INDOOR AIR POLLUTION FROM HOUSEHOLD ENERGY USE IN KENYA: ANALYSIS OF THE HEALTH OUTCOMES AND ABATEMENT EFFORTS

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as university supervisors.

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Professor L. P. Mureithi

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LIST OF ABBREVIATIONS

ARI	Acute Respiratory Infection
ALRI	Acute Lower Respiratory Infection
CEPA	California Environmental Protection Authority
CMP	Conditional Mixed Process
COPD	Chronic Obstructive Pulmonary Disease
CPCB	Central Pollution Control Board
DALYs	Disability Adjusted Life Year
EPA	Environmental Protection Agency
GDC	Geothermal Development Company
GoK	Government of Kenya
IAP	Indoor Air Pollution
IPCC	Intergovernmental Panel on Climate Change
ITDG	Intermediate Technology Development Group
KENGEN	Kenya Electricity Generating Company
KDHS	Kenya Demographic and Health Survey
KIHBS	Kenya Integrated Household Budget Survey
KWh	Kilowatts per hour
LCPDP	Least Cost Power Development Plan
LPG	Liquefied Petroleum Gas
LMCP	Last Mile Connectivity Project
LRI	Lower Respiratory Infections
MW	Mega Watts
M3	Cubic Metres
PCA	Principal Component Analysis
PM	Particulate Mater
SWER	Single Wire Earthing Return
URI	Upper Respiratory Infection
US$	United States Dollar
WHO	World Health Organisation
W/M2	Watt per square Meter

ABSTRACT

This thesis investigates the health outcomes of indoor air pollution from household energy use and demand for IAP abatement interventions. It has four objectives; first it determines the factors that influence the levels of indoor air pollution from household energy use, second it investigates the association between indoor air pollution form household energy use and ill health, third it estimates the health cost and productivity effects of household energy use and lastly it analyses the demand for indoor air pollution abatement interventions.

The study uses data from the Kenya Integrated Household Budget Survey conducted by the Government of Kenya in 2005/06. Different approaches, including; the Conditional Mixed Process ordered probit, Multivariate regression and the Heckman sample selection models are used to correct for endogeneity, address unobserved heterogeneity and sample selection bias. The study also uses the cost of illness approach to estimate the health cost and productivity effects of household energy use. The results indicate that education, income and type of dwelling are the key factors that influence the level of indoor air pollution. In particular, households with low levels of income and those living in manyatta type of dwellings are likely to encounter high levels of indoor air pollution. The findings indicate that household members using firewood, kerosene and traditional stove appliances are likely to manifest upper respiratory infection, lower respiratory infection and eyes illness. In addition, the health cost for lower respiratory illness and eyes illness are found to be higher than for upper respiratory illness.

Consequently the results show that; the geographical location, type of household energy used, cooking place/area, type of dwelling, income and whether households had a chimney or not are key factors that determines the demand for indoor air pollution abatement interventions. In order to reduce indoor air pollution and improve health outcomes, it is important the government introduces policies that target reduction of indoor air pollution from household energy use. Though such policies may include enhancing the use of modern energy, improved stoves and chimney as indoor air

pollution abatement interventions; there is need to focus on income, education, age, and residential location.

Chapter 1 : **INTRODUCTION**

1.1 Background

Energy is important in human life because it provides services such as cooking, heating, lighting, and refrigeration among other productive activities. Reliance on energy forms such as biomass, charcoal, and kerosene for cooking, coupled with inefficient fuel stove technologies produces smoke, soot and other toxic chemicals which contribute to indoor air pollution (IAP). Exposure to IAP is potentially significant to mothers who spend time cooking, accompanied by their children (Warwick and Doig, 2004). Inhaling indoor smoke is a major cause of respiratory diseases among other infections[1].

World Health Organisation (WHO) reports that seven million people die each year from indoor smoke produced by inefficient cooking fires (the deaths from IAP are more than twice as many as those from malaria) (WHO, 2014). At the same time Gadgil, Sosler and Stein (2013) report that half the world population cooks on smoky open fires, which not only cause deaths but also contribute to climate change. It is estimated that health effects from indoor smoke are equivalent to smoking two packs of cigarettes daily (WHO, 2006). In relation to the environment, about 1 billion metric tonnes of carbon dioxide from cooking fires are released into the atmosphere each year (Yadav, 2009). The use of

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[1] IAP has adverse effects on health including the irritation of mucous membranes (eyes, nose and throat infections), cough, wheeze and chest tightness, increased airway responsiveness to allergens, increased incidence of acute respiratory infection such as "cold", pneumonia, otitis media, trachea bronchitis, and exacerbation of asthma infection. Chronic health effects are long-term exposures that decrease lung growth, cause impairment of pulmonary function, and increase susceptibility to chronic obstructive lung diseases, including asthma (see WHO, 2006 and Smith, Samet, Romieu, & Bruce, 2000).

either clean or dirty household energy, adversely affects human health (Yan, 2010). Although the energy ladder model[2] identifies Liquefied Petroleum Gas (LPG) as one of the key clean forms of household energy, it is considered the second worst combustion pollutant after tobacco smoking in developed countries (Samet and Spengler, 1991). In addition to having adverse impacts on health, exposure to IAP also influences households' economic well-being. This is because adverse health reduces adult productivity and affects school attendance and children's productivity (Duflo, Greenstone and Hanna, 2008 and Pitt, Rosenzweig and Hassan, 2006).

Duflo and Hanna (2006) reported that about 60 percent of school absence in rural India was attributed to poor health. In terms of sick days, the annual health burden for India from exposure to IAP is 1.6 - 2.0 billion days of work lost (Smith, 2000). Income has a role to play in enhancing economic well-being. When income is below US$1 per day per capita, the prevalence of IAP is significantly higher (WHO, 2004). Given that twenty to thirty percent of income of the world's poor is spent on fuel alone (Flavein and Aeck, 2004), the problem of IAP is likely to be pervasive in poor households.

An estimate of about 1.3 billion people lacked access to electricity (International Energy Agency - IEA, 2014). The use of biomass fuel not only leads to IAP, but also deforestation and forest degradation, undermining their carbon sequestration ability (Gebreegziabher, Mekonnen, Kassie and Kohlin, 2010). Emissions from both deforestation and forest degradation account for about 18 percent of global greenhouse

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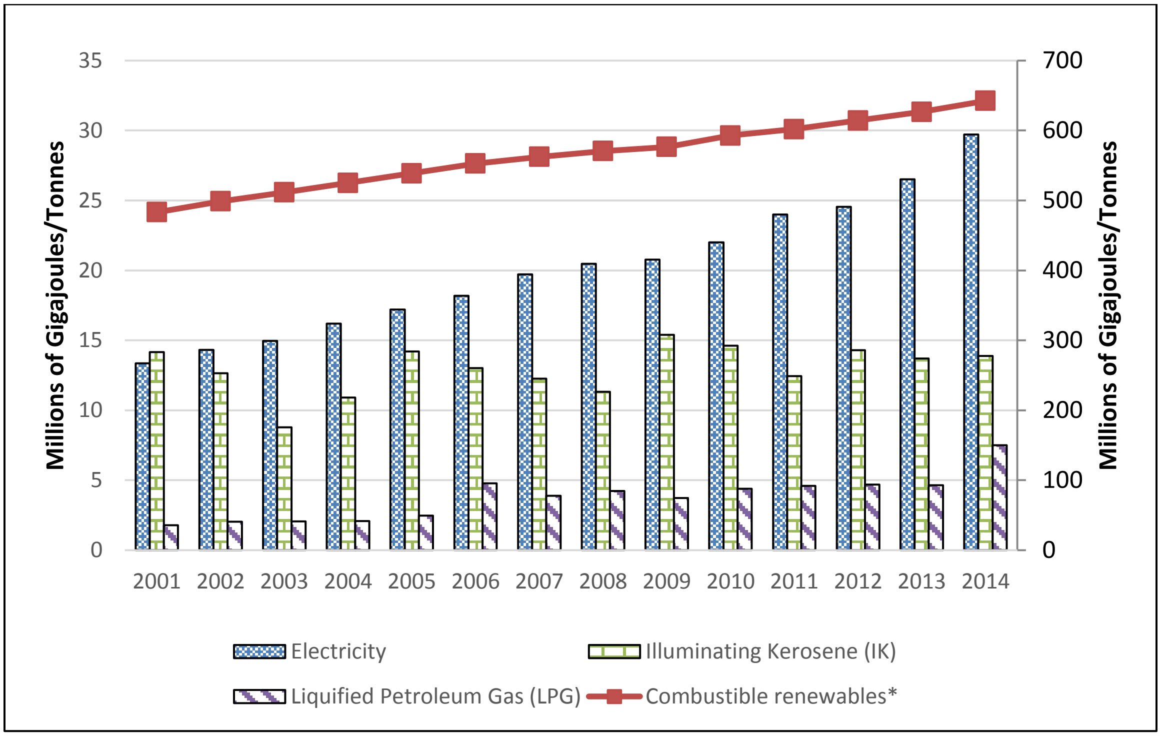
[2] The energy ladder shows how households transit from using traditional biomass fuels to clean, modern and less polluting fuels as their income increases.

gas emissions (Intergovernmental Panel on Climate Change-IPCC, 2007). In addition, households spend many hours per week collecting fuel (Gadgil et al., 2013).

Figure 1.1 demonstrates the energy consumption patterns in Kenya, from 2001 – 2014. The highest consumed is the combustible renewable (firewood, charcoal and material residues), followed by illuminating kerosene, LPG and electricity in that order.

Figure 1.1: Total energy consumption trends (in millions of Gigajoules/Tonne)



Source: Government of Kenya (various), Economic Survey and KENGEN Annual Report

The quality of indoor environment plays a key role in preventing illness, disability and injury. The use of traditional cooking stoves and dirty fuels such as biomass, coal and kerosene, produces smoke and black soot. The burning of fuels indoors produces higher concentrations of IAP than what international ambient air quality standards recommend[3], beyond which households are exposed (Environment Protection Agency-EPA, 2006).

There are several interventions that have been found to abate the levels of IAP from biomass combustion. The use of improved cooking stoves and modern fuels are popular ways to reduce the emission levels of IAP. However, even though improved cooking stoves and modern fuels have several economic, social, environmental, and health benefits, adoption rates are low worldwide (Barnes, Openshaw, Smith and van der Plas, 1994).

This thesis analyses the health and welfare effects of household IAP resulting from energy use. First, it examines the factors that influence the level of IAP from household energy use. Second, the association between household energy use and health status, taking into consideration the cost to health and the productivity of households is also analysed. Lastly, the demand for IAP abatement interventions examined.

1.2 Problem statement

Energy is vital for the well-being of humans. However, there is lack of awareness that the burning of cooking and lighting fuels exposes users to IAP which significantly affects human health, especially the infants and young children’s health (Duflo et al., 2008). IAP affects breathing, causes itching eyes, respiratory infection, and is also responsible for more than seven million deaths a year (WHO, 2014). In addition, IAP from household

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[3] The typical indoor exposure recommended is 7mg/m^3 for 24 hours.

energy not only affects health status, but also contributes to health costs and negatively affects household productivity (Duflo and Hanna, 2006 and Israel-Akinbo, 2012). Though the costs involved in cooking with wood energy may be lower compared to modern energy, the health costs of using wood energy are not only potentially higher but also not well appreciated by the less educated rural population (Pant, 2008).

Furthermore, several interventions aimed at abating IAP exposure have been found to positively reduce IAP and improve household welfare such as adoption of improved stoves and switching to modern energy (Pant and Pattanayak, 2008). However, the adoption of these interventions is low in Kenya. According to KIHBS (2008) only 8 percent, 8.4 percent and 4.1 percent of the total population had adopted the use of chimney, improved stoves and modern energy (electricity and LPG).

IAP affects both urban and rural population however research studies carried out mainly focus on rural population. Yan (2010) show how that different household energy use contributes to IAP, however empirical studies mostly provide evidence in biomass. This thesis fills the research gap by using a national sample that incorporates both urban and rural population. The analysis also captures biomass fuels in addition to other household energy sources such as kerosene, LPG and electricity.

Consequently previous studies mainly provide evidence of IAP on the respiratory illness (Mishra 2003; Pant and Pattanayak, 2008; Barnes et al. 2009; and Bukalassa 2011). According to Jaggernath (2012) IAP also cause eye illness, however empirical support on this is missing. The thesis fills the gap by not only focusing on eyes illness but also distinguishing the respiratory illness into upper and lower respiratory illness.

Several studies have been done on the effectiveness of different IAP interventions (WHO, 2000; Ezzati et al. 2002; Bates and Doig, 2001 and Goldemberg 2000). However demand studies on IAP abatement interventions focuses on modern energy and improved stoves. In addition to other IAP abatement interventions, the thesis focuses on the demand of chimney as an intervention that has rarely been analyzed

1.3 Research questions

The thesis seeks to address the following research questions:

1. What are the factors that influence the levels of IAP from household energy use?
2. What are the health effects of IAP from household energy use?
3. What are the health costs and productivity effects associated with IAP from energy use?
4. Why are households lowly/not adopting IAP abatement interventions?

1.4 Objectives of the thesis

The main objective of the thesis is to analyse the health outcomes and abatement efforts of IAP from household energy use. Specific objectives are to:

1. Determine the factors that influence the levels of IAP from household energy use;
2. Investigate the association between IAP from household energy use and ill health;
3. Estimate the health cost and productivity effects of household energy use; and
4. Analyse the demand for IAP abatement interventions.

1.5 Significance of the study

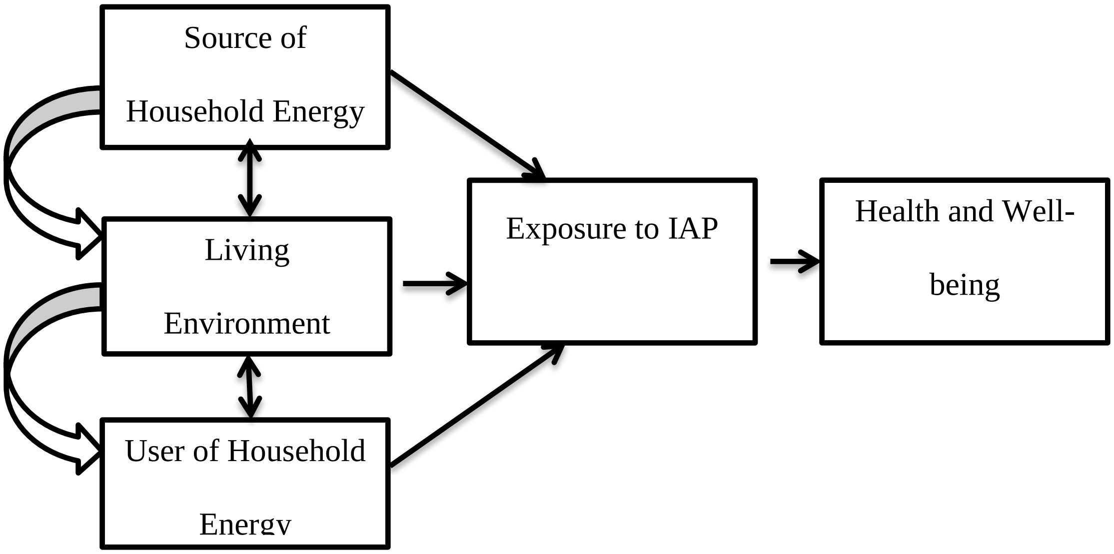
One long term objective of the government of Kenya has been to provide steady, predictable and affordable supply of energy to all sectors of the economy (Government of Kenya, 2007). However, due to scarcity of resources, many households have been left to use dirty energy sources, which expose them to excessive IAP (Duflo et al., 2008). The negative effects of exposure to IAP have received less attention in Kenya, despite their adverse effects on health leading to death. This could be due to limited empirical evidence on the importance of household energy use, IAP, health and welfare inter-linkages. More so, there are challenges of measuring levels of IAP and hence this limits the availability of data on the concentrations of IAP. This, therefore, limits the stock of knowledge and understanding on policy measures that can be used to reduce levels of IAP.

Carrying out a study that clearly identifies household energy use, IAP, health and welfare inter-linkages, should fill the gap and provide information to policy makers that will help in designing policies that improve household welfare. Such policies will target improved health, reduced health costs and improved indoor living environment. This study will thus provide critical information on the levels of IAP and the associated illness, an estimate of health costs, impact on human productivity, and potential policy options available on abatement of IAP.

1.6 Conceptual framework

The framework linking IAP, health and welfare was developed by Ballard-Tremeer and Mathee (2000). A modified version of this is in figure 1.2.

Figure 1.2: Linking IAP, Health and Welfare



Source: Adopted from Ballard-Tremeer and Mathee (2000)

Use of household energy produces pollutant smoke which has several poisonous gases. Households are exposed to these gases when they spread in the house causing them to suffer from major health risks. These health risks include; respiratory infections such as upper respiratory and lower respiratory infections and non-respiratory infections such as eye illness, burns, preterm birth, low birth weight and even cause death among others (WHO, 2004; Boy, Bruce & Delgado, 2002; Dherani et al., 2008 and Jaggernath, 2012). Different IAP abatement interventions can be applied to reduce the levels of IAP as discussed by Ballard-Tremeer and Mathee (2000). These interventions include use of improved stove, modern energy, improving living environment through use of chimney, windows and door, and behavioral changes such as reducing cooking time, fuel drying among others.

According to Duflo et al., (2008) there are numerous benefits from abatement of IAP among household. First, there are direct effects on health risks. Second, there are increased saving from medical expenditures, which tend to be a large portion of expenditures among the very poor. Third, households in good health are more productive with few cases of absenteeism in work place and in schools.

In the framework, the double arrows represent the interrelation between the energy system i.e. the source of IAP, living environment and the user while the curved right arrows captures the main path of exposure. The source of IAP is the direct emission from energy use and stoves. When fuels are burnt to provide various services including cooking, IAP in form of pollutant (particulate matter and gases) is generated. The amount pollutant dispersed in the air depends on the combustion conditions (Ballard-Tremeer and Mathee, 2000). The concentration of the pollutant in the indoor air depends on the emission rate from the source of the pollutant and the ventilation avenues. Biomass is considered to have very high concentrations of emissions compared to other sources such as LPG and electricity (Masera, Saatkamp, & Kammen, 2000). There are many factors such as individual preference, income, gender, household size, and cultural factors that influence household energy choice (Kowsari and Zerriffi, 2011 and Gebreegziabher, Mekonnen,Kassie, & Kohlin, 2010).

The living environment captures the various emission dispersion avenues such as the location of kitchen, use of chimney, windows and doors. Factors such as physical arrangement of rooms and construction materials used for building walls, roof and floors in the house determines the levels of concentration of IAP (Moturi, 2010); Pant and Pattanayak,2008; and Dasgupta, Huq, Khaliquzzaman, & Wheeler, 2007).

The user (behavioral habits) which consists of drying fuel, use of pot lids, use of among others may reduce the concentration of IAP. However, the cultural factors, household income and socio-economic factors such as gender and education may influence uptake of behavioral habits (Ballard-Tremeer and Mathee, 2000). There are also non-behavioral factors that influence concentrations of IAP such as the use of modern energy and stoves (Masera et al, 2000).

It is this exposure to IAP that causes health problems. The health status and well-being is influenced by socio-economic factors and exposure from IAP (through living environment characteristics, source of the pollutants and user/behiovaral habits). In turn, interventions targeting the user, source and living environment can influence exposure levels and bring positive health outcomes.

1.7 Scope of the study

The study analysed linkages between household energy use, IAP and health. The study identified the factors that explain differences in the levels of IAP from household energy use. The differences in the levels of IAP may result to different illness. Both upper and lower respiratory infections, including eyes infection were studied. The study also analysed the demand for three IAP abatement interventions (use of improved stoves, modern energy and chimney).

Micro data from Kenya Integrated Household Budget Survey (KIHBS) 2005/6 collected nationwide was used. The survey focused on education, health, labour, housing, water, sanitation, energy, and agriculture among other items.

1.8 Definition of terms

The following definitions for various cooking appliances, type of dwelling and kitchen location used in the study are provided for by Government of Kenya (2004/5).

Traditional Stone fire – It denotes to the type of appliance/stove where three or two stone are used mostly with firewood.

Improved Stone fire – it is a modified form of traditional stone fire where firewood the use of firewood continues to dominate

Ordinary jiko – It is the common jiko constructed from tin

Improved jiko – It is an improved jiko, generally with a coating of clay.

Kerosene stove – type of appliance which uses kerosene for cooking.

Gas/electric Cooker – they are cookers planned to burn using gas or electricity or both

Bungalow - Is a single storeyed self-contained dwelling unit in its own compound.
Mansionette – Is a semi-detached or terraced self-contained dwelling unit on two floors.

Flat - Is a dwelling unit merged to others in a single multi-storey building. Certain dwelling units in flats may not be self-contained.

Swahili –They are several dwelling units in a structure with a single main gate where facilities such as toilets, bathroom and kitchen are shared either by the same or different households living in single rooms within the main structure.

Shanty- This is dwelling structure, which is temporary in construction. They are made of materials like cartons, plastic sheets etc., they often don't have any sanitation facility or water.

Manyatta/ traditional huts – These are single structure mostly several within a compound that are occupied by individuals within a family. They are generally are detached from toilets, kitchens and other related facilities.

Other dwelling – Is any other type of dwelling structures.

Outdoor – It is where households cook outside the dwelling in the open.

Enclosed detached – It is where household cooks in a separate structure detached from the dwelling dwelling/house.

Enclosed *attached* - refers to a separate room/cooking area within the main dwelling

I*ndoor without partition* – This refers to cases where the cooking, sleeping sitting activities are undertaken with the same area.

Indoor with partition – refers to non-structural partition for example with the use of cardboards etc.

Chimney - The chimney is a structured construction aimed at directing out smoke.

1.9 Organization of the thesis

The rest of the thesis is structured in three chapters representing three essays. The first essay, presented as chapter three, focuses on the determinants of IAP. The second essay, chapter four, investigates the association between IAP from household energy use and health status, and estimates the health cost and productivity effects of IAP to households. Chapter five, the final essay, analyses the demand for IAP abating interventions. The conclusion and policy recommendations are presented in chapter six.

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Chapter 2 : **OVERVIEW OF HOUSEHOLD ENERGY IN KENYA**

2.1 Introduction

This chapter provides an overview of the household energy in Kenya. Specifically it documents the different forms of household cooking energy consumed in the country. The chapter also provides discussion on the association between indoor air pollution (IAP) from household energy use and illness. Finally, it also examines the cost of various fuel stove appliances and related household energy.

2.2 Household cooking and lighting energy

Historically, Kenyan households have relied on biomass as the main source of cooking energy, but with advances in technology and economic growth, LPG, electricity and biogas have been adopted by about 7 percent of the households (GoK, 2010).

The 2005/6, Kenya Integrated Household Budget Survey (KIHBS) shows that firewood is the most common source of cooking energy accounting for 68.3 percent (Table 2.1) of the total household energy consumed. Rural households are the major consumers (87.7%) of firewood. The second major form of fuel consumed by households is charcoal, representing 13.3 percent of the total household energy consumed. This is closely followed by paraffin/kerosene at 13.2 percent, with the urban households consuming about 44.6 percent.

At the national level, LPG is the most consumed modern fuel among households estimated at 3.5 percent, compared to electricity which accounts for 0.6 percent. The urban population is the major consumer of modern energy with 11.9 and 1.8 percent for LPG and electricity, respectively.

Table 2.1: Percentage distribution of the population by main source of cooking fuel

Data Source	Firewood	Grass	Kerosene	Electricity	LPG	Charcoal
National (%)- KIHBS(2006)	68.3	0.1	13.2	0.6	3.5	13.3
National (%)- KDHS(2010)	63.3	1.2	8.1	0.5	6.5	18.7
Rural (%) – KIHBS(2006)	87.7	0.1	2.7	0.2	0.7	7.7
Rural (%) - KDHS (2010)	83.3	1.4	1.5	0.1	1.2	18.7
Urban (%)- KIHBS(2006)	10	0.2	44.6	1.8	11.9	30.2
Urban (%)-KDHS(2010)	6.1	0.8	26.9	1.6	21.7	10.8

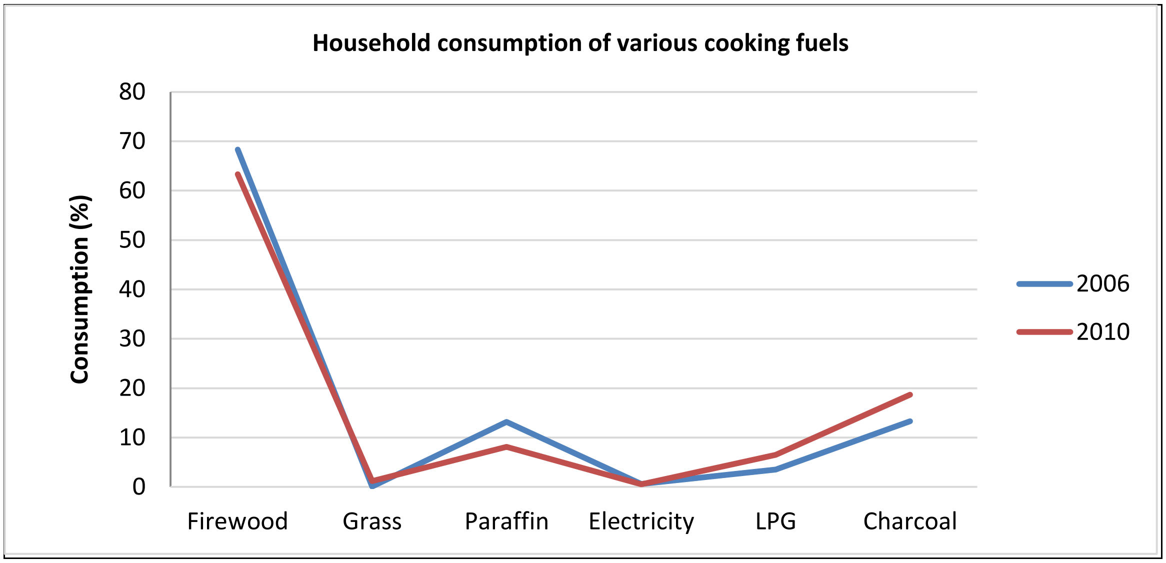
Source: GoK (2008), KIHBS and GoK (2010), KDHS

The Kenya Demographic and Health Survey (KDHS) show that the highest consumed household energy in 2010 was firewood representing 63.3 percent of the total household energy at the national level; and 83.3 percent and 6.1 percent in rural and urban areas, respectively. The least consumed was electricity accounting for 0.5 percent at the national level, while 0.1 percent and 1.6 percent was consumed by rural and urban population, respectively. There is no evidence of significant difference in household energy consumption between 2006 and 2010 as observed in figure 2.1.

