, J. (2009), 'Fuel wood scarcity, energy substitution and rural livelihoods in Namimbia', *Environment and Development Economics* Vol. 14 (06) pages 693-715

Peggy, P et al (2004), 'Agriculture around the protected forest of Kakamega. Dynamics under surveillance', *Cuheirs d'etudes et de recherché francophone/Agriculture Number13 Volume6, pp473-479, Nov-Dec2004*.http://www.john-liber-eurotext.fr/en/aide/index.mhtlm.

Peng, W., Hisham, Z. and Pan, J. (2010), 'Household level fuel switching in rural Hubei', *Energy for Sustainable Development* 14, 238–244

Pereira, C., R. Brouwer, M. Monjane and M. Falcao (2001), '*Charcoal potential in Southern Africa*', University Eduardo Mondlane, Mozambique.

Philips, L. (1983), 'Applied Consumption Analysis', Amsterdam, North- Holland.

Poi, B.P. (2002), 'Demand System Estimation', *The Stata Journal* Number 4, pp 403-410.

Pyo, S.S., Uyral, M. and McLellan, R.W. (1991), ‘A linear expenditure model for tourism demand’, *Annals of Tourism Research*, Vol 18 pp 443-454, 1991

Ransom, M. R. (1987), ‘A Comment on Consumer Demand System with Binding Non-negativity Constraints’, *Journal of Econometrics*, 34, 355-359

Reardon, T. and Vosti, S. A. (1995), ‘Links between Rural Poverty and the Environment in Developing Countries: Asset Categories and Investment Poverty’, *World Development* Vol. 23, No. 9, pp. 1495-1506

Republic of Kenya (2009), ‘Statistical Abstract – 2009’, Kenya National Bureau of Statistics, Nairobi, Kenya

Republic of Uganda (2002), ‘National Biomass Study. Draft Technical Report, Forest Department, Kampala, Uganda

Schaab, G., B. Khayota, G. Eilu, and J.W. Wägele (Eds.) (2010), ‘The BIOTA East Africa atlas; Rainforest change over time’, Karlsruhe University of Applied Sciences, Germany

Schlag, N and F. Zuzarte (2008), ‘Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature’, *An SEI Working Paper* Stockholm Environment Institute, Sweden.

Seidel, A. (2008), ‘Charcoal in Africa: Importance, Problems and Possible Solution Strategies’, Household Energy Programme – HERA, GTZ, Eschborn, Germany.

Sene, E.H. (2000), ‘Forests and food security in Africa; the place of forests in FAO’s special food security’, *Unisylva (English Ed.)* 51 (202) 13-18

Sepp, S. (2008), ‘Analysis of charcoal value chains - general considerations’, In Proceedings of the Charcoal and communities in Africa, Maputo, Mozambique

Sikei, G. Mburu, J. and Lagat, J. (2008), ‘Household labour allocation to forest extraction and other activities in areas adjacent to tropical forests: The case of Kakamega forest, Western Kenya *Int. J. Environment, Workplace and Employment*, Vol. 4, No. 1

Shonkwiler, J.S., and Yen, S.T (1999), ‘Two-Step Estimation of a Censored System of Equations’, *American Journal of Agricultural Economics* 81: 972-982

Song, X. and Lee, S. (2005), 'A Multivariate Probit Latent Variable Model for Analyzing Dichotomous Responses', *Statistica Sinica* 15, 645-664.

Tabet, A. (2007), 'Bayesian Inference in the Multivariate Probit Model- Estimation of the Correlation Matrix', Master of Science Thesis, The University of British Columbia, USA.

Theuri, D.K (2002), 'Woodfuel policy and legislation in Kenya', In: Mugo, F.W. and D. Walubengo (eds). 2002. *Woodfuel policy and legislation in eastern and southern Africa.* Proceedings of a Regional Workshop held at the World Agroforestry Centre, Nairobi, Kenya, March 4-6, 2002. RELMA, ICRAF.

Tomaselli, I (2007), 'Forests and energy in developing countries', Forests and Energy Working Paper No. 2; FAO, Rome

United Nations (2008), 'The Millennium Development Goals Report', United Nations, New York, 2008

Wambua, S. (2008), 'An economic analysis of forest extraction along a disturbance gradient and its linkage to community livelihoods: the case of Kakamega rainforest', Unpublished MSc thesis, University of Nairobi, Kenya.

Wandago, B. (2002), 'Tropical Secondary Forest Management in Africa; Reality and Perspectives', Kenya Country Paper, FAO

World Resources Institute (2005), 'What is driving the Charcoal Industry into a Dead End?', Eastern and Central African Policy Brief No. 3

Appendix

Appendix 1: Linear Expenditure System Estimation Results

constraint define 1
[annualexpfood]supernumarary3+[expenergy]supernumarary3+[expfarming]supernumarary3+[expschool
]super numarary3+[otherexps]supernumarary3=1

.