BIOMASS

Majority of Kenyan households use biomass for cooking and lighting purposes. This form of energy usage is associated with high levels of IAP and an increase in the incidence of illness. The illness include; pneumonia, tuberculosis, chronic obstructive pulmonary disease, low birth weight, cataracts, cardiovascular events and all-cause mortality both in adults and children (Fullerton, Bruce and Gordon, 2008).

Figure 2.1: Household consumption of various cooking fuels, 2006 and 2010



Source: GoK (2008), KIHBS; and GoK (2010), KDHS

Wood

Wood fuels (charcoal and firewood) are the dominant forms of biomass and are mainly sourced from different forest types. These include community/private plantations, public plantation forests, and trees on farm and natural forest (public and community forest). In 2013, the national wood supply potential was low at 31,372,531m^3 against a demand quantity of 41,700,664.45m^3. Firewood and charcoal supply stood at 13,654,022m^3 and 7,358,717m^3, while demand for the same was 18,702,748m^3 and 16,325,810m^3, respectively. By 2032 the increase in supply and demand is predicted at 20 percent and 21.6 percent respectively (GoK, 2013b).

Shortages occur when demand of wood fuels surpasses the supply, resulting in high wood prices. However, at local level or farm and community level when there are shortages, harvesting of wood is done from growing stocks leading to degradation and deforestation.

Biogas

Biogas is used for cooking and lighting in Kenya. The biogas technology was introduced in Kenya over 50 years ago (Hamlin, 2012). Since biogas can practically be used as a cooking fuel, it helps to address the health issues associated with indoor air pollution while decreasing dependence on biomass fuels.

However, uptake of biogas has been very low (Mugo and Gathui, 2010). The low demand is attributed to various challenges (GoK, 2014a); first, the high capital cost or upfront cost for domestic plant, commercial plant and equipment. Second, the inadequate skills for installation, operation and maintenance service for plant, equipment and appliance. Third, is lack of adequate water supplies required for biogas operation.

ELECTRICITY

Electricity is an energy source that support household cooking, lighting, heating and refrigeration services. The sources of electricity are hydro, thermal, geothermal, cogeneration and wind. In February 2015, geothermal power accounted for 51 percent of the national electricity generation mix, hydro was second at 36 percent. The drop in hydro power generation was due to low rainfall experienced in the Kenya. The third highest source of electricity was the thermal sources (with 21%) powered by medium speed diesel and heavy fuel oil (GoK, 2015a).

Geothermal

Geothermal has a potential capacity of 10,000MW, and it is mainly available at the Rift Valley. Electricity production from geothermal in Kenya is the largest in Africa (GoK, 2015b). Electricity from geothermal resource has both environmental and economic benefits. Since it is known to conserve fossils fuels, it substantially reduces the greenhouse gas emissions that pollute the environment. Another environmental benefit is that geothermal exploitation occupies minimal space. The economic benefits of geothermal include; creation of employment, generation of revenue through royalties, carbon credits through emission reduction, and reduced dependency on fossil fuel and oil imports (GoK, 2015b). In addition to these economic benefits, the Least Cost Development Plan (LCPDP) has identified geothermal power as the least cost power with a capacity factor[4] of 94 percent (GoK, 2013a).

Geothermal power is considered the cheapest source of electricity in Kenya. With the introduction of the 280 MW project in February 2015, the fuel cost of electricity generation dropped from Ksh 7.22 per KWh to Ksh 2.51 per KWh (GoK, 2015a).

Hydro

Historically, hydro power has been the major source of electricity in Kenya. For instance in 2013; hydro power contribution to the national electricity generation mix was close to 50 percent (GoK, 2014a). There are plans by the Kenyan government to reduce the

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[4] It is actual electricity generated compared to the maximum possible electricity generated at which the plant can operate. A higher capacity factor implies a lower levelized cost of electricity

contribution of hydro power due to unpredictable rainfall supply. The contribution of hydro power to the national energy mix is targeted at 11.7 MW in 2017 (GoK, 2014b).

Hydro power potential is about 6,000 MW of large hydro and 3,000 MW of small hydro. However, only 807 MW and 25MW of both large and small hydro's respectively, has been developed. A number of challenges have hampered the development of hydro power. According to GoK (2014a) hydropower is vulnerable to variations in hydrology and climate. It is faced with conflicting and competing land and water uses among various sub-sector of the economy. In addition, water charges have an effect of increasing the cost of hydro generated electricity.

Thermal

Thermal power production uses fossil fuels that adversely affect the environment through pollution. In 2013, thermal power generation amounted to 37.4 percent of the total electricity generated, but is now planned for 6.4 percent in 2017 by the Kenyan government (GoK, 2014b). The rising cost of oil has raised the demand for foreign exchange required to import fossils fuels for the thermal power plants. Apart from high costs needed for mitigating environmental pollution, thermal power production has high recurrent cost due to use of petroleum fuels that escalate the cost of electricity (GoK, 2014a). The Kenyan government plans to cut down these costs by developing, wind, solar and cogeneration power to substitute thermal power generation (GoK, 2014a).

Cogeneration, wind and coal

Cogeneration power is mainly from bagasse. Sugar millers form the main producers. Wind power has mainly been from Ngong with planned generation at Kipeto, Kinangop and Lake Turkana. The potential for coal in the country has not yet been established. However, according to the Least Cost Power Development Plan (LCPDP) for 2013-2033 (GoK, 2013a), there are proposed coal plants of upto 5,400MW. The coal plants proposed in the plan will be located in the Mwingi/Kitui area to minimise transportation costs (GoK, 2013a). Exploration of coal has also been planned in Mui Basin-Kituyi, in Taru basin-Kwale and Kilifi, and in Lamu. The estimated installed capacity for coal plant in Lamu is about 960MW. National generation mix from cogeneration, wind and coal power in 2013, stood at 1.6 percent, 0.3 percent and 0 percent respectively and is planned to be 0.7 percent, 9.4 percent and 28.4 percent respectively, in 2017 (GoK, 2014b).

The potential of wind in Kenya is as high at 346 W/m^2 and speeds of over 6m/s in parts of Marsabit, Kajiado, Laikipia, Meru, Nyandarua, Kilifi, Lamu, Isiolo, Turkana, Samburu, Uasin Gishu, Narok and Kiambu counties among others. However, excellent wind speeds are within restricted areas like national parks. In addition, there are competing interests in land use with other commercial activities such as construction of residential and commercial buildings and bird seeing cites (GoK, 2014a).

Solar

Solar power is mainly for lighting, drying and generating electricity. Solar insulation is estimated at 4-6 KWh/m^2/day (GoK, 2014a). Despite the large potential, the percentage of solar energy harnessed for commercial and domestic application is relatively small. Although there is favourable fiscal incentives, consumers are faced with lack of appropriate credit and financing mechanisms (GoK, ibid). In addition to these there is low consumer confidence as a result of inappropriate system standard, faulty installation, importation of sub-standard systems and poor after sale services (GoK, ibid). These issues will be addressed in time as the government has put in place policies such as the licensing of traders and technicians that are aimed to ensure standard quality products are sold and installed.

Use of modern energy (electricity), is associated with positive health benefits such as the reduction of IAP related to illnesses. However, uptake of electricity, especially among the rural domestic consumers, has been low. In 2014, the connectivity rate was estimated at 32 percent, which is expected to rise to 75 percent in 2019 through the introduction of Single Wire Earthing Return (SWER) system and the Last Mile Connectivity Project (LMCP) (GoK, 2015c).

PETROLEUM PRODUCTS

Kerosene and LPG are the most consumed petroleum products among households. These products are mainly used for cooking and lighting. About 149.7 thousand tonnes of LPG and 300.3 thousand tonnes of kerosene were consumed by households in 2014 (GoK, 2015d).

Kerosene

The use of kerosene, both for lighting and cooking contributes to IAP. Tracy & Jacobson (2012) estimate that in Kenya and Tanzania a single kerosene lamp produces upto one tonne of carbon in five years. Similar findings by Tracy and Jacobson (ibid) indicate that fumes inhaled from kerosene are equivalent to smoking 40 cigarettes per day. In addition to causing IAP, incomplete combustion of kerosene leads to black carbon that absorbs light, thereby heating the atmosphere and contributing to global warming (Lam, et al., 2012).

In their study, Tracy & Jacobson (2012) found that kerosene not only affects human health, but also leads to financial burden. They indicate that in Kenya, kerosene in the villages' costs 46 percent more than in pump stations in urban areas. A similar study by EcoEnergy (2014) also found Kerosene to be expensive as about 25 and 30 percent of a household income is used to purchase kerosene.

LPG

LPG in Kenya is mainly used for cooking and is rarely associated with illness. LPG supply is from imports. However, until the end of 2013, the Kenya Petroleum Refineries Limited (KPRL) used to handle 40 percent of LPG from crude oil refining. Closure of KPRL and introduction of VAT on LPG cylinders has led to high costs of cooking gas. For instance, the monthly inflation report shows that the cost of LPG rose by 4.7 percent from Ksh 2,882 in March 2013 to Ksh 3,018 in December 2014 (GoK, 2015d).

The Kenyan government through the Kenya National Energy Policy, 2015 has plans to commission an LPG import facility in Mombasa that will take advantage of economies of scale in import costs to stabilise domestic prices (GoK, 2015e). Early 2015, KPRL started storing fuel for marketers at a fee to make use of available storage capacity of 192,000m^3 for refined liquid products and 1,200 tonnes of LPG (GoK, 2015e).

2.3 Household energy use and related illness

Majority of the households may not be able to associate the indoor smoke from burning biomass as a threat to their health. The indoor smoke (IAP) is a threat to health, particularly for women and young children, who may spend more hours close to the fire (Bruce et al., 2006)

Table 2.2 links biomass fuels and coal with child and adult health outcomes. These health outcomes include; Acute Respiratory Infection (ALRI) and Chronic Obstructive Pulmonary Disease (COPD). Overall, the number of female deaths is more than male deaths but Disability Adjusted Life Years (DALYs) [5]for males (6901 000) and females (5417 000) are similar. Males are the ones who experience higher number of deaths; and DALYs from ALRI in children who are less than 5 years of age is higher than the overall than . DALYs and deaths from COPD are twice and three times higher in women, respectively. The COPD figures exclude male deaths resulting from smoking.

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[5] The World Health Organisation defines Disability Adjusted Life Years (DALYs) as the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability

Table 2.2: Solid fuels (Biomass and coal) and health

	Overall			ALRI(children below 5yrs			COPD (above 30 years)		
				Deaths (000)					
	Male	**Female**	**All**	**Male**	**Female**	**All**	**Male**	**Female**	**All**
Sub-Saharan Africa	211	181	392	198	153	351	13	28	41
World	658	961	1619	481	429	910	171	522	693
				DALYs (000)					
	Male	**Female**	**All**	**Male**	**Female**	**All**	**Male**	**Female**	**All**
Sub-Saharan Africa	6901	5417	12318	6777	5191	11968	124	227	351
World	19037	19495	38532	16860	15058	31918	2110	4336	6446

Source: Smith, Mehta and Feuz, 2004

Keraka et al. (2013) in Kenya found that the highest occurrence of most of the respiratory symptoms was evident among fuel wood and saw dust users. Charcoal came in second, while LPG and electricity came in third and fourth positions, respectively (Table 2.3).

Table 2.3: Reported health symptoms and fuel types

Respiratory symptoms	Charcoal	Fuel wood	Sawdust	Electricity	LPG	Total
Cough	40.8	73.9	61.5	7.7	16.7	42.0
Phlegm	14.2	23.2	23.1	5.8	5.6	14.5
Breathlessness	19.7	23.2	23.1	7.7	5.6	18.0
Wheezing	18.3	18.8	23.1	0	0	15.0
All symptoms	4.1	7.2	7.7	0	0	4.0

Source: Keraka et al., 2013

2.4 Indoor air pollution interventions

There are several interventions that can be targeted to reduce IAP, thereby reducing the resulting illnesses. The improved cooking stove has been identified as one way of reducing the levels of IAP. In Kenya there are several types of improved cooking stoves which have been developed and are currently commercially available (Clough, 2012). In 2012, the traditional metal stove for charcoal was the cheapest stove at only Ksh 255 (Table 2.4), because they are made from scrap metal and locally assembled by metal workers. The Kenya Ceramic Jiko (KC1 and KC3) were considered cheaper at Ksh 357 and Ksh 391 respectively, compared to the multipurpose stove (wood/charcoal) whichi is Ksh 739.5 and KuniMbili wood and Uhai stove at Ksh 816.

Table 2.4: Price of alternative cooking stoves

Fuel Appliance	**Fuel Used**	**Stove price, USD (Ksh)[6]**
Multipurpose Stove Wood (KWC1)	Wood	8.7 (739.50)
KuniMbili – Wood (KW2)	Wood	9.6 (816)
3 stone fire	Wood	0
Multipurpose Stove Charcoal (KWC1)	Charcoal	8.7 (739.5)
Kenya Ceramic Jiko (KC1)	Charcoal	4.6 (391)
Uhai Stove (KC2)	Charcoal	9.6 (816)
Kenya Ceramic Jiko Small – Charcoal (KC3)	Charcoal	4.2 (357)
Traditional Metal Stove – Charcoal (KTMS)	Charcoal	4.0 (340)
Traditional Metal Stove – Charcoal (KTMS SM)	Charcoal	3.0 (255)

Source: Clough, 2012

The use of chimney is also an alternative intervention that can reduce the level of IAP. About 8 percent of the total households in Kenya have chimney in their kitchen (KIHBS, 2008). The rural households are the major users of chimney intervention representing about 79 percent of the total population compared to 21 percent of the total population from the urban households. It is unclear on what are the expenditures associated with use of chimney. However, since erecting of chimney forms part of the housing structure, the monthly charges paid as rent can be used as a proxy for chimney expenditures.

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[6] 1 USD = 85.913 Ksh in 2012

The use of modern energy as an IAP intervention involves use of electricity and LPG. The price of modern energy is considered high (Kalpana et al., 2011). For instance, in Kenya the price of LPG rose from Kshs 1,927 in January 2010 to about Kshs 3,018 in December 2014, representing an increase of about 36 percent increase.

2.5 Conclusion

The reason why households are still using biomass as a cooking energy could be due to the high cost of modern cooking energy. Households may also not be aware of the health effects of such use. In the medium term plan II (2014-2023), the Kenya government has proposed measures that will promote use of alternative sources of energy and technologies such as biogas and solar as substitutes for biomass. In addition, with the 5000+ MW programme in place, it is expected that in the long run, electricity price will fall as thermal power plants are retired in favour of renewable energy sources.

Though there are policies promoting use of biomass alternatives, these policies are founded on cost elements rather than a holistic approach that aims at reducing IAP, and improving health and overall economic development.

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Chapter 3 : DETERMINANTS OF INDOOR AIR POLLUTION FROM HOUSEHOLD ENERGY USE

3.1 Introduction

Indoor air pollution (IAP) is very prevalent in Kenya and is associated with illness and even death (Ezzati & Kammen, 2001). Energy at the household level is mainly used for heating and cooking services. When fuels are burnt to produce energy, they emit smoke which is considered IAP, especially if inside dwellings. Apart from biomass smoke and nitrogen dioxide from gas cooking/heating, passive smoking is also a potential source of IAP that may change individual health status (Madjan, Coman, Gallova, Duricova, & Kallayoca, 2012; Graham, 1990; and Melia,du Ve Florey, Darby, Palmes, & Goldstein, 1978).

There are different levels of IAP depending on the source of energy (Bruce, Neufeld, Boy, & West, 1998; Rollin, Schirnding, Mathee, Bruce, & Levin, 2004 and Moturi, 2010). This may explain why some fuels are considered clean, while others dirty. Clean fuels such as LPG and electricity have lower concentration of emissions than dirty fuels such as biomass (Masera, Saatkamp, & Kammen, 2000). Biomass smoke contains particulate matter (PM)[7], carbon monoxide, nitrogen dioxide, sulfur oxides, formaldehyde, and carcinogens such as benzopyrene and benzene (Edwards and Langap, 2008). PM_{10} and $PM_{2.5}$, are particles less than 10 and 2.5 micrometres in diameter respectively, include inhalable particles small enough to penetrate the thoracic region of

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[7] PM is an air pollutant, consisting of a mixture of solid and liquid particles suspended in the air.

the respiratory system. Findings from WHO (2013) indicate that PM can alter the body's defense systems against foreign materials, damage lung tissues, exacerbate existing respiratory and cardiovascular disease, and may cause cancer and even death.

In 2002, Kenyan households that used biomass fuels had a typical daily concentration of PM_{10} ranging from 200µg/m^3 to 5,000µg/$m^3$with peak concentrations as high as 50,000µg/m^3 in the immediate vicinity of the fire. This is high compared to the US Environmental Protection Agency's standards for average daily concentrations of PM_{10} and $PM_{2.5}$[8] (Ezzati and Kammen, 2002). A different study done in Kenya found that the exposure concentrations from IAP for Kajiado and Western Kenya were 1713µg/m^3 and 5526µg/m^3, respectively(Intermediate Technology Development Group-ITDG, 2002). Likewise Ezatti, Salesh & Kammen (2000) established that the average daily exposure concentrations for young and adult women were 2795µg/m^3 and 4898µg/m^3, respectively.

The use of biomass has been linked with high levels of IAP and has also been associated with acute lower respiratory infections (ALRI), chronic obstructive pulmonary diseases (COPD), and lung cancer for the case of coal only (Ezzati & Kammen, 2001; and Behera, & Jindal, 1991). Mishra, & Retherford (1999) also provide evidence for blindness from cataracts, tuberculosis and asthma related to IAP, suggesting the need for more studies are on these linkages.

In 2012, IAP exposure from burning of biomass accounted for 4 million deaths worldwide (Smith, 2012); while WHO (2014) reports the number to be about 7 million.

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[8] The recommended levels for 24-hour $PM_{2.5}$is 35 µg/m^3

In 2010, premature deaths related to IAP (1.3 million) exceeded the predicted number of premature deaths currently related to malaria (1.2 million), almost as much as tuberculosis (1.6 million), and the amount linked to HIV/AIDS (2.8 million) (International Energy Agency -IEA, 2010).

Even though different fuels have varying levels of IAP, research that supports this evidence is scarce and limited to biomass fuels (Ezatti, & Kammen, 2002 and Dasgupta, Huq, Khaliquzzaman, & Wheeler, 2007). When analyzing the factors that influence IAP, the type of fuel and fuel stove appliance have been widely identified as key factors. However, factors such as type of dwelling, kitchen location, and ventilation characteristics, that is presence of chimney, are critical factors that need to be investigated (Mishra, 2003; Jack, 2004; and Rollin et al., 2004).

This essay examines the factors driving the levels of IAP from household energy use in Kenya. Specifically, the objectives are to:

a) Determine the factors that influence the levels of IAP from household energy use; and

b) Draw policy implication for reducing the levels of IAP.

This essay contributes to knowledge by examining factors that influence IAP from household energy use in Kenya. In addition to biomass fuels (firewood and charcoal), the study focuses on kerosene, LPG and electricity. The factors included in the analysis are; building materials for wall, roof and floor; kitchen location; presence of chimney; and social economics characteristics such as household expenditures, household head age, gender, head of the household's education, employment and location of residence. Further, the Conditional Mixed Process (CMP) ordered probit is used. This is an innovative model developed by Roodman (2011) to addresses endogeneity and unobserved heterogeneity.

The rest of the essay is organised as follows: section 3.2 reviews the theoretical and empirical literature on household energy use and IAP. Section 3.3 discusses the methodology, while section 3.4 presents data and description of variables. Section 3.5 presents the results and discussion, and section 3.6 provides the conclusion and policy implications.

3.2 Literature review

3.2.1 Theoretical literature

Theory on household energy use and indoor air pollution

Households use different energy sources to cook and heat among other services. The factors that influence household's energy choice differ from one energy source to another. Some of the key factors are income, fuel price, household head gender, education, location of residence (urban or rural) and distance to fuel source among others (Barnes, & Qian, 1992; Meckonen, & Kohlin, 2008; and Pundo, & Fraser, 2003). The energy ladder and energy stack models have been used to explain household behaviour regarding use of energy.

The energy ladder theory

The energy ladder theory posits that in response to higher income and other factors households will shift from traditional fuels such as biomass and other solid fuels to more modern and efficient cooking fuels such as LPG and/or even electricity. This process is usually termed 'fuel switching' (Barnes et al., 1992; and Leach, 1992).

The model portrays a three-stage fuel switching process. The first stage is manifested by universal reliance on biomass. In the second stage households move to "transition" fuels such as kerosene, coal and charcoal in response to higher incomes and other factors such as deforestation and urbanisation. The third stage has households that switch to LPG or electricity.

This model has been of great importance as it also demonstrates the ranking of various fuels according to their level of cleanliness and IAP. The first stage, dominated by use of biomass fuels, is depicted as the dirtiest. It embodies the highest levels of IAP while moving towards the third stage where electricity and LPG are considered cleaner, and with lower levels of IAP. In addition, those households on first and second stage of the energy ladder (where firewood, charcoal, kerosene and coal are in use) tend to use inefficient traditional fuel stove that produces toxic pollutants that affect health (Duflo, Greenstone, & Hanna, 2008).

Households' preferences influence how household energy is ordered in the energy ladder. This household preference includes cleanliness in terms of pollution, efficiency, ease of use and speed of cooking (Hiemstra-vanderHorst and Hovorka, 2008). Masera et al.

(2000) report that fuels which are ranked higher are usually more efficient and costly but are known to have low pollution and are less laborious.

The energy ladder model also portrays the level of technological advancement of a fuel which correspondingly reflects the efficiency of the appliance adopted. There exists a positive relationship between energy sophistication with stove efficiency (it increases at a decreasing rate as technology increases) and stove capital cost (Masera et al., 2000; and Adol-Agyarko, 2009). Electricity requires high capital cost in more efficient appliances and is used by more affluent households when compared to dung and crop residues. The efficiency of cooking technologies increases progressively from those that do not require any capital outlay to those that require least or massive capital expenditures (Adol-Agyarko, 2009; and Kammen, Goldemberg, & Johansson, 1995).

Masera et al., (2000) explain that the type of fuel adopted signifies the household status, implying that those who use expensive technologies are considered more prosperous. Therefore, households climbing up the energy ladder tend to show their rise in socio-economic status rather than to achieve greater fuel efficiency or less direct pollutions.

The energy ladder assumes switching to modern fuels is only possible with high incomes. In developing countries, income is not a limiting factor for fuel wood use. Fuelwood is used by both low and high income households (Hiemstra-vanderHorst, & Hovorka, 2008; and Hosier, & Kipondya, 1993).

Several critisms are leveled against the energy ladder. First, apart from income, there are other factors such as cultural, social and behavioural factors influencing energy choice

(Jebraj and Iniyan, 2006). Secondly, the perception that firewood is a fuel of the poor (Leach, 1992) is erroneous, as firewood is used by all income groups as explained by consumer preferences and lifestyle considerations rather than by level of income. Third, the energy ladder depicts a simple progression pattern where households switch from one fuel (either traditional fuels like biomass or transitional fuels like kerosene and charcoal) to a modern one (LPG or electricity). In developing countries, the households use multiple fuels and their energy patterns are explained better using energy stack models (Masera et al., 2000).

The energy stack theory

Energy switch does not happen swiftly as portrayed by the energy ladder model. Instead, households are observed to use multiple fuels (Leach, 1992; Masera et al., 2000; and Heltberg, 2004). Van der Kroon, Brouwer, Pieter, & VanBeukering (2013) note that fuel switching is a transient phenomenon rather than a linear and continuous process, especially in urban areas. Transition from one fuel to another is not unidirectional as households can shift back to traditional fuels despite adopting modern fuels (Masera et al., 2000). Households prefer specific fuels for particular purposes, therefore these fuels cannot be perfectly substituted (Kowsari, 2013).

Adoptions of modern fuel are not only based on income, but in household preferences where modern fuels compliment the traditional ones rather than act as substitute fuels (Elias and Victor, 2005).

A number of reasons explain why there is fuel stacking. Masera et al., (2000) and Oudejans, (2011) provide four reasons. First, energy security, where households with irregular income are found to use multiple fuels to cushion against periods of low income. Second, unreliable supply of modern energy. In this case, traditional fuels are only used as backup fuels. Third, fluctuating energy prices which prompt households to use multiple fuels in times of high energy prices. Fourth, cultural factors. The preference and convenience of specific fuels over others for particular forms of cooking influence households to move from traditional fuels to modern ones and back.

Cultural factors include taste and preferences, cooking practices, local cuisine among others. Masera et al. (2000) show how Mexican households, despite adopting LPG, preferred cooking with fuelwood to prepare “tortilla” a local meal in Mexico. Tortilla cooked using LPG was found unpleasant. In addition, due to cultural reasons, Elias et al., (2005) showed that even though households switch to modern fuels, they will also need to maintain traditional fuels. For instance, wood fuel smoke is used to repel mosquitoes in tropical areas.

Although the energy ladder model has been criticised in favour of energy stack model, the latter has its own limitations. Research shows that the energy stack model is still poorly defined and not able to strongly predict household behaviour in respect to adoption of an efficient fuel cooking stove (Elias et al., 2005). There is a difference between how policy designers and cooking stove users define success, especially if households are expected to adopt fuel types as perfect substitutes or exclusively improved cooking stoves.

It could be that “cooking stove stacking”, the use of multiple cooking stoves, can explain household energy behaviour better than energy ladder and energy stack (Elias et al., 2005). However, the energy ladder model explains the interaction between IAP and household energy use better than energy stack model.

3.2.2 Empirical literature

Empirical studies on determinants of IAP are scanty due to the extreme difficulties in measuring exposure to IAP, and largely due to lack of available data on concentration of indoor air pollutant (Jack, 2004). Discussions on determinants of IAP can be categorised into four; energy technology (type of stove), living environment (housing) characteristics, behavioural (cooking practices), and socio-economic characteristics.

Several studies such as the Madjan et al. (2012); Moturi (2010); Pant and Pattanayak (2008) and Dasgupta et al. (2007) provide evidence on the importance of living environment factors in enhancing IAP. Targeting a rural population of women in Guatemala, Bruce et al. (1998) analysed IAP from biofuels and respiration health. Arrangement of rooms and floor type were factors that enhanced IAP. Moturi (2010) also found similar results from rural households in Mauche division, Molo district in Kenya, where the state of housing (which included type of primary building in the homestead, number of rooms, and type of ventilation present) were found to be likely risk factors for IAP, which has been associated with various diseases.

Madjan et al. (2012) found environmental hazards such as lack of ventilation (where ventilation includes use of windows and doors) were vital. In addition, Pant and

Pattanayak (2008) also provide more evidence on the living environment factors that influence IAP. Focusing on individual children in rural Nepal, Pant, & Pattanayak (2008) identified the use of construction materials, space configurations and cooking locations act as potential-important determinants of IAP.

Dasgupta et al. (2007) conclude that if cooking with clean fuels is not possible, then building the kitchen with porous construction material and providing proper ventilation in cooking areas will yield a better indoor health environment.

Any building material that is considered permeable is one that allows liquids or gases to pass through it. According to Dasgupta et al. (2007), construction materials such as tin are considered more permeable and could be used in constructing kitchens. They note that in kitchen roofs, tin or thatch walls are significantly less air-trapping than mud walls, which, in turn, are less air trapping than brick. With regard to kitchen roofs, tin offers better air quality than thatch. In living rooms, tin walls offer better air quality than mud ones, which, in turn, are better than thatch or brick. Dasgupta et al., (2007) was able to link the level of indoor smoke with wall and roof permeability.

The energy technology (type of fuel and fuel stove appliance) determines IAP. Bruce et al., (1998) and Moturi (2010) identified the type of fuel as possible risk factors for IAP. Subsequently, Rollin et al. (2004) provided scientific evidence that electrified homes in rural South African villages have lower levels of air pollution (particulate matter and carbon monoxide) relative to their non-electrified counterparts. Graham (1990) also found that children who are exposed to gas heating in their homes are more prone to respiratory infection than those with electric heating.

Ezatti et al. (2002) and Madjan et al. (2012) are some of the studies that have successfully identified behavioural factors of IAP. Madjan et al. (2012) assessed the indoor environment and implications for health in Roma villages in Slovakia and Romania. Indoor air was sampled in 20 houses where behavioural hazards such as indoor smoking and indoor pets were found to contribute to IAP.

In addition, factors such as gender and age of children are found to be important socioeconomic determinants of IAP. Research shows that women, because of cooking responsibilities, are more exposed to IAP together with the children they tend to care for (Ezzati et al., 2002).

3.2.3 Summary of literature

This literature review has shown that studies linking IAP, household energy, health and welfare are scarce. Previous studies such as Ezatti et al. (2002) and Dasgupta et al. (2007) have concentrated on high polluting biomass fuels, mainly used in rural areas with little or no emphasis on kerosene, LPG and electricity, popularly consumed by urban households. Due to the limited data available on IAP concentrations, a number of proxies have also been adopted to indicate the concentration of IAP such as fuel type (Jack, 2004 and Mishra 2003).

Review of literature on determinants of IAP shows that the type of fuel and fuel stove appliance are dominant factors that have been widely considered and emphasised (Bruce et al., 1998; and Moturi, 2010). However, other factors influencing IAP such as living environment and socio economic factors to the best of my knowledge have not been examined in Kenya.

3.3 Methodology

This section discusses the methods used in analyzing the factors that influence IAP. The concentration of IAP differs from one pollutant source to another. This essay gives focus on household energy as a source of IAP. Factors explaining differences in IAP from household energy use include; type of stove, socio-economic factors and living environment characteristics. The conceptual framework discussing feedback effects of source of the pollutant and health is presented in chapter 1.

3.3.1 Theoretical model

The household production function is used in this study to explain how households combine non marketed environmental services and marketed products to maximise their utility. Most environmental services are not sold in the market but they are freely available and somehow degraded by marketed commodities (Chaudhuri and Pfaff, 2003). The use of household energy despite providing numerous services such as cooking also contributes to IAP.

The level of indoor air quality Q and cooking services C are non market products and are jointly produced through the use of marketed household energy/fuels. We assume that households have a choice of purchasing either clean modern energy F_m that is environmentally friendly or dirty traditional energy F_t that is environmentally destructive.

According to Chaudhuri, et al. (2003), if we assume that the total cooking services S is generated linearly from the use of these forms of energy, then:

$$S = F_t + F_m \tag{3.1}$$

where F_t and F_m are dirty and clean energy, respectively. As indicated earlier, households derive utility from the level of indoor air quality specified as:

$$Q = \bar{Q} - I \tag{3.2}$$

where $\bar{Q} > 0$ is the initial endowment and I is the level of IAP. The level of IAP is given by:

$$I = \propto F_t + \beta F_m \tag{3.3}$$

where both ($\propto and\ \beta$) represent the levels or concentration of pollution and $\propto > \beta > 0$. This implies that the use of either energy leads to pollution, but t is dirtier (ibid). The level of IAP, as measured by energy used is influenced by averting behaviour and socio-economic factors. Averting behaviour takes into account actions that aim to minimise or reduce the level of IAP, for example purchase of improved stoves (Brandt and Hanemann, 2003).

The household maximises utility function (3.4) with respect to X, C, F_t and F_m as given by Chaudhuri et al. (2003):

$$U(X, C, I) \tag{3.4}$$

Subject to the budget constraint (3.5):

$$P_x X + P_t F_t + P_m F_m = Y \tag{3.5}$$

where Y is household income, X is consumption goods, P_x is the price of the bundle of consumption goods normalized to 1, P_t is the per-unit price of dirty energy and P_m is per unit price of clean energy, with $P_m > P_t$.

The household utility maximisation problem is:

$$\text{Max} \quad U = U\{X, C, I\ (F_t, F_m)\} \tag{3.6}$$

$$\text{s.t:} \ P_x X + P_t F_t + P_m F_m = Y \tag{3.7}$$

The Langragean function, where λ is the Langragean multiplier is:

$$L = U\{X, C, I\ (F_t, F_m)\} + \lambda[Y - X - P_t F_t - P_m F_m] \tag{3.8}$$

The first order conditions are shown in equation (3.8a), (3.8b) and (3.8c)

$$\frac{\partial U}{\partial X} = \lambda \tag{3.8a}$$

$$\frac{\partial U}{\partial I}\frac{\partial I}{\partial F_t} = \lambda P_t \tag{3.8b}$$

$$\frac{\partial U}{\partial I}\frac{\partial I}{\partial F_m} = \lambda P_m \tag{3.8c}$$

The solution to the utility maximisation problem yields the demand function for clean and dirty energy respectively.

$$F_t = F_t(P_t, P_m, P_c\ \ Y) \tag{3.9}$$

$$F_m = F_m(P_t, P_m, P_c \;\; Y) \tag{3.10}$$

$$X = X(P_t, P_m, P_c \;\; Y) \tag{3.11}$$

3.3.2 Empirical model

This section addresses the objective of determining the factors that influence the level of IAP. The theoretical model in 3.3.1 adopted from Chaudhuri and Pfaff (2003) is used.

Given equation (3.3) it is possible to estimate the reduced form equations [9] (3.9 and 3.10) to determine the factors that influence the level of IAP. It linearly[10] depends on the regressors, hence the empirical specification for the levels of IAP function is linear and given as:

$$I_j = \propto_o + \propto_1 \; S_j + \propto_2 \; D_j + \propto_3 \; L_j + \propto_4 \; Z_j + \varepsilon_j \tag{3.12}$$

where $\mathrm{j} = 1 \ldots\ldots \mathrm{J}$ indexes households; I is the level of IAP taken as fuel used, $\propto_o, \propto_1, \propto_2, \propto_3, and \;\; \propto_4$ are coefficients to be estimated; S_j is the fuel stove appliance used (including the traditional three stone stove, ordinary jiko, improved jiko, kerosene stove, gas cooker and electric cooker); D_j is type of dwelling (which includes the bungalow, flat, mansionette, swahili, shanty and manyatta/traditional houses); L_j is a vector of other living environment characteristics (including presence of chimney, wall of

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[9] Reduced form equations express endogenous variables as functions only of exogenous variables and disturbances (Murray, 2006).

[10] An equation is linear when the exponent value or the power of the variables (in this case S, D, L and Z) are 1(Greene, 2003).

the house, roof type, floor type and kitchen location); Z_j is the socio-economic characteristics (such as household head's age and gender, household size, household income, fuel price, distance to fuel source and geographical location) and ε_j is the error term.

As indicated earlier, different fuels have varying levels of IAP. To depict this in the econometric specification in (3.12), the dependent variable (levels of IAP, I) is categorised into five ordered levels: very high, high, medium, low and very low. In this study, the dependent variable is proxied by the main type of fuel used which include; firewood, charcoal, kerosene, LPG and electricity. These fuels correspond to the five ordered levels of IAP respectively.

To estimate equation (3.12), the ordered probit model is employed. This is because, first, it captures the ordered levels of IAP using five ordered categories of the dependent random variable (very high, high, medium, low and very low levels of IAP). Second, the ordered models have a better performance, especially considering that these models include only half as many parameters as the non-ordered models (Anderson, 1984). Third, when the dependent variable is ordinal, the errors are heteroscedastic and not normal, thus contravening the assumptions of OLS. This is addressed by ordered probit. Lastly, with the ordered models, the linear predictor is the same for each category. Only the constant/cut points differ (Farsi, Filippini, & Pachauri, 2005).

The ordered probit model of IAP levels is given as:

$$I_{ij}^{*} = \beta X_j' + \varepsilon_j \qquad (3.13)$$

where I_{ij}^{*} is the latent dependent variable, with regard to the type of fuel i in household j. $X_h^{'}$ is a vector of explanatory variables which include; fuel stove appliance used (traditional three stone stove, ordinary jiko, improved jiko, kerosene stove, gas cooker and electric cooker); type of dwelling(bungalow, flat, mansionette, swahili, shanty and manyatta/traditional houses); other household living environment (indicated by presence of chimney, type of wall, roof type, floor type and kitchen location); and socio-economic characteristics (such as household head's age and gender, household size, household income, and geographical location). The error term ε_j is normally distributed.

The ordinal variable I represents the levels of IAP and is the observed counterpart of I^{*}. Since I^{*} is unobserved, according to Greene (2003) the following is observed is:

$$I = \begin{cases} 1: if\ I_1^{*} \leq \mu_1 \\ 2: if\ \mu_1 < I_1^{*} \leq \mu_2 \\ 3: if\ \mu_2 < I_1^{*} \leq \mu_3 \\ 4: if\ \mu_3 < I_1^{*} \leq \mu_4 \\ 5: if\ \mu_4 < I_1^{*} \end{cases} \tag{3.14}$$

where $\mu_1, \mu_2, \mu_3,\ and\ \mu_4$ are parameters to be estimated. They denote the switch from one IAP level to another. There are five categories in this study:

$$I = \begin{cases} 1: if\ very\ high\ level\ of\ IAP \\ 2: if\ high\ level\ of\ IAP \\ 3: if\ medium\ level\ of IAP \\ 4: if\ low\ level\ of\ IAP \\ 5: if very\ low\ level\ of IAP \end{cases} \tag{3.15}$$

For a normally distributed error term, the conditional probabilities for each category are:

$$\Pr(y_i = 1|X_i) = \Phi\left(\mu_1 - X_i^{'}\beta\right) \tag{3.16}$$

$\Pr(y_i = 2|X_i) = \Phi\left(\mu_2 - X_i'\beta\right) - \Phi\left(\mu_1 - X_i'\beta\right)$

$\Pr(y_i = 3|X_i) = \Phi\left(\mu_3 - X_i'\beta\right) - \Phi\left(\mu_2 - X_i'\beta\right)$

$\Pr(y_i = 4|X_i) = \Phi\left(\mu_4 - X_i'\beta\right) - \Phi\left(\mu_3 - X_i'\beta\right)$

$\Pr(y_i = 5|X_i) = 1 - \Phi\left(\mu_4 - X_i'\beta\right)$

where Φ is the standard normal cumulative density function. The respective marginal effects of the independent variables on the probability of attaining the level of IAP are given by:

$$\frac{\partial \Pr(I=J|X)}{\partial X} = \beta\left[\phi\left(\mu_{J-1} - \beta'X\right)\right] - \phi\left(\mu_J - \beta'X\right) \qquad (3.17)$$

where ϕ is the standard normal density function.

The marginal effect for a binary independent variable, say d, would be

$$\text{Marginal effect} = Prob\left[\mathrm{Y} = 1|\bar{X}_{(d)}, \mathrm{d} = 1\right] - Prob\left[\mathrm{Y} = 1|\bar{X}_{(d)}, \mathrm{d} = 0\right] \qquad (3.18)$$

where $\bar{X}$ denotes the means of all other variable in the model.

In order to have consistent and unbiased estimates, endogeneity and unobserved heterogeneity are identified as potential econometric problems and addressed.

Estimation issues: Endogeneity and unobserved heterogeneity

Endogeneity occurs when there is a correlation between the explanatory variables and the models residuals (Wooldridge, 2002). If endogeneity is present and not addressed, it may lead to biased and inconsistent estimates. In particular, it may lead to type I error (hypothesis that in fact is true is rejected) or type II error (hypothesis that is in fact false is not rejected). There are three sources of endogeneity: model misspecification or omitted variable, measurement error, and simultaneity (Wooldridge, 2002). Endogeneity may be a problem in more than one form. The solution depends on the type/source of endogeneity. Common methods used to address endogeneity are the instrumental variable and use of control functions

Heterogeneity occurs where there is unobserved variation across individual units studied. It is a common problem in cross sectional data where correlation between observables and unobservable is expected. According to Cameron and Trivedi (2005), when unobserved heterogeneity is not addressed, it may lead to confounding bias[11]. Unobserved heterogeneity bias can have substantial impact on the size, sign and significance of the parameter estimates.

The type of fuel appliance (S_j) and type of dwelling (D_j) may be endogenous as discussed by Pant (2008). The type of fuel appliance (S_j) is considered endogenous because the decision to use a particular type of fuel appliance may be influenced by the level of IAP. A household may, for example, decide to switch from a traditional three stone stove to a gas cooker in an attempt to lower or reduce the levels of IAP.

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[11] Confounding bias is the incorrect omission of regressors from the model and the inclusion of other variables that are proxies for the omitted variable (Cameron and Trivedi, 2005).

The type of dwelling (D_j) is considered endogenous because the decision to use a particular type of fuel may depend on the type of dwelling. Mansionettes and flats dwellers are unlikely to use firewood as a fuel of choice. When firewood is used, it produces soot which lowers the aesthetic of the dwelling. It is for this reason that most tenancy agreements prohibit tenants from using firewood and charcoal.

Changes in income may influence both the type of fuel and dwelling. As household's income increases, they tend to build/rent better houses, which may dictate the use of modern energy (i.e. the installation of electricity) and use of modern technology (such as gas cooker or electric cooker).

In order to correct for the endogeneity, equations (3.12), (3.19a), and (3.19b) are estimated jointly, where the endogenous variables; type of fuel appliance (S_j) and the type of dwelling (D_j) appear as predictors in equation (3.12).

$$S_j = \beta X_{1j} + \varepsilon_{1j} \qquad (3.19a)$$

$$D_j = \delta X_{2j} + \varepsilon_{2j} \qquad (3.19b)$$

X_1 and X_2 are independent variables that influence the type of fuel appliance used and the type of dwelling owned, respectively. They also include the control variables that help address the problem of unobserved heterogeneity. The dummy variables S_j and D_j are response variables and enter equation (3.12) as endogenous variables estimated by parameter β and δ in equation (3.19a) and (3.19b), respectively.

The dependent variable (I) is an ordered variable, while S_j and D_j are the two endogenous variables. Therefore, a Conditional Mixed Process (CMP) instrumental variable ordered probit with two endogenous regressors is used to correct the suspected endogeneity. A CMP fits a multi equation system and also allows different equations which have different kinds of dependent and independent variables to be estimated. CMP is also appropriate for models where some equations are structural, while others are reduced form, providing instruments for identification of the parameters in the structural equations, as in two-stage least squares. In this case, CMP is a limited-information (LIML) estimator, and only the final stages' coefficients are structural (Roodman, 2011). Using the two stage least squares, linear probability models with instrumental variables, and the control function approach as methods of controlling endogeneity, may lead to inconsistent results.

To find out if the two variables (type of fuel appliance and type of dwelling) are endogenous, an exogeneity test is carried out using the estimates of atanhrho[12]. The atanhrho estimate shows whether there is correlation between the treatment equation (type of appliance and type of dwelling) and the errors of the outcome equation (IAP). The null hypothesis states that the correlation is zero (atanhrho = 0).

If the null hypothesis is not rejected, the type of fuel appliance and type of dwelling variables are considered exogenous to the outcome equation (IAP equation). In this case, the ordered probit model, which assumes exogeneity is used to determine the factors that

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[12] Atanhrho is a transformed rho. The exogeneity test is inbuilt and forms part of the output with the CMP command.

influence the levels of IAP (as shown by equation 3.12), where the estimators are considered valid and efficient. Alternatively, when we reject the null hypothesis, it implies there is endogeneity. The instrumented variable ordered probit model (CMP IV ordered probit) is used to jointly estimate equations (3.12), (3.19a) and (3.19b), with valid estimators from the first equation of the three equation system[13].

3.4 Data and description of variables

The data used for analysis are secondary data drawn from the Kenya Integrated Household Budget Survey (KIHBS) 2005/6 database. It was based on the National Sample Survey and Evaluation Programme (NASSEP-IV) sampling frame. It comprises 1,800 clusters selected with probability proportion to size (PPS) from a set of all Enumeration Areas (EA) used during the 1999 Population and Housing Census. The data was collected from all eight provinces in the country. The KIHBS clusters sampled in each district now county were selected with equal probability from the NASSEP-IV frame, where a total of 13,430 households were targeted. The survey was conducted in 1,339 sampling units/clusters across all districts in Kenya, and comprised 857 rural and 482 urban clusters. The data was collected by KNBS.

KIHBS is one the richest database in Kenya in the last 10 years, and has detailed information on household energy use, health and welfare linkages that is crucial in the analysis of this study. Thus, KIHBS remains significantly relevant for analysis today, especially given that there has not been significant transformation changing the energy

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[13] Over identification tests for this kind of models are not available.

use patterns or change in socio-economic status of many households as discussed in chapter 2.

The variables obtained from the KIHBS and used in this study include: both the dependent and independent variables. The dependent variable is the level of IAP. The independent variables include: fuel stove appliance used; type of dwelling; other living environment characteristics indicated by presence of chimney, type of wall, roof type, floor type and kitchen location; and socio-economic characteristics such as household head's age and gender, household size, household income, and geographical location.

The description and measurement of the variables used is as follows:

<u>*Level of IAP*</u> (*iap*): This is the dependent variable, and represents the varying levels of IAP. It is an ordinal variable where it indicates 1 if very high, 2 if high, 3 if medium, 4 if low, and 5 if very low levels of IAP. The level of IAP is proxied by the main fuel which include; firewood, charcoal, kerosene, LPG and electricity. The fuels are ordered corresponding to their level of emissions. For example, firewood has the highest emissions while electricity has the least emissions.

<u>*Fuel stove appliance*</u> (*appliance*): This is the appliance used to burn fuel. It is represented by eight dummy variables, each of which represents a specific type of appliance. In particular, the fuel stove appliance includes; traditional three stone stove (*tradstove*), ordinary jiko (*ordjiko*), improved jiko (*imprstove*), kerosene stove (*kerostove*), gas cooker (*gascooker*), electric cooker (*eleccooker*), and other stove (*otherstove*). It should be noted that when one fuel stove appliance is considered, it takes a value of 1, while the other fuel

stove appliance takes a value of 0. Ezatti et al. (2002) found clean fuels and stoves have lower average emission concentrations. Therefore, it is anticipated that households that adopt stoves which require use of clean fuels are likely to have lower levels of IAP.

Type of dwelling (*dwelling*): This defines the type of house. There are seven types of dwelling, each represented by a dummy variable. They include: bungalow house (hse*bungalow*), flat house (*flat*), mansionette house (*mansionette*), swahili house (*swahili*), shanty house (*shanty*), manyatta house (*manyattatradhse*), and other dwelling (*otherdwelling*). When one type of dwelling is observed, it takes the value 1 and 0 otherwise. Type of dwelling is an important variable. Adhikari (2012) indicates that the type of dwelling is a proxy for wealth and the ability to take avertive actions.

Type of wall (*wall*): This is used to define the type of wall a particular house is made of. It is represented by nine dummy variables, each of which represents a specific type of wall. In particular, the type of wall includes; stone wall (*stone-wall*), brick-block wall (*brikblok-wall*), mud-wood wall (*mudwood-wall*), mud-cement wall (*mudcement-wall*), wood wall (*wood-wall*), corrugated-iron wall (*cor-wall*), grass-straw wall (*grassstraw-wall*) and other wall (*other-wall*). When one type of wall is observed, it takes the value 1 and 0 otherwise. Using construction materials that are permeable reduces the level of IAP (Dasgupta et al., 2007). Houses constructed with tin and thatch walls have lower levels of IAP compared to mud and brick walls (ibid).

Type of roof (*roof*): This defines the type of roofing. There are eight types of roof each represented by a dummy variable. They include: tin roof (*tin-roof*), corrugated-iron roof (*cor-roof*), tiled roof (*tiled-roof*), concrete roof (*concrete-roof*), asbestos roof (*asbestos-*

roof), grass roof (*grass-roof*), makuti roof (*makuti-roof*), and other roof (*other-roof*).If a particular type of roof is observed, it takes a value of 1 and 0 otherwise. Tined roofs have lower levels of IAP than mud, thatch and brick (Dasgupta et al., 2007).

Type of floor (floor): This is the type of floor a house is made of, which is represented by five dummy variables, each of which captures a specific type of floor. The type of floors include: cement floor (*cement-floor*), tiled floor (*tiled-floor*), wood floor (*wood-floor*), earthed floor (*earthed-floor*), and other floor (*other-floor*). If a specific type of floor is observed, it takes a value of 1 and 0 otherwise. It is expected that the levels of IAP will differ depending on the permeability of the type of floor.

Type of kitchen (*kitchen*): It defines the location of the kitchen/the cooking location. There are six types of kitchen, each represented by a dummy variable. They include: outdoor-kitchen (*outdoor-kitchen*), enclosed detached kitchen (*encdet-kitchen*), enclosed attached kitchen (*encatd-kitchen)*, indoor without partition kitchen (*indwout-kitchen*), indoor-with-partition kitchen (*indwith-kitchen*), and other floor (*other-kitchen*).When one type of kitchen is observed, it takes the value 1 and 0 otherwise. It is expected that those who cook outside have low levels of IAP.

Chimney (*chimney*): It is a type of ventilation represented by dummy variable that takes the value 1 if presence of chimney is observed and 0 otherwise. It is assumed that with presence of a chimney, there is ventilation which reduces the level of IAP.

Head-gender (*headgender*): This refers to the sex of the household head and is equal to 1 if the head is male and 0 otherwise. The exposure levels for males and females from IAP are different. Women’s roles including cooking tend to expose them more than men who work outside home (Adhikari, 2012).

Head-age (*headage*): Age of the household head in years. Aging increases the chances of falling ill as the health-stock deteriorates (Adhikari, 2012).

Head-age square (*headagesq*): This is the square of the age of the household head. It is used to capture non-linearity between age and IAP.

Head-education (*headeduc*): This is the education level of the household head. It is represented by four dummy variables each of which represents a specific level of education. The four level of education include: head with primary education (*hdprims*), head with secondary education (*hdsec*), head with graduate education (*hdgrad*), and head with no education (*hdnosch*). It should be noted that when one education level is considered it takes a value of 1 and 0 otherwise. It is expected that those who are educated are more concerned about their indoor air quality. Pant et al. (2008) found that indoor air quality is an increasing function of education.

Household size (*hhldsize*): It is the total number of members in a particular household. It is expected that those with large household members are less exposed to IAP. This may be because with a large household, roles are easily shared including cooking. This therefore reduces the chances of a household member from being extremely exposed to IAP.

Employment (*empy*): This is a dummy variable that captures those household heads on paid employment. It takes the value 1, when the household head is on paid employment and 0 otherwise. It is expected that those who are in paid employment are likely to adopt avertive actions that reduce the level of IAP than those who are in unpaid employment such as the unpaid family worker and those on apprentice.

Location (*rural*): This is the geographic location of the residence represented by a dummy variable which equals 1 when it is a rural and 0 if urban. It is expected that those who live in rural areas are more likely to be exposed to IAP because they are the major consumers (87.7%) of firewood.

Household expenditure (income): This is the total amount spent by households per month in Kenyan shillings. It is used as a proxy for income and the ability to take avertive actions.

This information is also captured in table 3.1 which shows the name of the variable, definition and how it is measured

3.5 Results and discussion

This section discusses the results obtained from the analysis that examined the factors influencing the levels of IAP. The section firsts presents the descriptive statistics followed by the empirical regression models.

Table 3.1: Definition of variables used in the regression models

Variable Name	Definition	Measurement
Level of IAP	It is the dependent variable, and represents the varying levels of IAP	It is an ordinal variable where it indicates 1 if very high, 2 if high, 3 if medium, 4 if low, and 5 if very low levels of IAP
Fuel stove appliance	It is the appliance used to burn fuel.	It is captured by 8 dummy variables that includes; traditional three stone stove (tradstove), ordinary jiko (ordjiko), improved jiko (imprstove), kerosene stove (kerostove), gas cooker (gascooker), electric cooker (eleccooker), and other stove (otherstove). It should be noted that when one fuel stove appliance is considered, it takes a value of 1, while the other fuel stove appliance takes a value of 0
Type of dwelling	It is the type of house	It is has seven types of dwelling, each represented by a dummy variable. They include: bungalow house (hsebungalow), flat house (flat), mansionette house (mansionette), swahili house (swahili), shanty house (shanty), manyatta house (manyattatradhse), and other dwelling (otherdwelling). When one type of dwelling is observed, it takes the value 1 and 0 otherwise.
Type of wall	It is the type of wall the house is made of	It is captured by nine dummy variables. They include; stone wall (stone-wall), brick-block wall (brikblok-wall), mud-wood wall (mudwood-wall), mud-cement wall (mudcement-wall), wood wall (wood-wall), corrugated-iron wall (cor-wall), grass-straw wall (grassstraw-wall) and other wall (other-wall). When one type of wall is observed, it takes the value 1 and 0 otherwise.
Type of floor	It is the type floor of the house	It is represented by five dummy variables, each of which captures a specific type of floor. The type of floors include: cement floor (cement-floor), tiled floor (tiled-floor), wood floor (wood-floor), earthed floor (earthed-floor), and other floor (other-floor). If a specific type of floor is observed, it takes a value of 1 and 0 otherwise.
Type of kitchen	It defines the location of the kitchen/the cooking location	It is captured buy six dummy variable. They include: outdoor-kitchen (outdoor-kitchen), enclosed detached kitchen (encdet-kitchen), enclosed attached kitchen (encatd-kitchen), indoor without partition kitchen (indwout-kitchen), indoor-with-partition kitchen (indwith-kitchen), and other floor (other-kitchen).When one type of kitchen is observed, it takes the value 1 and 0 otherwise
Chimney	It is a type of ventilation	It is represented by dummy variable that takes the value 1 if presence of chimney is observed and 0 otherwise
Head gender	It refers to the sex of the household head	It is equal to 1 if the head is male and 0 otherwise.