. sureg (annualexpfood subsisfood3 supernumarary3) (expenergy subsisenergy3 supernumarary3) (expfarming subsisfarming3 supernumarary3) (expschool subsisschooling3 supernumarary3) (otherexps subsisothers3 supernumarary3), const(1)

Seemingly Unrelated regression

Equation	Obs	Parms	RMSE	R-sq	chi2	P
annualexpf~d	285	2	23903.16	0.38	388.60	0
expenergy	285	2	6531.67	0.27	180.00	0
expfarming	285	2	8858.66	0.24	163.42	0
expschool	285	2	16371.85	0.45	356.31	0
otherexps	285	2	13705.39	0.46	386.88	0

	Coef.	Std. Err.	Z	P>z	[95% Conf. Interval]	
annualexpf~d						
subsisfood3	0.614	0.091	6.760	0.000	0.436	0.792
supernumar~3	0.354	0.019	18.740	0.000	0.317	0.391
_cons	25007.600	4627.495	5.400	0.000	15937.880	34077.330
expenergy						
subsisener~3	0.924	0.239	3.870	0.000	0.456	1.392
supernumar~3	0.077	0.006	12.980	0.000	0.066	0.089
_cons	-659.402	1396.788	-0.470	0.637	-3397.056	2078.253
expfarming						
subsisfarm~3	0.921	0.317	2.900	0.004	0.299	1.543
supernumar~3	0.099	0.008	12.550	0.000	0.083	0.114
_cons	-1814.210	1829.861	-0.990	0.321	-5400.670	1772.251
expschool						
subsisscho~3	1.921	0.426	4.510	0.000	1.086	2.757
supernumar~3	0.260	0.014	18.480	0.000	0.233	0.288
_cons	-16277.080	3267.950	-4.980	0.000	-22682.140	-9872.015
otherexps						
subsisothe~3	1.484	0.175	8.490	0.000	1.141	1.826
supernumar~3	0.209	0.012	18.030	0.000	0.187	0.232
_cons	-10006.210	2734.901	-3.660	0.000	-15366.520	-4645.907

Appendix 2: AIDS Model Parameter Estimates

Equation	RMSE	"R-sq"	chi2	P
swchar	1735269	0.2902	999.57	0
swkero	0.173458	0.1532	153.7	0
swlpg	0.100576	0.0299	502.58	0

	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
swchar						
plnchar1	0.010117	0.022802	0.44	0.657	-0.03457	0.054808
plnkero2	0.002964	0.008021	0.37	0.712	-0.01276	0.018684
plnlpg3	-0.00342	0.009739	-0.35	0.725	-0.02251	0.015665
plnfw4	-0.00966	0.024643	-0.39	0.695	-0.05796	0.038642
lnexpenergy	0.085554	0.068996	1.24	0.215	-0.04968	0.220785
hhsize	-0.02582	0.014684	-1.76	0.079	-0.0546	0.002963
EducHHM1	-0.00463	0.008747	-0.53	0.596	-0.02177	0.012511
Sourceincw~e	-0.09379	0.061746	-1.52	0.129	-0.21481	0.027226
impxswchar	-0.41999	0.121403	-3.46	0.001	-0.65793	-0.18204
_cons	-0.26364	0.864446	-0.3	0.76	-1.95792	1.430647
swkero						
plnchar1	0.002964	0.008021	0.37	0.712	-0.01276	0.018684
plnkero2	0.004822	0.00592	0.81	0.415	-0.00678	0.016425
plnlpg3	-0.00053	0.003689	-0.14	0.885	-0.00776	0.006695
plnfw4	-0.00725	0.009615	-0.75	0.451	-0.0261	0.011595
lnexpenergy	-0.01357	0.036823	-0.37	0.712	-0.08574	0.058598
hhsize	-8.8E-05	0.008633	-0.01	0.992	-0.01701	0.016834
EducHHM1	-0.00166	0.005408	-0.31	0.759	-0.01226	0.00894
Sourceincw~e	0.017595	0.029157	0.6	0.546	-0.03955	0.074742
impxswkero	-0.08155	0.046765	-1.74	0.081	-0.17321	0.01011
_cons	0.433741	0.434764	1	0.318	-0.41838	1.285862
swlpg						
plnchar1	-0.00342	0.009739	-0.35	0.725	-0.02251	0.015665
plnkero2	-0.00053	0.003689	-0.14	0.885	-0.00776	0.006695
plnlpg3	-0.00549	0.027575	-0.2	0.842	-0.05953	0.04856
plnfw4	0.009443	0.025107	0.38	0.707	-0.03977	0.058652
lnexpenergy	0.07927	0.044214	1.79	0.073	-0.00739	0.165928
hhsize	-0.01768	0.008325	-2.12	0.034	-0.034	-0.00137
EducHHM1	0.0098	0.00482	2.03	0.042	0.000354	0.019247
Sourceincw~e	0.032852	0.022471	1.46	0.144	-0.01119	0.076894
mgtagency	-1.0304	0.553438	-1.86	0.063	-2.11512	0.054316
impxswlpg	0.010874	0.010924	1	0.32	-0.01054	0.032286
_cons	(omitted)					

Marshallian [4,4]

	Plnfw	plnchar	plnkero	Plnlpg
swfw	-0.914	0.000	0.019	0.016
swchar	-0.405	-0.989	-0.115	-0.030
swkero	-0.017	0.048	-0.977	-0.036
swlpg	0.646	-0.942	-0.614	-2.089

Hicks[4,4]

	Plnfw	plnchar	plnkero	Plnlpg
swfw	-0.376	0.111	0.246	0.021
swchar	0.535	-0.793	0.280	-0.022
swkero	0.583	0.138	-0.725	0.003
swlpg	2.469	-0.546	0.151	-2.074

Expenditure	
swfw	0.834
swchar	1.854
swkero	0.972
swlpg	1.045

where,

swfw is the share of energy budget spent on firewood

swchar is the share of energy budget spent on charcoal

swkero is the share of energy budget spent on kerosene

swlpg is the share of energy budget spent on LPG

plnfw, plnchar, plnkero and plnlpg are the log of the price of firewood, charcoal, kerosene and LPG respectively

lnexpenergy is the log of estimated household annual expenditure on fuel (all energy types and sources)

hhsize is the household size

EducHHM1 is the education level of household head in completed years of formal education
Sourceincwife is whether the oldest female household member works away from home (Yes/No)

Mgtagency is a proxy for legal access to the forest (whether the management agency allows legal collection of firewood (Yes/No)