Variable Name	**Definition**	**Measurement**
Head age	It is the age of the household head	It is the age of the household head in years
Head age square	It is the squared-age of the household head	This is the square of the age of the household head in years
Head education	This is the education level of the household head.	The four level of education include: head with primary education (hdprims), head with secondary education (hdsec), head with graduate education (hdgrad), and head with no education (hdnosch). It should be noted that when one education level is considered it takes a value of 1 and 0 otherwise
Household size	The size to the household	It is the total number of members in a particular household.
Employment	It is the occupation of the household head	This is a dummy variable that captures those household heads on paid employment. It takes the value 1, when the household head is on paid employment and 0 otherwise.
Location	This is the geographic location of the residence	It is represented by a dummy variable which equals 1
Household expenditure	It used as a proxy for income	This is the total amount spent by households per month in Kenyan shillings.

3.5.1 Descriptive statistics

The descriptive statistics highlight the summary statistics of the various variables and captures the number of observations for each variable used. The mean, and standard deviation are some of the summary statistics that are presented in Table 3.2. The table shows different variables having different numbers of observations, mean and standard deviation. The missing values on some variables, for instance the type of fuel stove appliance used and type of dwelling explain why the total number of observations for the affected variable is small.

Table 3.2: Descriptive statistics of variables used in estimating factors determining IAP

	Full Sample		Very High IAP Sample		High IAP Sample		Medium IAP Sample		Low IAP Sample		Very Low IAP Sample	
Variable	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
Type of stove appliance												
Traditional stove (=1 if appliance used is a traditional three stone, 0 otherwise)	12,989	0.58	8,350	0.701	2,346	0.439	1,396	0.29	535	0.179	105	0.267
Improved stove (=1 if appliance used is an improved stove, 0 otherwise)	12,989	0.0753	8,350	0.0841	2,346	0.0725	1,396	0.0509	535	0.0374	105	0.00952
Ordinary jiko (=1 if appliance used is an ordinary jiko, 0 otherwise)	12,989	0.1	8,350	0.072	2,346	0.165	1,396	0.132	535	0.144	105	0.124
Improved jiko (=1 if appliance used is an improved jiko, 0 otherwise)	12,989	0.0859	8,350	0.0661	2,346	0.145	1,396	0.0953	535	0.0991	105	0.0667
Kerosene stove (=1 if appliance used is a kerosene stove, 0 otherwise)	12,989	0.105	8,350	0.0517	2,346	0.123	1,396	0.293	535	0.301	105	0.295
Gas cooker (=1 if appliance used is a gas cooker, 0 otherwise)	12,989	0.0402	8,350	0.0181	2,346	0.0384	1,396	0.107	535	0.191	105	0.21
Electric (=1 if appliance used is an electric, 0 otherwise)	12,989	0.00593	8,350	0.00204	2,346	0.00554	1,396	0.015	535	0.0318	105	0.0286
Type of dwelling												
Bungalow (=1 if dwelling is bungalow, 0 otherwise)	12,989	0.546	8,351	0.566	2,346	0.557	1,395	0.459	535	0.4	105	0.276
Flat (=1 if dwelling is flat, 0 otherwise)	12,989	0.036	8,351	0.0128	2,346	0.0409	1,395	0.113	535	0.163	105	0.114
Mansionette (=1 if dwelling is mansionette, 0 otherwise)	12,989	0.0116	8,351	0.00539	2,346	0.00512	1,395	0.033	535	0.0673	105	0.114
Swahili (=1 if dwelling is swahilli, 0 otherwise)	12,989	0.117	8,351	0.0869	2,346	0.14	1,395	0.24	535	0.178	105	0.2
Shanty (=1 if dwelling is shanty, 0 otherwise)	12,989	0.0399	8,351	0.037	2,346	0.0345	1,395	0.0337	535	0.11	105	0.124
Manyatta/traditional (=1 if dwelling is manyatta/traditional house, 0 otherwise)	12,989	0.209	8,351	0.259	2,346	0.163	1,395	0.076	535	0.0505	105	0.0762
Type of wall												
Stone-wall (=1 if wall is stone , 0 otherwise)	12,990	0.141	8,351	0.0849	2,346	0.177	1,396	0.321	535	0.363	105	0.314
Brick & block-wall (=1 if wall is brick & block , 0 otherwise)	12,990	0.17	8,351	0.151	2,346	0.177	1,396	0.233	535	0.211	105	0.19
Mud & wood-wall (=1 if wall is mud & wood, 0 otherwise)	12,990	0.432	8,351	0.491	2,346	0.401	1,396	0.236	535	0.202	105	0.286
Mud &cement-wall (=1 if wall is mud & cement , 0 otherwise)	12,990	0.0627	8,351	0.0656	2,346	0.0699	1,396	0.0458	535	0.0336	105	0.0286
Wood-wall (=1 if wall is wood , 0 otherwise)	12,990	0.0955	8,351	0.0969	2,346	0.102	1,396	0.0931	535	0.0804	105	0.0571
Corrugated iron-wall (=1 if wall corrugated iron, 0 otherwise)	12,990	0.0323	8,351	0.0212	2,346	0.0422	1,396	0.0516	535	0.0935	105	0.105
Grass & straw-wall (=1 if wall is grass & straw, 0 otherwise)	12,990	0.044	8,351	0.0627	2,346	0.0149	1,396	0.00501	535	0.00187	105	0.00952
Tin-wall (=1 if wall is tin , 0 otherwise)	12,990	0.00239	8,351	0.00192	2,346	0.00298	1,396	0.00358	535	0.00187	105	0.00952

Source: Authors computation based on KIHBS 2005/06

	Full Sample		Very High IAP Sample		High IAP Sample		Medium IAP Sample		Low IAP Sample		Very Low IAP Sample	
Variables	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
Type of roof												
Corrugated iron-roof (=1 if roof is corrugated iron , 0 otherwise)	12,990	0.707	8,351	0.686	2,346	0.771	1,396	0.726	535	0.662	105	0.686
Tiles-roof (=1 if roof is tiles , 0 otherwise)	12,990	0.0251	8,351	0.0125	2,346	0.0171	1,396	0.0645	535	0.127	105	0.114
Concrete-roof (=1 if roof is concrete, 0 otherwise)	12,990	0.0252	8,351	0.0073	2,346	0.0303	1,396	0.086	535	0.116	105	0.0952
Asbestos-roof (=1 if roof is asbestos , 0 otherwise)	12,990	0.00754	8,351	0.00419	2,346	0.00895	1,396	0.0186	535	0.0243	105	0.00952
Grass-roof (=1 if roof is grass , 0 otherwise)	12,990	0.169	8,351	0.212	2,346	0.131	1,396	0.0509	535	0.0336	105	0.0571
Makuti-roof (=1 if roof is makuti , 0 otherwise)	12,990	0.0323	8,351	0.0332	2,346	0.0256	1,396	0.0466	535	0.0243	105	0.0286
Tin-roof (=1 if roof is tin , 0 otherwise)	12,990	0.00331	8,351	0.00359	2,346	0.00298	1,396	0.00215	535	0.00374	105	0.00952
Type of floor												
Cement-floor (=1 if floor is cement , 0 otherwise)	12,989	0.397	8,351	0.303	2,346	0.509	1,396	0.645	534	0.631	105	0.524
Tiles-floor (=1 if floor is tiles , 0 otherwise)	12,989	0.0122	8,351	0.00671	2,346	0.00767	1,396	0.0315	534	0.0618	105	0.0571
Wood-floor (=1 if floor is wood, 0 otherwise)	12,989	0.0161	8,351	0.0138	2,346	0.0102	1,396	0.0229	534	0.0581	105	0.0571
Earth-floor (=1 if floor is earth , 0 otherwise)	12,989	0.572	8,351	0.674	2,346	0.472	1,396	0.294	534	0.243	105	0.352
Education												
Head graduate education (=1 if education level completed is graduate , 0 otherwise)	13,212	0.00984	1,627	0.00676	439	0.00228	260	0	95	0.0105	25	0
Head secondary education (=1 if education level completed is secondary, 0 otherwise)	13,212	0.153	1,627	0.122	439	0.128	260	0.112	95	0.0947	25	0.12
Head primary education (=1 if education level completed is primary , 0 otherwise)	13,212	0.459	1,627	0.498	439	0.487	260	0.481	95	0.537	25	0.24
Head no education (=1 if no education, 0 otherwise)	13,212	0.0232	1,627	0.0166	439	0.0159	260	0.0154	95	0.0105	25	0.04
Type of kitchen												
Outdoor-kitchen (=1 if kitchen is located outdoor , 0 otherwise)	12,991	0.173	8,352	0.201	2,346	0.151	1,397	0.0981	534	0.0543	105	0.0762
Enclosed and detached-kitchen (=1 if kitchen is enclosed and detached, 0 otherwise)	12,991	0.317	8,352	0.372	2,346	0.258	1,397	0.181	534	0.125	105	0.143
Enclosed and attached-kitchen (=1 if kitchen is enclosed and attached, 0 otherwise)	12,991	0.117	8,352	0.0923	2,346	0.142	1,397	0.16	534	0.238	105	0.267
Indoor with partition-kitchen (=1 if kitchen is indoor with partition, 0 otherwise)	12,991	0.294	8,352	0.253	2,346	0.329	1,397	0.409	534	0.429	105	0.419
Indoor without partition-kitchen (=1 if kitchen is indoor without partition, 0 otherwise)	12,991	0.093	8,352	0.0759	2,346	0.11	1,397	0.14	534	0.146	105	0.0952
Other household characteristics												
Chimney (=1 if there is presence of chimney, 0 otherwise)	12,988	0.0762	8,349	0.06	2,346	0.0857	1,396	0.117	535	0.157	105	0.152
Female head (=1 if the head is female, 0 otherwise)	13,212	0.297	1,627	0.301	439	0.317	260	0.315	95	0.368	25	0.28

Head age	13,155	44.11	1,621	45.44	437	46	259	46.53	95	46.06	25	40.04
Head age squared	13,212	2,212	1,627	2,346	439	2,383	260	2,430	95	2,345	25	1,730
Household size	13,212	5.05	1,627	5.187	439	5.328	260	5.608	95	4.989	25	5.56
Employed (=1 if in paid employment, 0 otherwise)	4,303	0.694	552	0.734	161	0.745	90	0.689	35	0.743	11	0.818
Rural (=1 if residing in rural area, 0 otherwise)	13,158	0.644	8,357	0.63	2,348	0.661	1,414	0.673	542	0.694	106	0.585
Income	13,118	3,602	8,367	3,551	2,353	3,869	1,412	3,144	542	4,042	106	4,520

Source: Authors computation based on KIHBS 2005/06

The summary statistics in Table 3.3 for instance show that the *headage* variable indicated that the head of the household had an average age of 44 years. An average of 58 percent households owned traditional stove (*tradstove),* with those with very high levels, high levels and medium levels of IAP being 70 percent, 44 percent and 29 percent respectively; while those with low and very low levels IAP were 18 percent and 27 percent respectively.

Only 7.6 percent of the households had presence of chimney. The proportion of those with presence of chimney was observed on households with very high, high, medium, low and very low levels of IAP at 15.7 percent, 15.2 percent, 11.7 percent, 8.6 percent and 6 percent respectively. An estimate of 64 percent of the household lived in rural location while an average household size had about 5 members. Among those educated household heads, 10 percent had graduate education, secondary education (15%), primary education (46%), and only 2.3 percent had no education.

3.5.2 Regression results

This section presents the results of the models estimated (on the determinants of IAP) as presented in equation (3.12), (3.19a) and (3.19b). The models estimated included the ordered probit and the Conditional Mixed-Process (CMP) ordered probit which identify presence of endogeneity and corrects for potential endogeneity. In both models, the levels of IAP (dependent variable) was captured by a categorical ordinal variable with 1, 2 ,3, 4 and 5 indicating very high, high, medium, low and very low levels of IAP. The independent variables used included variables from type of fuel stove appliance, and living environment characteristics, that is the type of dwelling and socioeconomic characteristics.

As noted earlier in preceding sections, type of fuel stove appliance and type of dwelling are potential endogenous. There are different types of fuel stove appliance including traditional stove, ordinary jiko, improved stove, kerosene stove, gas cooker and electricity cooker, while the different types of dwelling consist of mansionette house, flat house, bungalow house, shanty house, swahili house, and traditional/manyatta house. Given the many different types of fuel appliance and types of dwelling, it was important to reduce both the types of fuel stove appliance and types of dwelling. The Principal Component Analysis (PCA) was used to identify the dominant types of fuel stove appliance and the dominant types of dwelling. PCA aims at reducing the number variables of interest into a smaller set of components to allow for meaningful interpretation[14]. Among the dominant variables identified for type of fuel stove appliance were traditional stove, kerosene stove and ordinary jiko, while for types of dwelling were bungalow house, manyatta/traditional house and swahili house.

Several models were estimated using the dominant variables identified for fuel stove appliance and types of dwelling. The use of ordinary jiko (*ordjiko*) as a dominant type of fuel stove appliance and manyatta/traditional house (manyattatradhse) as a dominant type of dwelling, in addition to other independent variables, provided the best fitted models as shown in Table 3.3 (Appendix Table A.1). Columns 1 and 2 present the results for the ordered probit model, while columns 3 and 4 present the results for the CMP ordered probit that addresses potential endogeneity.

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[14] In order to identity the number of components to keep, PCA uses either a scree plot or keeps every component with an Eigen value over 1. To identify the variables that are most strongly correlated with each component, absolute correlation value above 0.5 is considered important (Eberly College of Sciences - ECS, 2015).

Table 3.3: Ordered probit and CMP ordered probit models for estimating determinants of IAP levels

	Ordered Probit		CMP Ordered Probit	
Manyatta/traditional house	-0.567**	(0.123)	-0.432*	(0.183)
Ordinary jiko	0.216	(0.135)	0.248	(0.204)
Female head	0.070	(0.093)	0.071	(0.090)
Household size	-0.008	(0.018)	-0.009	(0.017)
Headage	0.005	(0.017)	0.005	(0.016)
Headagesquared	-0.00007	(0.0001)	-0.0008	(0.000)
Head graduate education	-4.667	(160.199)	-4.214**	(0.271)
Head secondary education	-0.204	(0.136)	-0.189	(0.133)
Head primary education	-0.189*	(0.092)	-0.183*	(0.090)
Employed	-0.042	(0.096)	-0.041	(0.091)
Rural	0.098	(0.093)	0.093	(0.093)
Income	0.00002**	(0.000)	0.000+	(0.000)
cut1_cons	0.326	(0.398)	0.429	(0.400)
cut2_cons	0.963*	(0.399)	1.052**	(0.398)
cut3_cons	1.598**	(0.403)	1.674**	(0.399)
cut4_cons	2.217**	(0.413)	2.282**	(0.423)
antanhrho_12_cons			-0.350**	(0.059)
antanhrho_13_cons			0.339+	(0.182)
antanhrho_23_cons			-0.107	(0.151)
N		831		12986
LR Chi-square (28)		44.72	Wald Chi-square (60)	2347.23
Log likelihood		-821.928	Log-Pseudo likelihood	1102.36
Prob > Chi2		0.0000	Prob > Chi2	0.000
Pseudo R^2		0.0265		

Standard errors in parentheses

+ 0.10* <0.05** p<0.01"

The ordered probit estimations were done for the five different levels of IAP without addressing possible endogeneity. The effect of manyatta/traditional house, household heads with primary education and income variables on the levels of IAP were found to be statistically significant. Income variable had a positive coefficient while the household head with primary education variable had a negative coefficient as expected. Manyatta house variable had a negative coefficient though this was not expected.

However, when estimating the models using the CMP ordered probit that addresses potential endogeneity; manyatta house, household head with graduate education, household head with primary education, and income variables were found to be statistically significant. In addition, the coefficient for manyatta house variable was significant in both the ordered probit and CMP ordered probit. The coefficient for Manyatta house (-4.333) was high in the CMP ordered probit model by 23.6 percent, when compared to ordered probit model. The coefficients for the other independent variables were almost similar for the two models.

To identify if a manyatta house (a type of dwelling) and ordinary jiko (a type of fuel stove appliance) variables are endogenous and cause of this differences; the exogeneity test was carried out using the atanhrho estimates[15]. The null hypothesis of the exogeneity test states that there is no correlation. There were three antanhrho estimates as follows: (i) antanhrho_12 that relates type of manyatta house and ordinary jiko equations, (ii) antanhrho_13 that relates type of dwelling and IAP equations, and (iii) antanhrho_23 that relates ordinary jiko and IAP equations.

The results of all the three antanhrho estimates were found to be significant except for antanhrho_23. The significance of antanhrho_13 implies that manyatta house is an endogenous variable in equation (3.12) (that estimates the levels of IAP equation). The significance of antanhrho_12 implies that manyatta house equation (3.19a) and ordinary jiko equation (3.19b) are endogenous variables in each other’s equation. This suggests that using the results of the ordered probit estimates, which assumes exogeneity, would lead to biased results. Therefore, the remaining section discusses the result of the CMP ordered probit model.

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[15] Antanhrho estimate refers to a transformed rho. It checks whether there is correlation between the treatment equation (ie manyatta house and ordinary jiko) and the errors of the outcome equation (level of indoor air pollution).

Cut points/thresholds 1 – 4 for CMP ordered probit model (Column 4 Table 3.1) are the estimated cut points on the latent variable used to differentiate very low levels of IAP from low, medium, high and very high levels of IAP when values of the predictor variables are evaluated at zero. Subjects that had a value of 0.429 or less on the underlying latent variable that gave rise to our levels of IAP variable would be classified as very high levels of IAP. Subjects that had values between 0.429 and 1.052 on the underlying latent variable that gave rise to the levels of IAP variable would be classified as high levels of IAP. Those between 1.052 and 1.674 subjects would be classified as medium levels of IAP, while those between 1.674 and 2.282 subjects values would be classified as low levels of IAP. Those with subject values above 2.2282, would be classified as very low levels of IAP.

According to Greene and Hensher (2009), it is not possible to directly interpret the coefficients of ordered probit estimates, instead the marginal effects of CMP ordered probit model are used (Table 3.4).

The marginal effect for manyatta house variable was significant at 1 percent for all the five levels of IAP, however it was only found to have a positive marginal effect for very high levels of IAP, according to the a priori expectations set out earlier. The marginal effects show that a one percentage point increase in the probability of living in a manyatta house results to: (i) a 0.138 percentage point increase in the probability of having very high level of IAP, (ii) a 0.062, 0.048, 0.021, and 0.008 percentage point reduction in the probability of having high, medium, low and very low levels of IAP. Correlation results also show that high levels of IAP were positively associated with manyatta house at 25.9 percent, compared to 5.1 percent for those with low levels of IAP.

Table 3.4: Marginal effects of CMP ordered probit model for estimating determinants of IAP levels

	Very High IAP		High IAP		Medium IAP		Low IAP		Very Low IAP	
Manyatta house(d)	0.138*	(0.056)	-0.062*	(0.028)	-0.047*	(0.020)	-0.021*	(0.009)	-0.008*	(0.003)
Ordinary jiko (d)	-0.090	(0.073)	0.033	(0.027)	0.032	(0.026)	0.017	(0.014)	0.007	(0.006)
Female head	-0.024	(0.031)	0.010	(0.013)	0.009	(0.011)	0.004	(0.005)	0.002	(0.002)
Household size	0.003	(0.006)	-0.001	(0.002)	-0.001	(0.002)	-0.001	(0.001)	-0.000	(0.000)
Head age	-0.002	(0.005)	0.001	(0.002)	0.001	(0.002)	0.000	(0.001)	0.000	(0.000)
Head age squared	0.000	(0.000)	-0.000	(0.000)	-0.000	(0.000)	-0.000	(0.000)	-0.000	(0.000)
Head graduate	1.457**	(0.147)	0.598**	(0.075)	-0.515**	(0.079)	-0.247**	(0.055)	-0.097*	(0.040)
Head secondary	0.065	(0.047)	-0.027	(0.019)	-0.023	(0.017)	-0.011	(0.008)	-0.004	(0.003)
Head primary	0.063*	(0.032)	-0.026*	(0.013)	-0.022+	(0.012)	-0.011+	(0.006)	-0.004	(0.003)
Employed	0.014	(0.031)	-0.006	(0.013)	-0.005	(0.011)	-0.002	(0.005)	-0.001	(0.002)
Rural	-0.032	(0.032)	0.013	(0.013)	0.011	(0.012)	0.005	(0.006)	0.002	(0.002)
Income	-0.000+	(0.000)	0.000+	(0.000)	0.000+	(0.000)	0.000+	(0.000)	0.000	(0.000)
N	12986									
Wald Chi-square (60)	2347.23									
Log-Pseudo likelihood	1102.36									
Prob > Chi2	0.0000									

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

+ p<0.10 * p<0.05 **p<0.01

The marginal effects of household heads with graduate and primary education variables were found to be significant for all the five levels of IAP, but they had a positive coefficient for very high level of IAP against the expectations. Pant et al. (2008) found that indoor air quality in rural areas of central Nepal is an increasing function of education. The study findings can also be explained using cross tabulations between the levels of IAP and household heads with graduate education. Out of 0.9 percent of household heads with graduate education, 0.6 percent experience very high levels of IAP. This may imply that even though education creates awareness on the dangers of IAP, it may not be the only vital factor that influences the level of IAP. In addition, household heads with primary education are observed to use both traditional and modern energy technologies while household heads with graduate education are observed to use only traditional energy technologies. It means that when selecting cooking energy household heads with primary education are more driven by socio-economic status rather than achieving greater fuel efficiency and lower levels of pollution. It could also imply that household head with graduate and primary education are likely to be the ones who do the cooking.

The marginal effect for income variable was significant at 10 percent across the five levels of IAP except for very low IAP. It only had a negative coefficient for very high level IAP. This outcome corresponds to the expected results as discussed by Masera et al. (2000) who show that those that experience low pollution are associated with high incomes and can afford to purchase costly energy technologies including clean fuels and advanced fuel stove appliances.

CMP ordered probit model is used not only to address potential endogeneity, but also to provide in detail the unobserved factors of the endogenous variables (manyatta house and ordinary jiko). As earlier indicated, manyatta house was found to be an endogenous variable affecting the levels of IAP. It is therefore important to understand the underlying unobserved factors of manyatta house. Table 3.5 presents the marginal effects for living in a manyatta house. Using the other-type of walls as the reference, the coefficients for stone walls, mud-cement walls, wood walls, corrugated-iron walls, and tin walls were all statistically significant at 1 percent and were negative. This implies that those who dwell in a manyatta house are less likely to have walls build on stones, mud/cement, wood, corrugated-iron and tin building materials. A cross tabulation between the type of wall and manyatta house indicate similar results where 87.9 percent use grass/straw for their walls, while 32.7 percent use mud/wood compared to 7.9 percent who use mud/cement as a building material for the manyatta wall.

Table 3.5: Marginal effects of CMP ordered probit for living in a manyatta house

	Coefficients	Standard Errors
Improved stove (d)	-0.083+	(0.049)
Improved jiko (d)	-1.370**	(0.089)
Kerosene stove (d)	-1.736**	(0.106)
Stone-wall (d)	-1.388**	(0.103)
mud& cement -wall (d)	-0.717**	(0.070)
wood-wall (d)	-0.852**	(0.056)
Corrugatediron--wall (d)	-0.651**	(0.116)
Tin-wall (d)	-1.434**	(0.469)
Tiles-roof (d)	-0.757**	(0.244)
Concrete--roof ((d)	-0.869**	(0.258)
Tin--roof ((d)	0.230	(0.200)
Makuti-roof (d)	0.412**	(0.074)
Tiles-floor (d)	-0.645	(0.466)
Wood-floor (d)	-0.084	(0.122)
Other-floor (d)	-0.368	(0.266)
Outdoor-kitchen (d)	0.540**	(0.186)
Enclosed & detached-kitchen (d)	-0.004	(0.185)
Enclosed & attached-kitchen (d)	-0.060	(0.193)
Indoor without partion-kitchen (d)	0.789**	(0. 186)
Indoor with partion-kitchen (d)	0.245	(0.191)
chimney (d)	-0.943**	(0.119)
N	12986	
Wald Chi-square (60)	2347.23	
Log-Pseudo likelihood	1102.36	
Prob > Chi2	0.0000	

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

+ $p<0.10$ * $p<0.05$ **$p<0.01$

The variables for tiled roof, corrugated-iron roof and makuti roof coefficients were statistically significant at 1 percent and were negative except for makuti roof, which had a positive coefficient. Therefore, the roofs of manyatta houses are less likely to be built with tiles and corrugated-iron sheets. Descriptive analysis shows that the most used roofing material for manyatta houses is grass at 83.6 percent and makuti at 80.2 percent. Those build with tiles and corrugated iron sheets are 0.61 percent and 4.27 percent, respectively.

The variables indicating cooking outside and cooking inside without partition had a positive coefficient that was significant at 1 percent. The other-type of kitchen was used as a base. Those who dwell in manyatta house largely cook outside and their cooking location/kitchen is not partitioned. This study finds that households that cook outside and those whose kitchen is not partitioned represent 33.4 percent and 35.6 percent of manyatta houses, while those with enclosed attached and detached kitchen consists of 6.78 percent and 16.7 percent respectively.

The coefficient for chimney variable was statistically significant at 1 percent and was negative. This implies that manyatta houses have a lower probability of having chimney. Only 1.2 percent of the manyatta houses have a chimney.

Using electricity cooker as a reference variable, the variables indicating the use of improved stoves, improved jiko and kerosene stoves had a negative and significant coefficient. This means that those who dwell in manyatta houses have a lower probability of using improved stove, improved jiko and kerosene stove. An estimate of 45.9 percent and 4.2 percent were using traditional stone fire and ordinary jiko compared to 1.03 percent who use kerosene stove.

Manyatta house is an endogenous variable that affected the levels of IAP (outcome variable) directly, while ordinary jiko is an endogenous variable that affected the manyatta house directly, and indirectly affecting the levels of IAP. Identifying the unobserved factors for ordinary jiko is equally important. The result of the marginal effects of using an ordinary jiko is shown in Table 3.6. The dependent variable was ordinary jiko. Bungalow house, flat house, manyatta house and mansionette house when compared to other-types of dwellings, all had negative coefficients that were significant.

Table 3.6: Marginal effects of CMP ordered probit for using in an ordinary jiko

	Coefficients	**Standard Errors**
Bungalow-house (d)	-0.275**	(0.074)
Flat-house (d)	-0.459**	(0.128)
Swahili-house (d)	-0.050	(0.080)
Shanty-house (d)	-0.119	(0.099)
Manyatta/traditional-house (d)	-0.256*	(0.124)
Mansionette-house (d)	-0.456*	(0.231)
Wood-wall (d)	0.370**	(0.064)
Tin-wall (d)	-0.362	(0.465)
Brick & block-wall (d)	0.061	(0.054)
Mud & wood -wall(d)	-0.030	(0.056)
Mud&cement-wall (d)	0.270**	(0.072)
Corrugatediron-wall (d)	0.156+	(0.093)
Tin-roof (d)	0.040	(0.280)
Tiles-roof (d)	-0.108	(0.130)
Makuti-roof (d)	-0.123	(0.107)
Concrete-roof (d)	-0.210	(0.140)
Tiles-floor (d)	-0.489	(0.407)
Wood-floor (d)	-0.051	(0.346)
Earth-floor (d)	-0.183	(0.323)
Cement- floor (d)	0.152	(0.322)
N	12986	
Wald Chi-square (60)	2347.23	
Log-Pseudo likelihood	1102.36	
Prob > Chi2	0.0000	

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

+ $p<0.10$ * $p<0.05$ **$p<0.01$

Cross tabulations between ordinary jiko and type of dwelling variables show that those households in shanty and swahili houses were more likely to use ordinary jiko at 15.6 percent and 21.7 percent, respectively.

Using other-type of wall as a base variable, the variables for wood and mud-cement walls had positive coefficients and were statistically significant at 1 percent. The coefficient for corrugated-iron wall variable was statistically significant at 10 percent and it had a positive coefficient. This implied that there is a higher probability of using ordinary stove from households whose wall is built with wood, mud-cement and corrugated iron materials. The results indicate that the proportion of walls built with mud/cement were 17.1 percent, while those built with wood and corrugated-iron were 14.9 percent and 20.3 percent, respectively.

3.6 Conclusions and policy implications

3.6.1 Conclusions

This chapter aimed at determining the factors that influence the levels of IAP. Using the CMP ordered probit model, the types of dwelling, in particular those who live in manyatta house, had a higher probability of having high levels of IAP. The households sampled to live in manyatta were also observed to use firewood, an energy source that has very high IAP.

Household heads with graduate education and those with primary education were more likely to be associated with very high levels of IAP. This implies that though households are aware of the dangers of IAP, which may result from using traditional energy (firewood and charcoal), they are however observed to continue using them despite owning clean or modern technology that is less polluting. This means that households are driven by socio-economic status when selecting energy used rather than to achieve greater fuel efficiency or less pollution (Masera et al., 2000).

This study was able to show how as income increases, the probability of having high levels of IAP decreases. High income households have ability to purchase modern energy technologies with less IAP.

Manyatta house was an endogenous variable that affected the level of IAP. Therefore, it was important to identify factors that influence households to dwell in a manyatta house. The marginal effects show that those households with access to stone, mud/cement, wood, corrugated iron, and tin were less likely to dwell in a manyatta house as a type of dwelling. In addition, households with access to makuti roof had a higher probability of dwelling a manyatta house.

It was also observed that households willing to cook outside or inside without partitioned kitchen or those that lacked a chimney had a higher likelihood of dwelling a manyatta house. In addition, those cooking using improved stove, improved jiko and kerosene were less likely to be identified with manyatta houses.

The manyatta house type of dwelling had a direct relationship with IAP. Not only does ordinary jiko has an indirect relationship with IAP but also has direct relationship with manyatta house. Therefore, investigating the determinants of using ordinary jiko was found to be important. Households that dwell in shanty and swahili houses had a higher probability of using ordinary jiko. Lastly, households that can access wood, mud/cement and corrugated iron as building materials for their walls were more likely to use ordinary jiko.

3.6.2 Policy implications

Education is found to affects the levels of IAP. Although education may create awareness on the adverse effects of IAP, there is more than awareness that is needed to reduce the levels of IAP. Therefore, policy makers need to move from ‘soft’ policies like awareness creation to ‘hard’ policies where tangible measures are applied. Some of the hard policies include providing mechanism that addresses the ability to pay for improved energy technologies among households. Since improved energy technologies are expensive to most households. The government can partner with local banks to draw plans that will allow household to acquire these technologies and pay for them over a period of time through monthly installments.

The types of dwelling play a key role in determining the levels of IAP. According to Adhikari (2012), the type of dwelling is a proxy for wealth and the ability to take avertive actions. Policies directed towards abatement of IAP should target more at those households living in manyatta/traditional houses. Encouraging households to adopt construction materials that are more permeable and providing access to these construction materials is equally important. Through both private and public partnership, awareness creation can be enhanced by building low cost exhibition houses to serve as best practices for households to emulate. These houses should be build using permeable construction materials that allows easy flow of air.

Income also drives the level of IAP. The government should provide better environment for households to carry out income generating activities. In order to earn income, local artisan could engage in manufacturing of improved stoves while households could work as retailers in distributing modern energy sources such as LPG. Providing markets for produced improved stoves by households is one of the avenues of enhancing household incomes.

3.7 Areas of further research

Further research should be directed to establish which chemicals found in indoor air i.e. carbon monoxide, nitrogen dioxide, etc. are causing the most concern in the country. It is therefore important to examine the link between consumer products (such as; cleaning products, air fresheners among others) and adverse health effects. Therefore further studies could then proceed to estimate the household chemicals and products that can pollute indoor air.

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APPENDIX

Appendix Table A.1: Ordered Probit Model for IAP determinants

```
Ordered probit regression                         Number of obs   =        831
                                                  LR chi2(12)     =      43.79
                                                  Prob > chi2     =     0.0000
Log likelihood = -822.39279                       Pseudo R2       =     0.0259

---------------------------------------------------------------------------------
            iap |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
----------------+----------------------------------------------------------------
manyattatradhse |  -.5669881   .1227726    -4.62   0.000     -.807618   -.3263582
        ordjiko |   .2162783   .1348521     1.60   0.109    -.0480269    .4805836
        femhead |   .0699792   .0929498     0.75   0.452     -.112199    .2521574
       hhldsize |  -.0082324   .0177275    -0.46   0.642    -.0429776    .0265129
        headage |   .0046024   .0165579     0.28   0.781    -.0278504    .0370552
      headagesq |  -.0000719   .0001591    -0.45   0.652    -.0003838      .00024
         hdgrad |  -4.667418   160.1993    -0.03   0.977    -318.6523    309.3175
         hdsecs |  -.2035751   .1357241    -1.50   0.134    -.4695894    .0624391
        hdprims |  -.1893637   .0919858    -2.06   0.040    -.3696526   -.0090747
           empy |  -.0417726   .0959687    -0.44   0.663    -.2298677    .1463226
          rural |   .0982115   .0927785     1.06   0.290     -.083631     .280054
         income |   .0000237   9.15e-06     2.59   0.010     5.76e-06    .0000416
----------------+----------------------------------------------------------------
          /cut1 |   .3260211   .3982363                      -.4545076     1.10655
          /cut2 |   .9630577   .3992119                       .1806168    1.745499
          /cut3 |   1.597796   .4027748                       .8083716     2.38722
          /cut4 |   2.217378   .4134657                          1.407    3.027756
---------------------------------------------------------------------------------
Note: 4 observations completely determined.  Standard errors questionable.

.
```

Appendix Table A.2: CMP Order Probit Model for IAP determinants

```
Mixed-process regression                          Number of obs   =      12986
                                                  Wald chi2(59)   =    2345.17
Log pseudolikelihood = -11002.889                 Prob > chi2     =     0.0000

------------------------------------------------------------------------------
                 |               Robust
                 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------+------------------------------------------------------------
manyattatradhse  |
       imprstove |  -.0828124   .0490811    -1.69   0.092    -.1790096    .0133847
        imprjiko |  -1.369801    .089345   -15.33   0.000    -1.544914   -1.194688
       kerostove |  -1.735558   .1062347   -16.34   0.000    -1.943774   -1.527342
          wstone |  -1.387422   .1031042   -13.46   0.000    -1.589503   -1.185342
        wmudcemt |   -.717515   .0699183   -10.26   0.000    -.8545523   -.5804778
           wwood |   -.851853   .0563661   -15.11   0.000    -.9623286   -.7413774
 wcorrugatediron |  -.6513103   .1155579    -5.64   0.000    -.8777997    -.424821
            wtin |  -1.433614   .4691708    -3.06   0.002    -2.353172   -.5140564
          rtiles |  -.7572324   .2438537    -3.11   0.002    -1.235177   -.2792879
       rconcrete |  -.8695187   .2573243    -3.38   0.001    -1.373865   -.3651724
            rtin |   .2298224   .2003532     1.15   0.251    -.1628627    .6225074
         rmakuti |   .4119343   .0736022     5.60   0.000     .2676767     .556192
          ftiles |  -.6457919   .4655449    -1.39   0.165    -1.558243    .2666594
           fwood |   -.083659   .1224166    -0.68   0.494    -.3235911     .156273
          fother |  -.3682958   .2654601    -1.39   0.165    -.8885881    .1519966
         outdoor |   .5395564   .1858793     2.90   0.004     .1752396    .9038732
        encdetchd |  -.0043561   .1850826    -0.02   0.981    -.3671112    .3583991
        encatchd |  -.0600823   .1926741    -0.31   0.755    -.4377166    .3175519
    indwthoutpart |   .7888226   .1860638     4.24   0.000     .4241442    1.153501
      indwithpart |   .2444365   .1914867     1.28   0.202    -.1308706    .6197436
         chimney |  -.9433392    .118821    -7.94   0.000    -1.176224   -.7104543
           _cons |  -.6877593   .1838589    -3.74   0.000    -1.048116   -.3274025
-----------------+------------------------------------------------------------
ordjiko          |
     hsebungalow |  -.2752797    .073604    -3.74   0.000    -.4195408   -.1310186
            flat |  -.4590502   .1277841    -3.59   0.000    -.7095025   -.2085979
         swahili |  -.0500354   .0802655    -0.62   0.533    -.2073529    .1072822
          shanty |  -.1192357   .0991611    -1.20   0.229    -.3135878    .0751165
 manyattatradhse |  -.2560915   .1240069    -2.07   0.039    -.4991405   -.0130425
      maisonnett |  -.4559841   .2306274    -1.98   0.048    -.9080054   -.0039628
           wwood |   .3698723   .0641453     5.77   0.000     .2441498    .4955947
            wtin |  -.3619684   .4644646    -0.78   0.436    -1.272302    .5483654
        wbrkblok |   .0606803   .0544255     1.11   0.265    -.0459916    .1673523
        wmudwood |  -.0297047   .0559339    -0.53   0.595    -.1393332    .0799238
        wmudcemt |   .2704949   .0723435     3.74   0.000     .1287043    .4122855
 wcorrugatediron |   .1562294   .0929913     1.68   0.093    -.0260301    .3384889
            rtin |     .03985   .2802024     0.14   0.887    -.5093366    .5890366
          rtiles |  -.1077795   .1300267    -0.83   0.407    -.3626272    .1470683
         rmakuti |  -.1228118   .1067524    -1.15   0.250    -.3320426    .0864191
       rconcrete |  -.2097487    .140363    -1.49   0.135    -.4848552    .0653578
          ftiles |  -.4892022   .4075753    -1.20   0.230    -1.288035    .3096306
           fwood |  -.0511623   .3458541    -0.15   0.882    -.7290238    .6266992
          fearth |  -.1834926    .323158    -0.57   0.570    -.8168706    .4498855
         fcement |   .1516592    .322157     0.47   0.638    -.4797568    .7830752
         outdoor |   .4672307   .2955814     1.58   0.114    -.1120981    1.046559
        encdetchd |    .247316   .2951506     0.84   0.402    -.3311685    .8258006
        encatchd |   .8051798    .296532     2.72   0.007     .2239877    1.386372
    indwthoutpart |   .9060113   .2931389     3.09   0.002     .3314697    1.480553
      indwithpart |   .9014831   .2965351     3.04   0.002     .3202851    1.482681
         chimney |   .1162032   .0656244     1.77   0.077    -.0124182    .2448246
           _cons |  -1.827278   .4411943    -4.14   0.000    -2.692003   -.9625534
-----------------+------------------------------------------------------------
```

Appendix Table A.2: CMP Order Probit Model for IAP determinants…cont.

```
                │
────────────────┼──────────────────────────────────────────────────────────────────
iap             │
manyattatradhse │  -.4320329   .1831316    -2.36   0.018    -.7909641   -.0731016
        ordjiko │   .2475373    .203723     1.22   0.224    -.1517524     .646827
        femhead │   .0706203   .0895614     0.79   0.430    -.1049167    .2461574
       hhldsize │  -.0094033   .0168653    -0.56   0.577    -.0424586     .023652
        headage │   .0045973   .0158415     0.29   0.772    -.0264514     .035646
      headagesq │  -.0000823   .0001519    -0.54   0.588      -.00038    .0002155
         hdgrad │  -4.213965   .2707218   -15.57   0.000     -4.74457    -3.68336
         hdsecs │  -.1886007   .1334946    -1.41   0.158    -.4502452    .0730439
        hdprims │  -.1828422   .0904203    -2.02   0.043    -.3600628   -.0056217
           empy │  -.0407016   .0907919    -0.45   0.654    -.2186505    .1372472
          rural │   .0931244   .0933141     1.00   0.318    -.0897678    .2760166
         income │   .0000212   .0000113     1.89   0.059    -8.37e-07    .0000433
────────────────┼──────────────────────────────────────────────────────────────────
        /cut_3_1│   .4290347   .3995069     1.07   0.283    -.3539844    1.212054
        /cut_3_2│   1.052389    .398115     2.64   0.008     .2720978     1.83268
        /cut_3_3│   1.674471   .3990104     4.20   0.000     .8924254    2.456517
        /cut_3_4│    2.28173   .4228622     5.40   0.000     1.452936    3.110525
  /atanhrho_12  │  -.3503389   .0587365    -5.96   0.000    -.4654602   -.2352175
  /atanhrho_13  │   .3388144   .1818294     1.86   0.062    -.0175647    .6951935
  /atanhrho_23  │  -.1065266   .1513793    -0.70   0.482    -.4032246    .1901714
────────────────┼──────────────────────────────────────────────────────────────────
         rho_12 │  -.3366761   .0520786                      -.434524   -.2309735
         rho_13 │   .3264185   .1624557                     -.0175629     .601308
         rho_23 │  -.1061255   .1496744                     -.3827047    .1879116
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Chapter 4 : **HEALTH OUTCOMES ASSOCIATED WITH INDOOR AIR POLLUTION FROM HOUSEHOLD ENERGY USE**

4.1 Introduction

Research in various fields has shown that indoor air pollution (IAP) from energy use affects human health (Ezzati and Kammen, 2002; Zhang, 2009; Pant, 2008; and Barnes, Mathee, Thomas, & Bruce, 2009). Studies by Bukalassa (2011), Yan (2010), Barnes et al. (2009), and Pant (2008) have shown that IAP from solid fuels (biomass and coal) pose a major health risk. The effects of air pollution on human health are wide-ranging (Jaggernath, 2012) and can include irritation of the eyes and upper respiratory system, chronic respiratory disease, wheezing, asthma, lung cancer, heart disease, preterm birth, low birth weight and death (WHO, 2004; Boy, Bruce & Delgado, 2002; and Dherani et al., 2008).

Different types of energy use involve burning fuels which produce pollutants such as particulate matter, carbon monoxide, nitrogen dioxide, and hydro-carbons. The main sources of air pollutants and their effects on health are described in Table 4.1.

Evidence from research shows that there is a relationship between IAP and illness amongst all age groups, especially the poor children, women, the elderly, people with pre-existing diseases and other illnesses (Pandey, Kumar,& Devotta, 2005). Mishra (2003) argues that the impacts of air pollution on human health are relatively dependent on the main type of pollutant, its concentration in the air, exposure duration, additional pollutants in the air, and individual resistance.

Table 4.1: Main sources of air pollutants and their effects on health

Pollutant	**Potential health effects***
Particle Matter[abc]	• Eye, nose and throat irritation; worsening of asthma; increased respiratory disease; lung cancer; cardiovascular disease; premature death
Carbon Monoxide (CO)[abc]	• Low birth weight, headache; nausea; angina; difficulty concentrating; death at high concentrations
Nitrogen Dioxide (NO_2)[abc]	• Eye, nose, and throat irritation; lung irritation and damage; increased respiratory infections in children, asthma and death
Sulphur dioxide[c]	• Asthma, respiratory infection COPD, CVD
Ozone (O_3)[abc]	• Respiratory tract (lung) irritation and inflammation, serious breathing difficulty including asthma, permanent lung damage
Lead (pb) [ab]	• Nerve and brain damage, particularly in children; anemia; kidney damage; cardiovascular effects; growth retardation
Hydro-carbons (HC)[a]	• Headaches, nausea, cancer
Asbestos[b]	• Asbestosis, lung cancer, mesothelioma, and other cancers
formaldehde[bc]	• Eye, nose, and throat irritation; headache; allergic reactions; cancer
Organic chemicals[b]	• Eye, nose, and throat irritation; headaches; loss of coordination; damage to liver, kidney and brain; various types of cancer
Biological agents (house dust mites, animal dander, mold, bacteria, viruses)[b]	• Allergic reactions; asthma symptoms; eye, nose, and throat irritation; humidifier fever; influenza and other infectious diseases

*Depends on factors such as the amount of pollutant inhaled, the duration of exposure and susceptibility of the individual exposed (California Environmental Protection Authority-CEPA, 2088; and Mishra, 2003).

[a] EPA Victoria (2014)
[b] CEPA (2008)
[c] Bruce, Perez-Padilla & Albalak (2002)

Israel-Akinbo (2012) indicates that related to health problems is societal welfare losses due to rise in workdays lost and high health cost. Improvement of air quality is related to direct positive health outcomes. According to Central Pollution Control Board-CPCB 2012), in economics the interest is to evaluate: (i) the value of avoiding illness by the patient or the caregiver; (ii) the medical cost of treatment, the amount paid to avoid the pain and suffering associated with the illness; and (iii) the value of leisure time lost due to the illness by the patient or caregiver.

Studies in both developed and developing countries (Dockery *et al.,* 1993; Pope, Bates,& Raizenne, 1995; Pant 2008; and Adhikari, 2012) show that there is a strong linkage between exposure to ambient air pollution concentration, health risk and very high health costs. Estimating health cost of energy use is important in providing intervention mechanisms aimed at improving the overall welfare.

It is still unclear how IAP from household energy affects health. Research showing linkages between household energy use, IAP and health are few and scanty. To add to this, the available studies give less attention to health cost analysis of IAP from household energy use both globally and in Kenya.

The primary objective of this essay is to examine the health outcomes associated with IAP from household energy use. Specifically, the objectives of the essay are to:

a) Investigate the association between IAP from household energy use and ill health;
b) Estimate the health cost and productivity effects of household energy use; and
c) Draw policy implications that can improve health outcomes.

This essay contributes to literature by examining the effects of IAP from household energy use. Specifically, this essay makes the following contributions. First, it segregates ill health into: upper respiratory infection, lower respiratory infection and eyes illness. This is important because the effects of IAP differ from one illness to another. More notably, this essay compares the effects of IAP on these illnesses in a single study. Second, it analyses eyes illness from IAP.

Eyes illness was pointed out by Jaggernath (2012) as a negative effect of IAP from household energy use, but it is yet to receive empirical backing. Third, the essay estimated the health cost and productivity effects associated with energy use which has not been estimated in Kenya. It also provides specific health cost estimates for different illness associated with household energy. This information is important in designing public health policies and programs that aim to improve health status.

4.2 Literature review

4.2.1 Theoretical literature

Theory on household energy use and health outcomes

Health outcomes are changes in the health status of an individual or a given population which depends on a proposed intervention, irrespective of whether it was intended to alter health status. Though health outcomes can be of final outputs or intermediate outputs. The main focus is usually on the final outputs which this study emphasizes.

There is an indirect relationship between energy use and health outcomes. Household energy use affects health through IAP. The use of household energy is associated with both positive and negative effects. On the positive effects perspectives, when fuels are burnt, they produce energy required for household use. For instance, household energy produces cooking services. The cooked food provides nutrients and required energy for proper functioning of human bodies.

At the same time, household energy use is associated with negative effects. The burning of fuels emits smoke and other indoor air pollutants that have deleterious effects on human health. This section discusses negative health outcomes and focuses more on the illnesses associated with IAP (Edwards and Langpap, 2008; Pant, 2008 and Adhikari, 2012).

Various households' energies produce different levels of IAP allowing ranking of household energy depending on the levels of IAP. Those that are highly ranked (LPG and electricity) are associated with low levels of IAP, and the lowly ranked (firewood and charcoal) are associated with high levels of IAP (Masera, Saatkamp,& Kammen, 2000).

Different energy uses by households are associated with different health outcomes. The energy ladder can also be used to explain the association between energy use and health outcomes. The energy ladder model portrays a three-stage fuel switching process. In the first stage, because of the massive use of biomass fuel which is considered dirty and high polluting, there are adverse health outcomes. The second stage is viewed as a transition stage where kerosene, coal, and charcoal fuels are used and are perceived to be moderate polluting fuels with associated negative health effects. The third stage, households switch to LPG or electricity that is viewed as clean and less polluting with associated positive health outcomes.

Apart from the different concentrations/levels of IAP produced, sources of household energy also differ by type of pollutant they produce. Examples of pollutants include particulate matter, carbon monoxide, nitrogen dioxide, sulphur dioxide, formaldehyde and hydro-carbons (Bruce et al., 2002). Burning of wood products produces mainly particulate matter which is considered the most dangerous pollutant. Other household energy sources such as coal, kerosene and LPG are associated with carbon dioxide (EPA Victoria, 2014; and CEPA, 2008)

As regards the type of household energy, research provides evidence of biomass as the dominant household energy source associated with illnesses followed by kerosene and LPG in that order (Edwards and Langpap, 2008; Rollin, Schirnding, Mathee, Bruce, & Levin, 2004; Graham, 1990). Households' energy use in developing countries does not depict the energy ladder model earlier discussed. However in developing countries, the household energy behavior is well explained by the energy stack model, as discussed in the first essay. There may be a high probability of having one or more illnesses depending on several factors such as presence of pre-existing diseases, and type of household energy and fuel stove appliance used.

The complimentary aspects between the type of fuel stove appliance adopted and type of fuel used has consequences on household health. The type of fuel stove adopted and the related technology dictates the choice of energy used by households. Households that have adopted inefficient traditional fuel stove appliance tend to use biomass and kerosene fuels that produce toxic pollutants and affect health negatively (Duflo, Greenstone, & Hanna, 2008).

Living environmental characteristics (ventilation and type of building materials used) and socio-economic factors (income, education level attained, age, and gender) indirectly affect health outcomes and form part of this study contribution.

4.2.2 Empirical literature

Association between household energy use and ill health

This section discusses the empirical studies done on factors that influence health outcomes. The first part of the section discusses the role played by household energy used, while subsequent discussion focuses on individual or personal and household characteristics. There after living environment characteristics are discussed.

There are several studies linking IAP from household energy use to different health outcomes. The type of energy used is vital in determining the health impacts. However, there is scanty literature on how IAP from particular fuels affects specific health outcomes.

Silwal and McKay (2013) using household survey data collected in Indonesia analysed the effects of cooking with solid fuels on household health, where respiratory health was measured by lung capacity. The study found a correlation between choice of cooking energy (a proxy for IAP) and lung capacity (a measure for respiratory health). Utilising the results from the instrumental variable estimation, cooking with solid fuels exacerbates lung capacity. The study concluded that switching to cleaner cooking energy improves lung capacity, while switching to dirtier energy lowers lung capacity.

Mishra (2003) confirms that households use of high polluting biomass fuels were associated with Acute Respiratory Infection (ARI) in children after adjusting for a number of confounding factors[16]. Barnes et al. (2009) reviewed studies on the association between household energy, IAP, and child Acute Lower Respiratory Infections (ALRI) in South Africa. The review of the studies shows the likelihood of ALRI between two and four years amongst children living in households using polluting fuels compared to households using electricity. The findings confirm IAP is responsible for the deaths of up to 1,400 children annually from ALRI. Research findings

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[16] The confounding factors included; child's age, sex, mother's age at childbirth, sex, birth order, nutritional status, education, religion, household living standard and region or residence.

from Bukulassa (2011) suggest that IAP as a result of cooking fuels were associated with ARI in children. However it was not clear which particular cooking fuel contribute to ARI. Pant and Pattanayak (2008) provided evidence suggesting that the use of biogas tended to reduce the symptoms of ARI. The use of biogas was also found to extensively reduce the problem of chronic bronchitis (Pant, 2008).

Effort has been made to associate IAP from household energy use to specific health outcomes, but these outcomes have not been matched to particular household energy. The effects of IAP on lung cancer and lung disease were analysed by Zhang (2009). Using spirometry indicators, it was found that IAP has major impacts on restrictive lung cancer rather than obstructive lung diseases. In addition, IAP from energy use was found to have adverse health impact compared to smoking in India.

Though use of household energy has adverse effects on health, dirty household energy has been associated with more adverse health outcomes than clean fuels. Yan (2010) using cross sectional data from China, employed a logit regression model to estimate the likelihood of becoming ill from effects of environmental risks, including IAP. In the regression, fuel type was adopted as a proxy for pollution exposure; dirty fuel types were captured by coal, wood, and straw while the clean fuel types were captured by liquefied natural gas and natural gas.

Clean fuels have less adverse impacts than do the dirty fuel. The use of wood or straw was more extensively correlated with poor health compared to coal fuel. Applying the linear and logistic regression models to estimate the associations between individual health status and domestic cooking as a source of IAP, Peabody et al. (2005) showed that coal has a lower health status compared to other fuels types analysed.

Generally, IAP affects health. This has been acknowledged worldwide even though the specifics of which household energy use would result to a particular disease have not been identified. Usman & Raheem (2010) also show that the use of unclean energy among urban households in IIorin, Nigeria, is also confounded with health related problems of IAP.

Personal characteristics such as age of the household member have been found to be an important factor in determining illness as a result of IAP from energy use. While small children aged 0-5 years are the most vulnerable, Pant (2008) found that the problem of respiratory health is more severe among older age cohorts. The study surveyed 600 rural households from Syangja and Chitwan districts in Nepal after addressing the problem of endogeneity of biogas fuels and stoves to estimate the health effects, and the costs of IAP resulting from biomass fuel. It utilised instrumental variable probit regression and the cost of illness method to estimate the health effects and the health costs, respectively. The effects of IAP on health outcomes (upper respiratory infections, lower respiratory infection and eyes illness) were regressed on cooking technology, fuel, and personal characteristics like age and gender. Smoke averting activities and IAP were proxied by stove and biogas fuels.

Although Pant (2008) shows evidence of IAP effects on health on older households, the effects of IAP on health also affects children health. Mishra (2003) also provides evidence on the importance of the age factor by analysing IAP from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe. The study used Zimbabwe Demographic and Health Survey that for 1999 with 3,559 children aged 0-59 months were targeted. The results from the logistic regression results indicated that household use of high pollution biomass fuels was associated with ARI in children after correcting for child's age, sex, mother's age at childbirth, sex, birth order nutritional status, education, education, religion, household living standard, and region or residence.

Another driving factor explaining differences in health outcomes associated with IAP is education of household members. Using dose response function for symptoms of ARI, Pant et al. (2008) estimated a probit model and found that educated household members tended to have lower IAP, therefore lower chances of having ARI symptoms.

Income has a great role in influencing health outcomes, Surrender (2012) reviewed literature on valuation of health impacts of air pollution in India which showed that air pollution has large impact on health and the well-being of households especially the poor families. In addition, there is uneven distribution of the impact of air pollution across the sections of the societies[17]. Similar results are provided by Bukalassa (2011) using cross sectional data collected from all regions of Tanzania, including Zanzibar and Pemba in 2007-2008. Bukalassa (2011) sought to find out if IAP and social inequality[18] were related to acute respiratory disease in children. The results suggest that social inequality and IAP as a result of cooking fuels were associated with ARI in children. The study concluded that children from low income (poor) households suffered more in ARI compared to those from high income (rich) households.

Location/Region of residence has been found to be an important factor in determining illness as a result of IAP from energy use (Mishra, 2003). However, details on whether urban or rural locations are more affected are not available.

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[17] The sections of the societies are defined by income groups

[18] Social inequality in health was understood by looking at different dominant explanations i.e. materialist/structural, cultural/behavior and psychosocial along with the life course approach (Bukalassa, 2011).

Living environment characteristics also play a role in influencing health outcomes. Ezzati et al. (2002) found that cooking location is key in reducing illness, where the study used a longitudinal health data coupled with detailed monitoring of personal exposure for more than two years of field measurements in rural Kenya, Ezzati et al. (ibid) examined the reductions in diseases from a range of interventions, including changes in energy technologies (stove or fuel) and cooking locations. Likewise, Pant et al. (2008) observe that a larger kitchen size tends to reduce the symptoms of ARI.

In addition, the living environment characteristics also contribute to health effects. Pant et al. (2008) showed that children living in traditional houses with thatched or corrugated tin roof have a higher chance of ARI symptom compared to those living in cemented roof.

Health cost of indoor air pollution from household energy use

A number of studies have also estimated the health costs associated with energy use and found different health cost amounts. The amount stated in the various studies use different currencies which makes comparison a challenge.

For instance, Adhikari (2012) employed a dose response function and a medical expenditure function to estimate the monetary benefits of reducing air pollution using survey data of 120 households (641 individuals) in Kathmandu valley of Nepal. To estimate the welfare benefits, the household data was matched with air pollution data. The results showed that the annual saving from reduced mitigating expenditure to a representative individual in Kathmandu valley as NRs 266 (or USD 3.70) per annum. In addition, the savings in health costs per annum for the two cities (Kathmandu and Lalitpur) is NRs 315 million (USD 4.37 million). Furthermore, the discounted health benefits for the next 20 years, if the government of Nepal implements its Energy Master Plan to reduce indoor pollution from fossil fuel, promote the use of renewable energy and reduce air pollution to the range of NRS 6,085 million (USD 80.53 million). This study however focuses on air pollution rather than IAP from household energy use. It also does not include the specific costs associated with particular health outcomes.

Pant (2008) also analysed household shadow values for chronic bronchitis, asthma and acute respiratory infections using the cost of illness method. The study found that biomass fuels are more expensive than modern ones and the traditional Chula is more expensive than the improved Chula, when health costs are counted. Subsequently, promotion of improved stoves was found to reduce health costs by Rs 1,217 per year. This benefit is 20 times higher than the annual depreciated cost of an improved stove. Similarly, a biogas plant, with an annual depreciated cost of Rs 654, is found to reduce annual health cost by Rs 647. In addition, the study highlighted that the cost of a biogas plant is almost equal to its health benefits. Improved cook stove and biogas have added benefits of energy efficiency to the households, and environmental benefits to the society.

4.2.3 Summary of literature

There is no specific theory explaining the relationship between household energy use and health outcomes. An attempt is given by the energy ladder and energy stack models, but the scope of these theories is limited to household energy and fuel stove appliances. The aspects of living environment, personal and household characteristics that explain the aforementioned relationship are lacking. Literature shows that there are numerous empirical studies on IAP from energy use and health outcomes (Silwal et al., 2013; Bukalassa, 2011; Pant, 2008; and Mishra, 2000). However, very few are from developing countries, especially Kenya. In addition, countries that have moved a step further to estimate the resulting health cost are limited even in the developed countries (Adhikari, 2012; and Pant, 2008).

The most common health outcome investigated is the ARI as discussed by Bukalassa (2011), Barnes et al. (2009), and Pant et al. (2008). Chronic bronchitis, lung cancer and lung disease, are health outcomes that have been emphasised as discussed by Pant (2008) and Zhang (2009). The most studied type of energy/fuel is biomass by Silwal et al., (2013), Barnes et al. (2009) and Zhang (2009). Biogas is another fuel that has received some focus as investigated by Pant and Pattanayak (2008).Very few empirical studies such as Barnes et al. (2009) and Zhang (2009) have analysed the association between health outcomes and clean fuels (LPG and electricity).

Subsequently most studies have lumped up the health outcomes of IAP from energy use, making it difficult to assess specific health outcomes. Some of these studies include Silwal et al. (2013) and Usman et al. (2010). A limited number of studies such as Pant (2008) were able to assess association between IAP from energy use and other respiratory related disease such as chronic bronchitis, asthma and ARI. However, the study mainly focused on biomass.

This study adds value by: first, analysing health outcomes of IAP from household energy use. Several health outcomes are considered including upper respiratory infection, lower respiratory infection and other non-respiratory illnesses (eyes illness). Second, the health cost associated with IAP from energy use is estimated with respect to the aforementioned illness. In addition, to biomass which incorporates firewood and charcoal, this study also emphasis on kerosene, LPG and electricity.

4.3 Methodology

This section discusses the methods used in analyzing the health outcomes associated with IAP from energy use. According to Jaggernath (2012), the effect of IAP on human health is wide and ranging. It may be a cause for many disease and even death. It also contributes to health costs and adversely affects productivity (Israel-Akinbo, 2012). Health status is in turn influenced by IAP, socio-economic factors, averting (reducing IAP through living environment characteristics i.e. use chimney and window) and mitigating (seeking medical services) activities as discussed in the conceptual framework in chapter 1.

4.3.1 Theoretical model

A household health production function model is developed (borrowing from Gupta, 2006 and Adhikari, 2012) to examine the health effects from IAP. Based on the health status, mitigation activities, averting activities and socio-economic activities, an individual household member is able to produce good health. The health production function is given as:

$$H_j = H_i(I, A, M, Z) \tag{4.1}$$

where $j = 1, \dots, J$ indexes individual household members and i capture the respective households. H represents the health status taken as illness associated with IAP (I). A is a vector of averting activities that aim to minimise or reduce exposure to IAP such as adopting the use of improved stove and modifying the living environment characteristics (Brandt and Hanemann, 2003). M is a vector of mitigating activities which include expenses incurred as a result of IAP related diseases (Gupta, 2006). These expenses comprise individual's expenses related to travel to a clinic to consult a doctor, medication, laboratory tests, hospitalisation and other investments that reduce the effects of IAP (Adhikari, 2012; and Brandt et al., 2003). Z is a vector of individual characteristics including individual health stock and other socioeconomic factors.

The utility function of an individual is defined as:

$$U = U(X, L, H) \tag{4.2}$$

where X is consumption of market goods; L, leisure time; H, the illness due to IAP. The individual derive utility from the consumption of X and L, while H leads to disutility. The household head determines the health of individual household members by deciding on consumption and production functions (Larson and Rosen, 2002). Health is taken as a production function where the fuel type and fuel stove appliance used create emissions. These emissions, depending on living environment characteristics such as dwelling type, may reduce the quality of indoor air environment and expose household members to IAP. In turn, the IAP may affect the health of the individual household members, which also reduces the general household welfare.

By selecting a given averting and mitigating activity, individual household members can achieve a specified health status, even when faced with high levels of IAP (Gupta, 2006). This points out the substitution probabilities among the indoor air quality, averting and mitigating activities.

The individual's budget constraint is expressed as:

$$Y + W(T - L - \propto H) = X + P_a A + P_m M \tag{4.3}$$

where Y is non-wage income; W, wage rate; $(T - L - \propto H)$, is time spent at work (T, is total time; L, leisure time; and $\propto H$, lost days of work due to self-nursing/attending to child with respiratory infection caused by IAP); X, consumption goods; A, averting activities done by a household; P_a, price per unit of averting activities; M, mitigating activities done by household; P_m, price per unit of mitigating activities; $P_X = 1$, price of the bundle of consumption goods normalised to one.

The indiviudual maximises the utility function (4.2) with respect to X,L, A and M given the budget constraint (4.3). The individual utility maximisation problem is:

$$\text{Max} \quad U = U[X, L, H(I, A, M, Z)] \tag{4.4}$$

Subject to $X + P_a A + P_m M = Y + W(T - L) - W \propto H(I, A, M, Z)$

The Langragian function, where λ is the Langragian multiplier is:

$$\mathcal{L} = U[X, L, H(I, A, M, Z)] + \lambda[Y + W(T - L) - W \propto H(I, A, M, Z) - (X + P_a A + P_m M)] \tag{4.5}$$

The first order conditions are shown in equations (4.6a), (4.6b) and (4.6c).

$$\frac{\partial U}{\partial X} = \lambda \tag{4.6a}$$

$$\frac{\partial U}{\partial L} = \lambda W \tag{4.6b}$$

$$\frac{\partial U}{\partial H}\frac{\partial H}{\partial A} = \lambda\left[W \propto \frac{\partial H}{\partial A} + P_a\right] \tag{4.6c}$$

$$\frac{\partial U}{\partial H}\frac{\partial H}{\partial M} = \lambda\left[W \propto \frac{\partial H}{\partial M} + P_m\right] \tag{4.6d}$$

Re-arranging equation (4.6c) and (4.6d) yields:

$$\frac{\partial U}{\partial H} / \frac{\partial U}{\partial X} = W \propto + \frac{P_a}{\frac{\partial H}{\partial A}} \tag{4.7a}$$

$$\frac{\partial U}{\partial H} / \frac{\partial U}{\partial X} = W \propto + \frac{P_m}{\frac{\partial H}{\partial M}} \tag{4.7b}$$

The solution to utility maximisation problem yields demand functions for consumption goods, leisure, averting and mitigating activities. That is:

$$X = X(P_a, P_m, W, Y + WT, Z) \tag{4.8}$$

$$L = L(P_a, P_m, W, Y + WT, Z) \tag{4.9}$$

$$A = A(P_a, P_m, W, Y + WT, Z) \tag{4.10}$$

$$M = M(P_a, P_m, W, Y + WT, Z) \tag{4.11}$$

Given that the monetary benefit from a reduction in discomfort is difficult to measure accurately, Adhikari (2012) proposes the use of cost of illness derived from equations (4.1), (4.2), (4.3) and (4.11) to measure the health benefits:

$$Cost\ of\ Illness\ (COI) = w\frac{dH}{dI} + P_m\frac{dM}{dI} \tag{4.12}$$

The savings from the cost of illness resulting from abatement of IAP takes into account the sum of the individual’s marginal lost earnings and marginal expenditures of mitigation activities. The cost of illness estimated is a lower bound estimate because it does not consider disutility from illness (Gupta, 2006; Pant, 2008; and Adhikari, 2012).

4.3.2 Empirical model

Association between indoor air pollution from household energy use and related illness

The health production function (equation 4.1) is used to examine the association between IAP from household energy use and related illness. In the function, H is the dependent variable which captures the health status taken as illness due to IAP. The illnesses are categorised into respiratory infection (upper respiratory and lower respiratory) and non-respiratory illness (eyes illness).

The empirical specification for the health production function is given as:

$$H_{jik} = \beta_o + \beta_{1k}F_{j1} + \beta_{2k}A_{j2} + \beta_{3\,k}L_{j3} + \beta_{4\,k}Z_{j4} + \varepsilon_{kj} \qquad (4.13)$$

where $\mathrm{j} = 1 \ldots\ldots \mathrm{J}$ indexes individual household member; $\mathrm{k} = 1 \ldots\ldots \mathrm{K}$ indexes response/ outcome variable in this case the illness related to IAP; $\mathrm{H_{jik}}$ is the health status of the j^{th}individual in household i;$\beta_o, \beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ coefficients to be estimated for each illness outcome; F, type of fuel used; A, is the fuel stove appliance used; L, a vector of the living environment characteristics (including presence of chimney, type of dwelling and kitchen location); Z, is the socio-economic characteristics (such as individual characteristics on age, gender, education and employment, household size, household income, geographical location, consulting a health provider and other factors away from IAP which influence health status, i.e. chronic illness, malnutrition and smoking) and ε, a vector of error term.

The dependent variable (health status) takes into account three categories of illness (upper respiratory infection, lower respiratory infection and eye illness) associated with IAP. In order to estimate the effects of IAP on health (equation 4.13), a multivariate multiple regression model is employed. The multivariate multiple regression model allows more than one outcome and several explanatory variables to be estimated in a single equation (Wooldridge, 2009; and Hildalgo and Goodman, 2013).

The multivariate multiple regression models is defined as:

$$H_{n*r} = X_{n*p+1}\beta_{p+1*r} + \varepsilon_{n*r} \tag{4.14}$$

where $H$is matrix of n observations on $r$dependent variables or outcome variables; $X,$ is a model matrix with columns for $p+1$independent variables, which include an initial column of $1s$ for the regression constant; $\beta,$ is a matrix of regression coefficients, one column for each response variable; and $\varepsilon,$ is a matrix of errors.

equation (4.14) is estimated using the maximum likelihood method. The likelihood function for the model is:

$$L\,(\sigma_e^2) = \frac{1}{(2\pi)^{\frac{1}{2}}|\sigma_e^2|^{\frac{1}{2}}}\exp\left(-\frac{1}{2}(y_{nr}-\hat{y}_{nr})(\sigma_e^2)^{-1}\,(H_{nr}-\widehat{H}_{nr})\right) \tag{4.15}$$

where $\widehat{H}_{nr} = X_{n*p+1}\beta_{p+1*r}$ is the condition mean of H_{nr} (model for the means); $\sigma_e^2,$ is the error variance (or the residual variance), the conditional variance of H_{nr} (the model for the variance).

By using multivariate regression model, highly correlated variables are avoided which increases the power of the tests and reduces the probability of a type I error occurring[19]. Multivariate

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[19] Type I is an error that occurs when one rejects a null hypothesis yet it is actually true, while a type II error occurs when one fails to reject a null hypothesis yet it is false.

regression model is widely used where there are a large number of a potential confounding variables. It also addresses endogeneity bias, by controlling observable covariates in order to measure the unmeasured (Duncan and Magnuson, 2004).

Some of the limitations of this model are that it relies on a large sample size, it is more complicated than ANOVA, and it is not easy to interpret. The model is sensitive to outliers; hence it is not clear whether type I or type II is produced in the analysis from the presence of outliers. The problem of sample size is addressed by use of a large sample data, in this case the data from the Kenya Integrated Household Budget Survey which has a large database was used. Type I and Type II errors were corrected by eliminating the outliers.

Estimating the health costs and productivity effects of indoor air pollution from households energy use

The cost of illness approach (equation 4.11) is used to evaluate the health costs and productivity effects of IAP from households energy use, following Pant (2008). The health costs used in the analysis include: diagnostic tests including X-ray and laboratory examinations, fees charged by the doctors and hospitals, cost of medicine, and travel costs to and from the health facility. The time spent away from work by adults and from failing to attend school by children is estimated and valued using the opportunity cost of time lost. The total cost of illness calculated as a result of respiratory and no-respiratory infections the lower bound of the household shadow value of health. To examine the health gains from adopting improved stoves, the product of marginal reduction in the respiratory related illness and the household shadow value of the illness are used.

4.4 Data and description of variables

The data employed for the analysis is drawn from the Kenya Integrated Household Budget Survey (KIHBS) 2005/6, where 13,430 households were targeted. Data on illness was collected on household members who were sick in the last four (4) weeks preceding the survey. Specific details are discussed in section 3.4 of chapter three. The description and measurement of the variables used is as follows:

The dependent variable is health status (*illness*): It takes into account illnesses associated with IAP. It has three outcomes (upper respiratory infections, lower respiratory infections and eyes illness). It takes the value of 1, if an individual has a particular illness and otherwise 0, and it measures the health stock of an individual. An individual who has a particular illness from the three outcomes is more prone to IAP exposure and has a potential of having higher medical expenses and number of work days lost (Adhikari, 2012). Upper respiratory infection also include; ear, nose and throat infections. Lower respiratory infection takes into account bronchitis, pneumonia and tuberculosis[20]. The chronic illnesses consist of cancer, blood pressure and diabetes.

Chronic illness (*ltichronic*): It is a long term illness suffered by a household member. It is a dummy variable and it takes the value of 1 if there is presence of chronic illness (cancer, blood pressure and diabetes), otherwise 0. It accounts for individual health stock. According to Gupta

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[20] Flu is the short form for influenza. It affects both upper and lower respiratory infections, and it was purposely left out in the analysis.

(2006), an individual who has chronic illness is more susceptible to air pollution and has a high chance of having higher medical expenses and number of work days lost.

Type of household energy used (*iap*): It captures the different types of energy used by a household. Five types of household energy are considered which include: firewood, charcoal, kerosene, LPG and electricity. When one type of energy is observed, it takes the value 1 and 0 otherwise. It is 1 if very high, 2 if high, 3 if medium, 4 if low, and 5 if very low levels of IAP. These levels of IAP correspond to firewood, charcoal, kerosene, LPG and electricity respectively. The type of energy was interacted with age because the impact of IAP from household energy use differs depending on the type of energy used (Gupta, 20o6 and Adhikari, 2012)

Fuel stove appliance (*appliance*): This is the appliance used to burn fuel. It is represented by eight dummy variables, each of which represents a specific type of appliance. In particular, the fuel stove appliance includes: traditional three stone stove (*tradstove*), ordinary jiko (*ordjiko*), improved jiko (*imprstove*), kerosene stove (*kerostove*), gas cooker (*gascooker*), electric cooker (*eleccooker*), and other stove (*otherstove*). It should be noted that when one fuel stove appliance is considered, it takes a value of 1 while the other fuel stove appliances take a value of 0. Use of modern energy technology is associated with lower average emission concentrations (Ezzati et al., 2002).

Type of dwelling (*dwelling*): This defines the type of house. There are seven types of dwelling each represented by a dummy variable. They include: bungalow house (hse*bungalow*), flat house (*flat*), mansionette house (*mansionette*), swahili house (*swahili*), shanty house (*shanty*), manyatta house (*manyattatradhouse*) and other dwelling (*otherdwelling*). When type of dwelling is observed, it takes the value 1, and 0, otherwise. The type of dwelling is a proxy for wealth and the ability to take avertive actions (Adhikari, 2012).

Type of kitchen: It defines the location of the kitchen/the cooking area. There are six types of kitchen each represented by a dummy variable. They include: outdoor-kitchen (*outdoor-kitchen*), enclosed detached kitchen (*encdet-kitchen*), enclosed attached kitchen (*encatchd*), indoor without partition kitchen (*indwout-kitchen*), indoor-with-partition kitchen (*indwith-kitchen*) and other floor (*other-kitchen*).When one type of kitchen is observed, it takes the value 1, and 0, otherwise. It is expected that those who cook from outside have low levels of IAP.

Chimney: It is a type of ventilation. It is represented by dummy variable that takes the value 1, if presence of a chimney is observed, and 0, otherwise. It is assumed that with presence of a chimney, there is ventilation which reduces the level of IAP.

Gender: This refers to the sex of an individual and it is equal to 1, if the individual is female and 0 otherwise. The exposure levels for males and females from IAP are different and may be explained by the different roles played by each. For instance, the role of cooking is performed by women who tend to be more exposed than men (Adhikari, 2012).

Age: Age is categorized into four dummies: age 0 – 4 years (*dage04*), age 5-14 years (*dage514*), age 15 – 49 years (*dage1549*), and age above 50 years (*dage50*). When a particular age group is observed, it takes the value 1, and 0, otherwise. Aging increases the chances of falling ill as the health-stock deteriorates (Adhikari, 2012). According to Gupta (2006), with ageing, the health stock deteriorates, which increases mitigation activities. The likelihood of having acute respiratory infection between two to four years among children is higher in households using polluting fuels (biomass) compared to those using electricity (Barnes et al., 2009).

Education: This is the education level of an individual. It is represented by four dummy variables, each of which represents a specific level of education. The four level of education include: individual with primary education (*hdprims*), individual with secondary education (*hdsec*), individual with graduate education (*hdgrad*), and individual with no education (*hdnosch*). It should be noted that when one education level is considered, it takes a value of 1 and 0 otherwise. It is expected that educated household heads are more concerned about their indoor air quality. Pant et al. (2008) found that indoor air quality is an increasing function of education.

Location (*rural*): This is the geographic location of the residence. It is represented by a dummy variable which equals 1, when it is a rural location, and 0, if urban.

Household expenditure (*income*): This is the total amount spent by households per month. It is used as a proxy for income and the ability to take aversive actions. It is captured by a categorical variable which was represented by low (income below Kshs 1570.88), middle (income between Kshs 1570.89 and Kshs 3216.92), and high (income above Kshs 3216.93) income groups. Bukalassa (2011) found that children from low income households suffered acute respiratory infection more compared to those from high income households

Smoking expenditures (*expsmoke*): Total cost on smoking spent by households per month in Kenya shillings. Smoking is also another indicator that captures individual health stock. It exacerbates the probability of falling ill due to IAP (Adhikari, 2012).

This information can be represented in a table, similar to the one presented in section 3.4.

4.5 Results and discussion

Descriptive statistics and various regression models which are used to answer objectives two and three are presented and discussed in this section. The aim of objective two is to investigate the association between household energy use and illness, while objective three estimates the health cost and productivity effects of household energy use.

4.5.1 Descriptive statistics

The summary statistics such as the number of observations, mean, standard deviation, minimum and maximum statistics for each variable used in the study are presented in Table 4.2. Group variables, in this case household variables, amounted to 13,158 observations, while the individual variables had about 66,725 observations. The missing values, either as a result of non-response, omission and commission during data entry, may explain the differences in the total number of observations for most of these variables. There are three binary dependent variables: upper-respiratory infection, lower-respiratory infection and eye illness. Several independent variables were also used in the analysis.

Table 4.2: Descriptive statistics of variables influencing a particular disease

	Full Sample		**Upper Respiratory Infection Sample**		**Lower Respiratory Infection Sample**		**Eyes Illness Sample**	
Variables	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
Type of household energy								
Paraffin (=1 if household energy used is paraffin/kerosene, 0 otherwise)	12,989	0.1090	98	0.1430	374	0.0909	57	0.0702
Electricity (=1 if household energy used is electricity, 0 otherwise)	12,989	0.0082	98	0.0204	374	0.0027	57	0.0175
Lpg (=1 if household energy used is LPG, 0 otherwise)	12,989	0.0417	98	0.0408	374	0.0481	57	0.0877
Charcoal (=1 if household energy used is charcoal, 0 otherwise)	12,989	0.1820	98	0.1940	374	0.1580	57	0.1400
Firewood (=1 if household energy used is firewood, 0 otherwise)	12,989	0.6460	98	0.6020	374	0.6790	57	0.6840
Type of appliance								
Traditional stove (=1 if appliance used is a traditional three stone, 0 otherwise)	12,989	0.5800	99	0.5350	373	0.5920	58	0.5860
Improved stove(=1 if appliance used is improved, 0 otherwise)	12,989	0.0753	99	0.0404	373	0.0751	58	0.0345
Ordinary jiko(=1 if appliance used is ordinary jiko, 0 otherwise)	12,989	0.1000	99	0.0808	373	0.0965	58	0.1210
Improved jiko (=1 if appliance used is improved jiko, 0 otherwise)	12,989	0.0859	99	0.1010	373	0.0724	58	0.0517
Kerosene stove(=1 if appliance used is kerosene, 0 otherwise)	12,989	0.1050	99	0.1410	373	0.1050	58	0.1550
Gascooker (=1 if appliance used is gas cooker, 0 otherwise)	12,989	0.0402	99	0.0808	373	0.0429	58	0.0172
Electric cooker(=1 if appliance used is electric cooker, 0 otherwise)	12,989	0.0059	99	0.0101	373	0.0054	58	0.0345
Type of dwelling								
Bungalow (=1 if dwelling is bungalow, 0 otherwise)	12,989	0.5460	99	0.5050	373	0.5740	58	0.5170
Flat (=1 if dwelling is flat, 0 otherwise)	12,989	0.0360	99	0.1110	373	0.0322	58	0.0172
Mansionette (=1 if dwelling is mansionette, 0 otherwise)	12,989	0.0116	99	0.0101	373	0.0107	58	0.0000
Swahili (=1 if dwelling is swahili, 0 otherwise)	12,989	0.1170	99	0.1720	373	0.0992	58	0.0862
Shanty(=1 if dwelling is shanty, 0 otherwise)	12,989	0.0399	99	0.0101	373	0.0322	58	0.0345
Manyatta (=1 if dwelling is manyatta/traditional, 0 otherwise)	12,989	0.2090	99	0.1410	373	0.2140	58	0.2930

Source: Authors computation based on KIHBS 2005/06

Variables	Full Sample		Upper Respiratory Infection Sample		Lower Respiratory Infection Sample		Eyes Illness Sample	
	N	**Mean**	**N**	**mean**	**N**	**Mean**	**N**	**Mean**
Kitchen location								
Outdoor (=1 if kitchen is located outdoor, 0 otherwise)	12,991	0.1730	99	0.1620	373	0.1820	58	0.1550
Enclosed detached (=1 if kitchen is enclosed and detached, 0 otherwise)	12,991	0.3170	99	0.3540	373	0.3590	58	0.3100
Enclosed and attached (=1 if kitchen is enclosed and attached, 0 otherwise)	12,991	0.1170	99	0.1720	373	0.0938	58	0.0690
Indoor without partition kitchen (=1 if kitchen is indoor without partition, 0 otherwise)	12,991	0.2940	99	0.2020	373	0.2520	58	0.2760
Indoor with partition (=1 if kitchen is indoor with partition, 0 otherwise)	12,991	0.0930	99	0.1010	373	0.1020	58	0.1900
Education								
Graduate education (=1 if education level completed is graduate , 0 otherwise)	66,725	0.0108	456	0.0197	1802	0.0089	275	0.0073
Secondary education (=1 if education level completed is secondary , 0 otherwise)	66,725	0.1540	456	0.1340	1802	0.1500	275	0.1640
Primary education (=1 if education level completed is primary , 0 otherwise)	66,725	0.4500	456	0.4190	1802	0.4430	275	0.4250
No education (=1 if no education , 0 otherwise)	66,725	0.0241	456	0.0482	1802	0.0228	275	0.0255
Age								
Age 0-4 (=1 if age is between 0-4 years, 0 otherwise)	66,725	0.1470	456	0.1400	1802	0.1530	275	0.1640
Age 5-14 (=1 if age is between 5-14 years, 0 otherwise)	66,725	0.2790	456	0.2790	1802	0.2710	275	0.2800
Age 15-49 (=1 if age is between 15-49 years, 0 otherwise)	66,725	0.4760	456	0.4960	1802	0.4720	275	0.4550
Age 50 (=1 if age is above 50 years, 0 otherwise)	66,725	0.0986	456	0.0855	1802	0.1040	275	0.1020
Other characteristics								
Chimney (=1 if there is presence of chimney, 0 otherwise)	12,988	0.0762	99	0.1110	373	0.0777	58	0.0517
Female (=1 if gender is female, 0 otherwise)	66,725	0.5070	456	0.5150	1802	0.5020	275	0.4910
Rural (=1 if residing in rural area, 0 otherwise)	13,158	0.6440	99	0.6260	373	0.6620	58	0.6380
Smoke expenditures	13,116	1,174	100	1,318	371	1,034	58	418
Middle income	13,116	0.3333	100	0.3000	375	0.2880	58	0.2759
High income	13,116	0.3333	100	0.2800	375	0.3147	58	0.430
Breastfed (=1 if exclusively breast fed for 6 months)	11834	0.0198	77	0.0519	331	0.0332	52	0.0192

Source: Authors computation based on KIHBS 2005/06

In Table 4.2, out of 64.6 percent of households that use firewood, 60.2 percent, 67.9 percent and 68.4 percent are associated with upper respiratory infection, lower respiratory infection and eye illness, respectively. There is substantive difference when these results are compared to household using electricity; only 2.0 percent, 0.26 percent and 1.75 percent are associated with upper respiratory infection, lower respiratory infection and eye illness respectively.

The probability of having upper respiratory infection, lower respiratory infection and eye illness was high for households using traditional stove at 53.5 percent, 59.2 percent and 58.6 percent, respectively. These statistics were lower for households using electric cooker at 1.01 percent, 0.54 percent and 3.45 percent, respectively.

In terms of education, household members who had graduate education had better health status compared to those with no education. Household members with graduate education are least associated with upper respiratory infection (1.97%), lower respiratory infection (0.89%) and eye illness (0.73%). There is also a high association of upper respiratory infection, lower respiratory infection and eye illness from household members with no education at 4.82 percent, 2.28 percent and 2.55 percent, respectively. The association of upper respiratory infection, lower respiratory infection and eye illness were high from rural than urban at 62.6 percent, 66.2 percent and 63.8 percent correspondingly.

4.5.2 Regression results

Several illnesses are likely to be influenced differently by various types of energy/fuel type used by a household. For this reason, it was important to consider how each disease behaves. In doing so, a multivariate regression model was used to investigate the association between household energy use and illness.

In the multivariate regression, the dependent variable, which has three health outcomes (upper respiratory infection, lower respiratory infection, and eyes illness), is captured in a single equation (Hildalgo et al., 2013). Highly correlated variables are dropped from the model, minimising the occurrence of type 1 and type 2 error. It is applicable where there are many confounders, and it is able to correct endogeneity bias where observed covariates are used as controls to measure the unmeasured variables (Duncan et al., 2004).

Depending on the type of household energy used, the effect of illness also differs by age. Research studies show that small children aged 0-5 years and older age cohorts are likely to be more vulnerable to respiratory illness (Pant, 2008 and Mishra, 2003). To capture the effects of household energy by age, the age variable was categorized into four dummies: age 0-4 years, age 5-14, age 15-49 and age 50 years and above. The age dummies were then interacted with household energy. This resulted into 4 models that were estimated using multivariate regression.

Multivariate regression model

The multivariate analysis of variance[21] (MANOVA) output produces four multivariate test statistics: Wilks' lambda, Pillai's trace, Lawley-Hotelling trace and Roy's largest root[22]. The F

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[21] MANOVA tests whether there are statistically significant mean differences among groups on a combination of dependent variables. It not only gives emphasis to the mean differences, but also the direction and size of correlations among the dependents.

[22] Wilks' lambda, Pillai's trace, Lawley-Hotelling trace, and Roy's largest root are test statistics used in multivariate analysis of variance (MANOVA) to test whether there are differences between the means of identified groups of subjects on a combination of dependent variables.

statistics and associated p-value for each multivariate test statistics are also provided. The multivariate test statistics are calculated from the models Eigen values[23]. In each of the four models estimated, there were four eigenvalues i.e.; 0.989, 0.010, 0.010 and 0.005 for model 1 (Appendix Table B1).

The null hypothesis for F-test of the overall model is that the given predictors have no effect on either of the outcomes. Prob>F is the p-value related with the F-stastic. The F-statistics (Wilks' lambda, Pillai's trace, Lawley-Hotelling trace and Roy's largest root) are significant for all the four models estimated. This means that the null hypothesis is rejected and concludes that the given predictors have an effect on the outcomes/dependent variables irrespective of the multivariate test statistics used.

The R-squared for each of the three illness equations in the multivariate regression models were quite small. Cross sectional data are common to have low R^2 . A moderate, even low, R^2 is not necessarily bad (Lewis-Beck and Skalaban, 1990). Low R^2 may imply that only a small proportion of Y can be explained. It may be a bad sign if the relationship is nonlinear and also when the aim, is to carry out prediction which is not the case for this study.

The results of the multivariate regression model are shown in Table 4.3 to Table 4.6 which captures the estimates for the effects of energy use among households members aged 0-4 years, 5-14 years, 15-49 years and above 50 years correspondingly.

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[23] The Eigen value represents the ratio of the between-groups sum of squares to the within-groups sum of squares.

Upper respiratory infection

In model 1 and model 4 the coefficient for use of firewood variable was significant at 5 percent level, but it had a positive and negative coefficient respectively. This implies that the use of firewood among households with children aged 0 – 4 years are significantly more likely to manifest upper respiratory infection. However, the use of firewood among household members above 50 years is less likely to predispose upper respiratory infection. This result was expected and corresponds to other studies such as Mishra (2003) and Barnes et al., (2009). Mishra (2003) indicated that household use of high pollution biomass fuels predisposes children to ARI after controlling for sex, mother's age at childbirth, birth order, nutritional status, education, religion, household living standard, and region/residence. Likewise, Ezzati et al. (2002) also found similar results where the highest exposure levels were observed on infants and children.

In model 1 the coefficient for use of kerosene variable was positive and significant at 10 percent level. This implies that children age 0 – 4 years among household that use kerosene are significantly more likely to manifest upper respiratory infection than those who use electricity. A related study by Tracy & Jacobson (2012) found that kerosene affects human health.

The primary education variable had a negative coefficient and significant at 10 percent level for all the four models estimated. This implies that individuals with primary level education are less exposed to upper respiratory infection relative to those without any education. This is consistent with Pant et al. (2008) finding that households with educated individuals tended to have lower IAP, therefore lower chances of having ARI.

Table 4.3: Multivariate regression for estimating health effects of IAP (Model 1)

	Upper respiratory		Lower respiratory		Eyes illness	
Chronic illness	-0.0070	(0.0096)	0.0333+	(0.0187)	0.0206**	(0.0075)
Smoke expenditures	0.0000	(0.0000)	-0.0000	(0.0000)	-0.0000	(0.0000)
Firewood*age 0-4 years	0.0056*	(0.0027)	0.0132*	(0.0053)	0.0020	(0.0021)
Charcoal*age 0-4 years	-0.0006	(0.0048)	-0.0033	(0.0093)	0.0020	(0.0037)
Kerosene* age 0-4 years	0.0111+	(0.0062)	-0.0178	(0.0120)	-0.0041	(0.0048)
Lpg*age 0-4 years	0.0037	(0.0099)	-0.0139	(0.0192)	0.0091	(0.0077)
Female	0.0019	(0.0015)	0.0023	(0.0029)	-0.0009	(0.0012)
Middle income	-0.0029	(0.0019)	-0.0093*	(0.0036)	-0.0001	(0.0014)
High income	-0.0030	(0.0019)	-0.0064+	(0.0037)	0.0018	(0.0015)
Graduate education	-0.0088	(0.0112)	0.0183	(0.0217)	0.0287**	(0.0087)
Secondary education	-0.0032	(0.0025)	-0.0030	(0.0049)	0.0009	(0.0019)
Primary education	-0.0032+	(0.0016)	-0.0024	(0.0032)	0.0001	(0.0013)
Bungalow house	-0.0008	(0.0020)	-0.0007	(0.0038)	-0.0027+	(0.0015)
Shanty house	-0.0035	(0.0041)	-0.0060	(0.0081)	-0.0035	(0.0032)
Flat house	0.0159**	(0.0047)	-0.0052	(0.0092)	-0.0063+	(0.0037)
Mansionette house	-0.0032	(0.0077)	-0.0057	(0.0150)	-0.0084	(0.0060)
Swahili house	0.0052+	(0.0029)	-0.0051	(0.0056)	-0.0043+	(0.0023)
Enclosed detached kitchen	0.0011	(0.0023)	0.0009	(0.0045)	0.0010	(0.0018)
Enclosed attached kitchen	0.0004	(0.0031)	-0.0104+	(0.0061)	-0.00004	(0.0024)
Indoor without partition kitchen	-0.0047+	(0.0024)	-0.0080+	(0.0048)	-0.0006	(0.0019)
Indoor with partition kitchen	-0.0014	(0.0032)	-0.0019	(0.0062)	0.0059*	(0.0025)
Traditional stove	-0.0019	(0.0029)	-0.0095+	(0.0056)	-0.0044+	(0.0022)
Improved stove	-0.0042	(0.0038)	-0.0097	(0.0074)	-0.0068*	(0.0030)
Ordinary jiko	-0.0020	(0.0033)	-0.0047	(0.0064)	-0.0021	(0.0026)
Improved jiko	0.0003	(0.0035)	-0.0087	(0.0068)	-0.0050+	(0.0027)
Gas cooker	0.0002	(0.0047)	0.0021	(0.0092)	-0.0047	(0.0037)
Chimney	0.0032	(0.0031)	0.0011	(0.0061)	-0.0014	(0.0024)
Rural	-0.0017	(0.0016)	0.0009	(0.0031)	0.0002	(0.0012)
Exclusively breastfed	0.0057	(0.0044)	0.0076	(0.0085)	-0.0020	(0.0034)
_cons	0.0126**	(0.0042)	0.0446**	(0.0082)	0.0094**	(0.0033)

Equations:	N	R squared	F
Upper respiratory illness (URI)	12809	0.0042	1.8576
Lower respiratory illness (lRI)	12809	0.0026	1.1641
Eyes illness (EYES)	12809	0.0036	1.5762

Standard errors in parentheses; + p<0.10, * p<0.05, ** p<0.01

Smoke expenditures coefficients are very low at an average of $2.63*10^{-8}$ for URI, $1.31*10^{-8}$ for LRI, and $3.41*10^{-8}$ for eyes illness

Table 4.4: Multivariate regression for estimating health effects of IAP (Model 2)

	Upper respiratory		Lower respiratory		Eyes illness	
Chronic	-0.0074	(0.0096)	0.0326+	(0.0187)	0.0209**	(0.0075)
Smoke expenditures	0.0000	(0.0000)	-0.0000	(0.0000)	-0.0000	(0.0000)
Firewood* age 5-14 years	0.0007	(0.0020)	-0.0063	(0.0039)	0.0018	(0.0016)
Charcoal* age 5-14 years	0.0002	(0.0035)	-0.0097	(0.0068)	-0.0044	(0.0027)
Kerosene* age 5-14 years	-0.0067	(0.0045)	-0.0033	(0.0088)	-0.0015	(0.0035)
Lpg*age 5-14 years	-0.0045	(0.0068)	0.0211	(0.0133)	0.0083	(0.0053)
Female	0.0019	(0.0015)	0.0022	(0.0029)	-0.0009	(0.0012)
Middle income	-0.0029	(0.0019)	-0.0095**	(0.0036)	-0.0001	(0.0014)
High income	-0.0031	(0.0019)	-0.0068+	(0.0037)	0.0019	(0.0015)
Graduate education	-0.0088	(0.0112)	0.0191	(0.0217)	0.0287**	(0.0087)
Secondary education	-0.0031	(0.0025)	-0.0032	(0.0049)	0.0009	(0.0019)
Primary education	-0.0031+	(0.0016)	-0.0022	(0.0032)	0.0001	(0.0013)
Bungalow house	-0.0007	(0.0020)	-0.0011	(0.0038)	-0.0026+	(0.0015)
Shanty house	-0.0034	(0.0042)	-0.0069	(0.0081)	-0.0036	(0.0032)
Flat house	0.0164**	(0.0047)	-0.0077	(0.0092)	-0.0064+	(0.0037)
Mansionette house	-0.0028	(0.0077)	-0.0079	(0.0150)	-0.0092	(0.0060)
Swahili house	0.0054+	(0.0029)	-0.0064	(0.0057)	-0.0042+	(0.0023)
Enclosed detached kitchen	0.0011	(0.0023)	0.0009	(0.0045)	0.0011	(0.0018)
Enclosed attached kitchen	0.0005	(0.0031)	-0.0107+	(0.0061)	-0.000004	(0.0024)
Indoor without partition kitchen	-0.0045+	(0.0025)	-0.0081+	(0.0048)	-0.0003	(0.0019)
Indoor with partition kitchen	-0.0013	(0.0032)	-0.0020	(0.0062)	0.0060*	(0.0025)
Traditional stove	-0.0028	(0.0067)	-0.0066	(0.0130)	-0.0085	(0.0052)
Improved stove	-0.0051	(0.0071)	-0.0069	(0.0139)	-0.0109*	(0.0055)
Ordinary stove	-0.0028	(0.0070)	-0.0027	(0.0136)	-0.0061	(0.0054)
Improved jiko	-0.0006	(0.0070)	-0.0066	(0.0137)	-0.0090	(0.0055)
Kerosene stove	-0.0002	(0.0070)	0.0008	(0.0137)	-0.0048	(0.0055)
Gas cooker	-0.0001	(0.0076)	0.0025	(0.0148)	-0.0087	(0.0059)
Chimney	0.0032	(0.0031)	0.0011	(0.0061)	-0.0015	(0.0024)
Rural	-0.0016	(0.0016)	0.0007	(0.0031)	0.0002	(0.0012)
Exclusively breastfed	0.0061	(0.0044)	0.0079	(0.0085)	-0.0019	(0.0034)
_cons	0.0139+	(0.0072)	0.0453**	(0.0140)	0.0134*	(0.0056)

Equations:	N	R squared	F
Upper respiratory illness (URI)	12809	0.0038	1.6375
Lower respiratory illness (lRI)	12809	0.0025	1.0505
Eyes illness (EYES)	12809	0.0039	1.6763

Standard errors in parentheses; + $p<0.10$, * $p<0.05$, ** $p<0.01$; Smoke expenditures coefficients are very low at an average of $2.63*10^{-8}$ for URI, $1.31*10^{-8}$ for LRI, and $3.41*10^{-8}$ for eyes illness

Table 4.5: Multivariate regression for estimating health effects of IAP (Model 3)

	Upper respiratory		Lower respiratory		Eyes illness	
Chronic illness	-0.0074	(0.0096)	0.0336+	(0.0187)	0.0206**	(0.0075)
Smoke expenditures	0.0000	(0.0000)	-0.0000	(0.0000)	-0.0000	(0.0000)
Firewood*age 15-49 years	-0.0005	(0.0017)	-0.0030	(0.0034)	-0.0013	(0.0013)
Charcoal*age 15-49 years	0.0018	(0.0028)	-0.0081	(0.0055)	-0.0005	(0.0022)
Kerosene*age 15-49 year	0.0017	(0.0036)	-0.0026	(0.0070)	-0.0018	(0.0028)
Lpg*age 15-49 years	-0.0005	(0.0058)	-0.0040	(0.0112)	0.0039	(0.0045)
Female	0.0018	(0.0015)	0.0023	(0.0029)	-0.0009	(0.0012)
Middle income	-0.0030	(0.0019)	-0.0095**	(0.0036)	-0.0001	(0.0014)
High income	-0.0031	(0.0019)	-0.0066+	(0.0037)	0.0019	(0.0015)
Graduate education	-0.0090	(0.0112)	0.0185	(0.0217)	0.0286**	(0.0087)
Secondary education	-0.0031	(0.0025)	-0.0033	(0.0049)	0.0009	(0.0019)
Primary education	-0.0032+	(0.0016)	-0.0023	(0.0032)	0.0001	(0.0013)
Bungalow house	-0.0008	(0.0020)	-0.0009	(0.0038)	-0.0027+	(0.0015)
Shanty house	-0.0035	(0.0042)	-0.0061	(0.0081)	-0.0036	(0.0032)
Flat house	0.0160**	(0.0047)	-0.0067	(0.0092)	-0.0064+	(0.0037)
Mansionette house	-0.0033	(0.0077)	-0.0066	(0.0151)	-0.0089	(0.0060)
Swahili house	0.0051+	(0.0029)	-0.0058	(0.0057)	-0.0043+	(0.0023)
Enclosed detached kitchen	0.0010	(0.0023)	0.0011	(0.0045)	0.0011	(0.0018)
Enclosed attached kitchen	0.0004	(0.0031)	-0.0103+	(0.0061)	0.00004	(0.0024)
Indoor without partition	-0.0046+	(0.0025)	-0.0079+	(0.0048)	-0.0004	(0.0019)
Indoor with partition	-0.0014	(0.0032)	-0.0016	(0.0063)	0.0059*	(0.0025)
Traditional stove	-0.0019	(0.0067)	-0.0080	(0.0130)	-0.0083	(0.0052)
Improved stove	-0.0043	(0.0071)	-0.0083	(0.0139)	-0.0108+	(0.0055)
Ordinary jiko	-0.0023	(0.0070)	-0.0037	(0.0136)	-0.0063	(0.0054)
Improved jiko	-0.00004	(0.0070)	-0.0075	(0.0137)	-0.0091+	(0.0055)
Kerosene stove	-0.0002	(0.0070)	0.0004	(0.0137)	-0.0049	(0.0055)
Gas cooker	0.0001	(0.0076)	0.0020	(0.0148)	-0.0090	(0.0059)
Chimney	0.0032	(0.0031)	0.0011	(0.0061)	-0.0014	(0.0024)
Rural	-0.0017	(0.0016)	0.0008	(0.0031)	0.0002	(0.0012)
Exclusively breastfed	0.0058	(0.0044)	0.0079	(0.0085)	-0.0021	(0.0034)
_cons	0.0133+	(0.0072)	0.0462**	(0.0140)	0.0140*	(0.0056)

Equations:		N	R squared	F
Upper respiratory illness	(URI)	12809	0.0037	1.5728
Lower respiratory illness	(lRI)	12809	0.0021	1.8948
Eyes illness	(EYES)	12809	0.0035	1.5107

Standard errors in parentheses; + $p<0.10$, * $p<0.05$, ** $p<0.01$; Smoke expenditures coefficients are very low at an average of $2.63*10^{-8}$ for URI, $1.31*10^{-8}$ for LRI, and $3.41*10^{-8}$ for eyes illness

Table 4.6: Multivariate regression for estimating health effects of IAP (Model 4)

	Upper respiratory		Lower respiratory		Eyes illness	
Chronic illness	-0.0063	(0.0096)	0.0302	(0.0187)	0.0207**	(0.0075)
Smoke expenditures	0.0000	(0.0000)	-0.0000	(0.0000)	-0.0000	(0.0000)
Firewood*age50	-0.0051+	(0.0030)	0.0157**	(0.0058)	-0.0004	(0.0023)
Charcoal*age50	-0.0056	(0.0053)	0.0129	(0.0102)	-0.0010	(0.0041)
Kerosene*age50	-0.0046	(0.0070)	-0.0010	(0.0136)	0.0025	(0.0054)
Lpg*age50	-0.0096	(0.0116)	0.0279	(0.0226)	-0.0045	(0.0090)
Female	0.0018	(0.0015)	0.0023	(0.0029)	-0.0009	(0.0012)
Middle income	-0.0029	(0.0019)	-0.0096**	(0.0036)	-0.0001	(0.0014)
High income	-0.0031	(0.0019)	-0.0068+	(0.0037)	0.0019	(0.0015)
Graduate education	-0.0088	(0.0112)	0.0183	(0.0217)	0.0287**	(0.0087)
Secondary education	-0.0031	(0.0025)	-0.0033	(0.0049)	0.0009	(0.0019)
Primary education	-0.0031+	(0.0016)	-0.0023	(0.0032)	0.0001	(0.0013)
Bungalow house	-0.0006	(0.0020)	-0.0011	(0.0038)	-0.0027+	(0.0015)
Shanty house	-0.0035	(0.0041)	-0.0063	(0.0081)	-0.0033	(0.0032)
Flat house	0.0164**	(0.0047)	-0.0068	(0.0092)	-0.0063+	(0.0037)
Mansionette house	-0.0031	(0.0077)	-0.0064	(0.0150)	-0.0087	(0.0060)
Swahili house	0.0053+	(0.0029)	-0.0061	(0.0057)	-0.0043+	(0.0023)
Enclosed detached kitchen	0.0010	(0.0023)	0.0012	(0.0045)	0.0011	(0.0018)
Enclosed attached kitchen	0.0004	(0.0031)	-0.0101+	(0.0061)	0.0001	(0.0024)
Indoor without partition kitchen	-0.0046+	(0.0025)	-0.0077	(0.0048)	-0.0003	(0.0019)
Indoor with partition kitchen	-0.0013	(0.0032)	-0.0017	(0.0062)	0.0060*	(0.0025)
Traditional stove	-0.0022	(0.0067)	-0.0078	(0.0130)	-0.0086+	(0.0052)
Improved stove	-0.0045	(0.0071)	-0.0081	(0.0139)	-0.0110*	(0.0055)
Ordinary jiko	-0.0023	(0.0070)	-0.0038	(0.0136)	-0.0064	(0.0054)
Improved jiko	-0.0002	(0.0070)	-0.0075	(0.0137)	-0.0092+	(0.0055)
Kerosene stove	-0.0001	(0.0070)	0.0006	(0.0137)	-0.0050	(0.0055)
Gas cooker	-0.0001	(0.0076)	0.0026	(0.0148)	-0.0089	(0.0059)
Chimney	0.0032	(0.0031)	0.0011	(0.0061)	-0.0014	(0.0024)
Rural	-0.0017	(0.0016)	0.0009	(0.0031)	0.0002	(0.0012)
Exclusively breastfed	0.0057	(0.0044)	0.0082	(0.0085)	-0.0020	(0.0034)
_cons	0.0140+	(0.0072)	0.0428**	(0.0139)	0.0138*	(0.0056)

Equations:	N	R squared	F
Upper respiratory illness (URI)	12809	0.0040	1.7065
Lower respiratory illness (lRI)	12809	0.0027	1.1472
Eyes illness (EYES)	12809	0.0034	1.4571

Standard errors in parentheses; + $p<0.10$, * $p<0.05$, ** $p<0.01$

Smoke expenditures coefficients are very low at an average of $2.63*10^{-8}$ for URI, $1.31*10^{-8}$ for LRI, and $3.41*10^{-8}$ for eyes illness

The coefficient for flat and swahili type of dwelling variables were positive and significant at 1 percent and 10 percent level, respectively for all the four models estimated. Compared to traditional type of dwelling, those household members living in either flats or swahili dwellings are more likely to be predisposed to upper respiratory infection. This suggests that traditional type of dwellings is built with materials more permeable such as grass and tin at 82.7 percent compared to flats (1.04%) and swahili (1.25%) dwellings. According to Dasgupta et al. (2007), construction materials such as tin and thatch are more permeable and could construct kitchens. They are also significantly less air-trapping than mud walls, which, in turn, are less air trapping than brick.

The coefficient for indoor-without-partition kitchen variable was negative and significant at 10 percent level for all the four models estimated. This means that household members who cook indoors without partition are less likely to manifest upper respiratory infection than those who cook outdoors. It may be because such a kitchen has better ventilation. Households that cook from an indoor-without-partition kitchen and who used chimney represented 10.3 percent compared to 3.73 percent of households that cook from outdoor and had presence of chimney. In addition, those households cooking in indoor-without-partition kitchen have less IAP because the kitchen is constructed with material considered more permeable. For example, 35.4 percent of households cooking in indoor-without-partition kitchen used construction materials (thatch and grass) that are considered more permeable compared 27.1 percent of those households cooking outdoors. Barnes et al., (2009) observed that those who cook from outdoors are associated with low levels of IAP compared to those who cook indoors. This finding does not specify the indoor environment, whether it is partitioned or not.

Lower respiratory infection

In model 1 and model 4, use of firewood variable had a positive and significant coefficient at 5 percent and 1 percent level respectively. This implies children aged 0 – 4 years and household members above 50 years have a higher probability of being predisposed with lower respiratory infections than those household who use electricity. The result for children is similar to that of Barnes et al. (2009) who found a higher likelihood of acute lower respiratory illness in children aged 2-4 years.

The middle income and high income variable had a negative coefficient for all the four estimated models. The middle household income variable had a significant coefficient at 1 percent level for all the four models estimated while the high household income variable had a significance level of 10 percent (for models 1 and 3) and 5 percent level (for models 2 and 4) respectively. This means that individual in middle and high household income levels are less likely to be predisposed to lower respiratory infection than those in low household income levels. Similarly, Bukalasa (2011) concluded that children from low income (poor) households suffered more in acute respiratory illness compared to those from high income (rich) households.

The variable indicating cooking in enclosed-attached kitchen had a negative coefficient and was significant at 10 percent level for all the four models estimated. Compared to outdoor cooking, households that cook in enclosed-attached kitchen are less likely to manifest lower respiratory infection. This may be because about 24.3 percent of households that cook in enclosed-attached kitchen have adopted modern energy that have low levels of IAP compared to 5.7 percent of household s that cook outdoors. In addition, the use of chimney reduces the levels of IAP as 46.5

percent of households that cook from enclosed-attached kitchen are observed to use a chimney compared to 3.7 percent of households who cook outdoors.

The coefficient of cooking indoor without partition kitchen variable was negative and significant at 10 percent level (for model 1, 2 and 3). This implies that household members who cook in indoor kitchen without partition are less likely to manifest lower respiratory infection when compared to those who cook outdoors. It may be because such a kitchen has better ventilation as a result of using chimney and construction materials that are more permeable (as discussed in upper respiratory infection estimations).

The coefficient for chronic illness variable was positive and significant at 10 percent level for all the four models estimated except for model 4. This implies that household members who have chronic illness are more likely to suffer from lower respiratory infections.

Eyes illness

The variable for graduate education had a positive coefficient and was significant at 1 percent level for all the four models estimated. Compared to individuals' without any education, graduates are more likely to be exposed to eyes illness. This may be explained by the high unemployed levels among graduates compared to those who are not educated at all. The lack of employment may imply low or lack of income required to purchase modern energy and associated fuel appliances. About 36.8 percent of household members who are graduates were employed. In addition, only 4.9 percent of graduates made use of modern energy compared to 13.1 percent of individuals with no education. It could also imply that those who have graduate education are more empowered and are likely to report such cases.

The coefficient for flat, swahili and bungalow type of dwelling variables were negative and significant at 10 percent level each, for all the four models estimated except for the coefficient of bungalow house which was not significant for model 2 only. This implies that household members living in either flat, swahili or bungalow dwelling are less likely to manifest eyes illness. This may mean that those who live in flat or swahili dwellings use modern energy with a proportion of 15.5 percent and 18. 1 percent respectively, compared to 5.5 percent from traditional type of dwelling. About 6.0 percent of those in flats and 6.8 percent of those in swahili dwellings use a chimney compared to 1.29 percent of those in traditional type of dwelling. The use of modern energy and chimney may lead to lower levels of IAP.

The coefficient for indoor with partition kitchen variable was positive and significant at 5 percent level for all the four models. This means that household members who cook from indoor with partion kitchen are more likely to predispose eye illness compared to those who cook outdoors. It could be that those cooking outdoor have better ventilation as smoke produced form cooking get easily dispersed in the air when compared to cooking indoors with partitioned kitchen where smoked may be trapped from dispersion because of poor ventilation

The variable for improved stove had a negative coefficient and significant at 10 percent for all the 4 models except for model 4 which had 5 percent significance level. In addition the coefficient for improved jiko was negative and significant at 10 percent level only for model 1. This means that household members who use improved stove and improved jiko especially from households with children aged 0 – 4 years are less likely to manifest eye illness.

The coefficient for chronic illness was positive and significant at 1 percent level for all the four models estimated. Presence of chronic illness among household members implies a higher likelihood that they will suffer from eyes illness. This finding is similar to that of Gupta (2006).

4.6 Heath cost and productivity effects of household energy use

This essay also addresses the third objective that seeks to analyses the health cost and productivity effects of households energy use. Using the cost of illness approach adopted from Pant (2008), the health cost of upper respiratory infection, lower respiratory infection and eyes illness for households using firewood, charcoal and kerosene was estimated. The cost included medication cost, traditional doctors and medicine, medical procedure fees, hospitalisation, transport to and from hospital, health insurance, therapeutic equipment and appliances, and expenditures on other health care items (Table 4.7).

As indicated in Table 4.8, the household cost of illness for upper-respiratory infection (Kshs 87,754), lower-respiratory infection (Kshs 119,572.66) and eyes illness (Kshs 119,000) annually. The cost of medical procedure fee was high for household members with lower respiratory infection at Kshs 7,675; while that of therapeutic equipment and appliance was high for those with lower-respiratory illness. Some values on transport cost, health insurance cost, hospitalisation cost, and therapeutic equipment and appliance cost for upper-respiratory infection were missing because of either non-response or the cost item was not applicable to the household member.

Table 4.7: Household annual cost of illness (Kshs, 2006)

Cost Item	**Upper-Respiratory**	**Lower-Respiratory**	**Eyes Illness**
Transport	-	65.33	45
Health insurance	-	66.33	50
Medication cost	1,294.00	2,652.00	1093
Traditional doctor & medicine	1,260.00	2,001.00	200
Medical procedure fees	3120	7,675.00	1,980.00
Hospitalization	-	11,160.00	25,200.00
Therapeutic equipment	-	17,100.00	-
Other health cost	6,480.00	3,325.00	3,454.20
Total direct cost	**12,154.00**	**44,044.66**	**28,568.00**
Work days lost due to illness	21	21	25
School days lost due to illness	21	23	20
Opportunity cost of time per year for working adults (@Kshs 300/8 hours)	75600	75528	90432
Total cost of illness	**87,754.00**	**119,572.66**	**119,000.00**

Source: Author's computation based on KIHBS 2008

Cost savings can be achieved by implementing various interventions out various interventions, For instance adopting improved stoves for the case of lower-respiratory infection and eyes illness resulting into an annual average reduction in health costs per household of Kshs 5,434.58 and Kshs 6,610.45, respectively (Table 4.8).

Table 4.8: Average reduction in health costs (Kshs 2006)

	Lower respiratory	**Eyes illness**
Indoor air pollution reducing intervention - Improved stoves	**Coefficient**	**Coefficient**
	-0.009	-0.011
Total cost of illness	119,572.66	119,000.00
Average household size	5.05	5.05
Average annual reduction in health costs[24]	**5,434.58**	**6,610.45**

Source: Author's computation, Based on KIHBS 2008

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[24] This cost is a product of the marginal effect of the intervention on the illness, total cost of illness, and average household size

4.7 Conclusions and policy implications

4.7.1 Conclusions

This chapter investigated the association between household energy use and ill health using a multivariate regression. The results show that children aged 0 – 4 years among households that use either firewood or kerosene are likely to manifest upper respiratory infections compared to households that use electricity. Conversely individuals above 50 years among household that use firewood are less likely to be predisposed to upper respiratory infections. Also children aged 0 – 4 years and individuals above 50 years in households that use firewood have a higher likelihood of predisposing lower respiratory infections.

When compared to individuals with no education, individuals with at least primary education were less likely to be associated with upper respiratory infection, while individuals with graduates were more likely to be associated with eye illness. Education creates awareness of the effects of IAP from household energy use on health. However, lack of employment implies low levels or lack of income that is required to purchase modern energy and modern fuel stove appliances necessary to lower the levels of IAP. In addition, those with graduate education are empowered and are more likely to report cases of eye illnesses than those without any education.

Household members who dwell in flats and swahili houses had a higher chance of being associated with upper respiratory infection compared to those who live in traditional houses. However the size of the magnitude was larger for swahili than flat houses. At the same time, the likelihood of being associated with eyes illness was lower for household members who dwell in in flats, swahili and bungalow houses compared to those households who dwell in traditional houses.

Households that cook from indoors without partition kitchen were less likely to manifest upper and lower respiratory infections compared to those that cook outdoors. Also, households that cook from enclosed attached kitchen were less likely to be associated with lower respiratory infection compared to cooking outdoors. In addition individuals among households who cook from indoor with partition kitchen are more likely to predispose eye illness than those who cook from outside.

Use of improved stove and improved jiko especially among children aged 0 – 4 years are unlikely to manifest eye illness. Also, individuals among middle and high income households are unlikely to manifest lower respiratory infections. In addition individuals who have chronic illness are more likely to predispose lower respiratory infection and eye illness.

The chapter also analysed the health cost and productivity of households, where the cost of illness approach was adopted. The costs for illness for upper-respiratory, lower-respiratory, and eyes were Kshs 87,754**,** Kshs 119,572.66, and Kshs 119, 000.00 respectively. If households adopted the use of improved stoves, about Kshs 4, 434.38 and Kshs 6, 610.45 per household annually can be saved in respect of lower-respiratory infections and eyes illness respectively.

4.7.2 Policy implications

Use of firewood and the traditional stove enhance manifestation of upper respiratory infection and lower respiratory infection. In addition those who are educated are unlikely to associated with IAP related illness. Therefore, the government should encourage use of modern energy technology that targets both modern household energy and modern stove appliances that are considered not only to have lower emission but are also efficient. Government through educational programs and public awareness campaigns can assist households understand the importance of using modern energy technologies. Households could then be made aware of the substantive savings they could make annually by reducing the health costs and increasing their productivity through reduced work days lost associated with IAP related illness.

The likelihood of being associated with IAP related illness also depends on the type of dwelling and whether there is presence or absence of chimney. Households and residential flats developers should be enlightened to use construction materials that are more permeable when building dwellings. Permeable construction materials allow easy flow of air, meaning that polluted air can easily move and not be trapped. To add to this, the government should ensure permeable construction materials are affordable and accessible. Introducing policies that enhance use of chimney is equally important.

Since household with middle and high income levels are unlikely to manifest eye illness. This means that the government needs to strengthen policies that enhance adoption of fuel appliance that are less polluting and also provide conducive business environment that will improve the incomes of low income households. The government through educational programmes can carry out public awareness and also encourage entrepreneurship. For instance promoting of local artisans and retailers to engage in production and distribution of modern energy technologies not only enhances uptake but also provides incomes among households.

4.8 Areas of further research

Further research on association of IAP from household energy use and ill health should be directed to supporting the information from self-reported illnesses by using clinical measures such as spirometry test for lungs. Similar studies have been done in India such as Zhang (2009). In addition, there should be further studies focusing on the health cost of specific illnesses for example bronchitis and pneumonia. Such studies should compute the health cost savings when household take up mitigating activities.

This study focused on health effects from household energy uses, it is important that research studies be carried to investigate and compare the health effects of energy generation and conversion for different energy sources such as coal, thermal, wind, solar and geothermal. The Kenyan government has plans to increase energy generation from diversified sources, it will be important to look at the pollution levels from different energy sources at the generation and conversion stages and how they affect the human health and the environment.

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APPENDIX

Tables B1. MANOVA Outputs

Model 1: MANOVA OUTPUT

```
                           Number of obs =   12809

                           W = Wilks' lambda      L = Lawley-Hotelling trace
                           P = Pillai's trace     R = Roy's largest root

                  Source │  Statistic     df   F(df1,    df2) =   F   Prob>F
            ─────────────┼──────────────────────────────────────────────────
                   Model │ W   0.9896     29    87.0 38230.9     1.53 0.0010 a
                         │ P   0.0104           87.0 38337.0     1.53 0.0010 a
                         │ L   0.0104           87.0 38327.0     1.53 0.0010 a
                         │ R   0.0048           29.0 12779.0     2.12 0.0004 u
                         ├──────────────────────────────────────────────────
                Residual │            12779
            ─────────────┼──────────────────────────────────────────────────
                         │
```

Model 2: MANOVA OUTPUT

```
                           Number of obs =   12809

                           W = Wilks' lambda      L = Lawley-Hotelling trace
                           P = Pillai's trace     R = Roy's largest root

                  Source │  Statistic     df   F(df1,    df2) =   F   Prob>F
            ─────────────┼──────────────────────────────────────────────────
                   Model │ W   0.9898     30    90.0 38234.6     1.46 0.0032 a
                         │ P   0.0102           90.0 38334.0     1.46 0.0032 a
                         │ L   0.0103           90.0 38324.0     1.46 0.0032 a
                         │ R   0.0050           30.0 12778.0     2.12 0.0003 u
                         ├──────────────────────────────────────────────────
                Residual │            12778
            ─────────────┼──────────────────────────────────────────────────
                         │
```

Model 3: MANOVA OUTPUT

```
                           Number of obs =   12809

                           W = Wilks' lambda      L = Lawley-Hotelling trace
                           P = Pillai's trace     R = Roy's largest root

                  Source │  Statistic     df   F(df1,    df2) =   F   Prob>F
            ─────────────┼──────────────────────────────────────────────────
                   Model │ W   0.9907     30    90.0 38234.6     1.33 0.0209 a
                         │ P   0.0093           90.0 38334.0     1.33 0.0210 a
                         │ L   0.0093           90.0 38324.0     1.33 0.0209 a
                         │ R   0.0046           30.0 12778.0     1.96 0.0014 u
                         ├──────────────────────────────────────────────────
                Residual │            12778
            ─────────────┼──────────────────────────────────────────────────
                         │
```

Model 4: MANOVA OUTPUT

```
              Number of obs =    12809

              W = Wilks' lambda      L = Lawley-Hotelling trace
              P = Pillai's trace     R = Roy's largest root

      Source |  Statistic     df   F(df1,    df2) =   F   Prob>F
  -----------+--------------------------------------------------
       Model | W   0.9899     30    90.0 38234.6     1.44 0.0043 a
             | P   0.0101           90.0 38334.0     1.44 0.0043 a
             | L   0.0101           90.0 38324.0     1.44 0.0042 a
             | R   0.0047           30.0 12778.0     2.02 0.0008 u
             |--------------------------------------------------
    Residual |             12778
  -----------+--------------------------------------------------
```

Table B2. Multivariate regression models

Model 1: Multivariate regression for estimating health effects of IAP

```
Equation          Obs  Parms        RMSE    "R-sq"          F        P
----------------------------------------------------------------------
uri             12809     30    .0857202    0.0042   1.857632   0.0034
lri             12809     30    .1665805    0.0026   1.164106   0.2485
eyes            12809     30    .0665189    0.0036   1.576189   0.0253

--------------------------------------------------------------------------------
                |      Coef.  Std. Err.        t    P>|t|     [95% Conf. Interval]
----------------+---------------------------------------------------------------
uri             |
   1.ltichronic |  -.0070159   .0096306    -0.73   0.466    -.0258933    .0118615
      expsmoke1 |   2.63e-08   6.74e-08     0.39   0.696    -1.06e-07    1.58e-07
     1.fireda04 |   .0056267   .0027021     2.08   0.037     .0003302    .0109232
   1.charcoda04 |  -.0006471    .004783    -0.14   0.892    -.0100225    .0087283
     1.keroda04 |   .0110766   .0061571     1.80   0.072    -.0009923    .0231455
      1.lpgda04 |   .0036878   .0098764     0.37   0.709    -.0156714     .023047
       1.female |   .0018756   .0015164     1.24   0.216    -.0010967    .0048479
                |
       quintile |
             2  |  -.0029473   .0018546    -1.59   0.112    -.0065827     .000688
             3  |  -.0030362    .001887    -1.61   0.108     -.006735    .0006627
                |
         1.grad |  -.0088485   .0111507    -0.79   0.427    -.0307055    .0130085
         1.secs |  -.0031654   .0024962    -1.27   0.205    -.0080583    .0017276
        1.prims |  -.0031859   .0016479    -1.93   0.053     -.006416    .0000442
  1.hsebungalow |  -.0007914   .0019746    -0.40   0.689    -.0046619    .0030791
       1.shanty |  -.0034767   .0041449    -0.84   0.402    -.0116013     .004648
         1.flat |   .0159127   .0047381     3.36   0.001     .0066253    .0252001
   1.maisonnett |  -.0032482   .0077068    -0.42   0.673    -.0183546    .0118583
      1.swahili |   .0051761    .002904     1.78   0.075    -.0005161    .0108683
    1.encdetchd |   .0010668   .0022992     0.46   0.643      -.00344    .0055737
     1.encatchd |    .000411   .0031322     0.13   0.896    -.0057285    .0065506
1.indwthoutpart |  -.0046668   .0024458    -1.91   0.056    -.0094609    .0001272
  1.indwithpart |  -.0013803   .0032101    -0.43   0.667    -.0076726    .0049119
    1.tradstove |  -.0019307   .0028989    -0.67   0.505    -.0076131    .0037517
    1.imprstove |  -.0041985   .0038123    -1.10   0.271    -.0116711    .0032741
      1.ordjiko |  -.0019506   .0033116    -0.59   0.556    -.0084419    .0045407
     1.imprjiko |   .0002827   .0034825     0.08   0.935    -.0065435    .0071089
    1.gascooker |   .0002455   .0047125     0.05   0.958    -.0089918    .0094827
      1.chimney |    .003159   .0031315     1.01   0.313    -.0029793    .0092972
        1.rural |  -.0016882   .0015968    -1.06   0.290    -.0048181    .0014417
     1.brstfed6 |    .005707   .0043953     1.30   0.194    -.0029085    .0143225
          _cons |   .0125986   .0041996     3.00   0.003     .0043668    .0208305
----------------+---------------------------------------------------------------
lri             |
   1.ltichronic |    .033307   .0187151     1.78   0.075    -.0033775    .0699915
      expsmoke1 |  -1.31e-08   1.31e-07    -0.10   0.921    -2.70e-07    2.44e-07
     1.fireda04 |   .0131746    .005251     2.51   0.012     .0028819    .0234673
   1.charcoda04 |  -.0032762   .0092948    -0.35   0.724    -.0214954     .014943
     1.keroda04 |  -.0178342   .0119652    -1.49   0.136    -.0412877    .0056194
      1.lpgda04 |  -.0139261   .0191928    -0.73   0.468    -.0515469    .0236947
       1.female |   .0023341   .0029468     0.79   0.428     -.003442    .0081102
                |
       quintile |
             2  |  -.0092777   .0036041    -2.57   0.010    -.0163423   -.0022131
             3  |  -.0063772   .0036671    -1.74   0.082    -.0135652    .0008109
                |
         1.grad |   .0183368   .0216691     0.85   0.397     -.024138    .0608115
         1.secs |  -.0029741   .0048509    -0.61   0.540    -.0124826    .0065344
        1.prims |  -.0023644   .0032023    -0.74   0.460    -.0086414    .0039126
  1.hsebungalow |  -.0007169   .0038372    -0.19   0.852    -.0082384    .0068047
       1.shanty |  -.0059964   .0080548    -0.74   0.457    -.0217851    .0097923
         1.flat |  -.0051812   .0092076    -0.56   0.574    -.0232294     .012867
   1.maisonnett |  -.0056764   .0149766    -0.38   0.705    -.0350328    .0236801
      1.swahili |  -.0051411   .0056433    -0.91   0.362    -.0162028    .0059207
    1.encdetchd |   .0009226   .0044681     0.21   0.836    -.0078357    .0096808
     1.encatchd |  -.0103701   .0060868    -1.70   0.088    -.0223012    .0015609
1.indwthoutpart |  -.0080077   .0047529    -1.68   0.092     -.017324    .0013086
  1.indwithpart |   -.001903   .0062382    -0.31   0.760    -.0141308    .0103247
    1.tradstove |  -.0095159   .0056335    -1.69   0.091    -.0205585    .0015267
    1.imprstove |  -.0097378   .0074084    -1.31   0.189    -.0242594    .0047837
      1.ordjiko |   -.004664   .0064355    -0.72   0.469    -.0172785    .0079505
     1.imprjiko |  -.0087474   .0067675    -1.29   0.196    -.0220127    .0045179
    1.gascooker |   .0020569   .0091579     0.22   0.822    -.0158939    .0200077
      1.chimney |     .00114   .0060855     0.19   0.851    -.0107885    .0130684
        1.rural |   .0009058    .003103     0.29   0.770    -.0051765    .0069881
     1.brstfed6 |   .0076494   .0085414     0.90   0.371    -.0090931    .0243918
          _cons |   .0445633   .0081611     5.46   0.000     .0285663    .0605603
--------------------------------------------------------------------------------
```

Model 1:Multivariate regression for estimating health effects of IAP…Cont.

```
----------------+----------------------------------------------------------------
eyes            |
   1.ltichronic |   .0206178   .0074733     2.76   0.006      .005969    .0352667
      expsmoke1 |  -3.41e-08   5.23e-08    -0.65   0.514    -1.37e-07    6.84e-08
     1.fireda04 |   .0020014   .0020968     0.95   0.340    -.0021087    .0061115
   1.charcoda04 |   .0020094   .0037116     0.54   0.588    -.0052659    .0092847
     1.keroda04 |  -.0040812   .0047779    -0.85   0.393    -.0134467    .0052843
      1.lpgda04 |   .0090567   .0076641     1.18   0.237     -.005966    .0240794
       1.female |  -.0008848   .0011767    -0.75   0.452    -.0031913    .0014217
                |
       quintile |
             2  |   -.000112   .0014392    -0.08   0.938     -.002933    .0027091
             3  |   .0018458   .0014643     1.26   0.208    -.0010246    .0047161
                |
         1.grad |   .0287032   .0086529     3.32   0.001     .0117422    .0456643
         1.secs |    .000932   .0019371     0.48   0.630    -.0028649     .004729
        1.prims |   .0000843   .0012787     0.07   0.947    -.0024223    .0025908
  1.hsebungalow |  -.0027002   .0015323    -1.76   0.078    -.0057037    .0003033
       1.shanty |   -.003488   .0032165    -1.08   0.278    -.0097927    .0028167
         1.flat |  -.0063324   .0036768    -1.72   0.085    -.0135394    .0008746
   1.maisonnett |  -.0083732   .0059805    -1.40   0.162    -.0200958    .0033494
      1.swahili |  -.0043199   .0022535    -1.92   0.055     -.008737    .0000973
    1.encdetchd |   .0010346   .0017842     0.58   0.562    -.0024627    .0045319
     1.encatchd |  -.0000473   .0024306    -0.02   0.984    -.0048116    .0047171
1.indwthoutpart |  -.0006413   .0018979    -0.34   0.735    -.0043615    .0030789
  1.indwithpart |   .0058867    .002491     2.36   0.018     .0010039    .0107695
    1.tradstove |   -.004359   .0022496    -1.94   0.053    -.0087686    .0000505
    1.imprstove |  -.0068267   .0029583    -2.31   0.021    -.0126255    -.001028
      1.ordjiko |  -.0021299   .0025698    -0.83   0.407    -.0071672    .0029073
     1.imprjiko |  -.0049848   .0027024    -1.84   0.065    -.0102819    .0003123
    1.gascooker |  -.0047436   .0036569    -1.30   0.195    -.0119117    .0024246
      1.chimney |  -.0013853   .0024301    -0.57   0.569    -.0061486     .003378
        1.rural |   .0001889   .0012391     0.15   0.879    -.0022399    .0026177
     1.brstfed6 |  -.0019684   .0034108    -0.58   0.564     -.008654    .0047172
          _cons |   .0094213   .0032589     2.89   0.004     .0030334    .0158093
----------------+----------------------------------------------------------------
```

Model 2: Multivariate regression for estimating health effects of IAP

```
Equation          Obs  Parms        RMSE    "R-sq"          F        P
----------------------------------------------------------------------
uri             12809     31    .0857394    0.0038   1.637463   0.0154
lri             12809     31    .1666016    0.0025   1.050484   0.3906
eyes            12809     31    .0665096    0.0039   1.676273   0.0117

---------------------------------------------------------------------------------
                |      Coef.   Std. Err.        t   P>|t|     [95% Conf. Interval]
----------------+----------------------------------------------------------------
uri             |
   1.ltichronic |  -.0074004   .0096363    -0.77   0.443    -.0262891    .0114882
      expsmoke1 |   2.39e-08   6.74e-08     0.35   0.723    -1.08e-07    1.56e-07
    1.fireda514 |   .0007265   .0020006     0.36   0.716    -.0031949    .0046479
  1.charcoda514 |   .0001925   .0034877     0.06   0.956    -.0066439     .007029
    1.keroda514 |  -.0066822   .0045211    -1.48   0.139    -.0155441    .0021798
     1.lpgda514 |  -.0044614   .0068208    -0.65   0.513    -.0178312    .0089084
       1.female |   .0018708   .0015167     1.23   0.217    -.0011023    .0048438
                |
       quintile |
              2 |  -.0029305   .0018552    -1.58   0.114     -.006567    .0007059
              3 |  -.0030933   .0018872    -1.64   0.101    -.0067925    .0006059
                |
         1.grad |  -.0088441   .0111538    -0.79   0.428    -.0307071     .013019
         1.secs |   -.003115   .0024969    -1.25   0.212    -.0080093    .0017794
        1.prims |   -.003103   .0016488    -1.88   0.060    -.0063349     .000129
  1.hsebungalow |  -.0007123   .0019761    -0.36   0.718    -.0045858    .0031611
       1.shanty |  -.0034113   .0041503    -0.82   0.411    -.0115465    .0047238
         1.flat |   .0163574    .004743     3.45   0.001     .0070603    .0256544
   1.maisonnett |  -.0027805    .007745    -0.36   0.720    -.0179618    .0124008
      1.swahili |   .0053626   .0029133     1.84   0.066     -.000348    .0110731
    1.encdetchd |   .0010793   .0023045     0.47   0.640    -.0034379    .0055965
     1.encatchd |   .0005327   .0031356     0.17   0.865    -.0056135    .0066789
1.indwthoutpart |  -.0045295   .0024764    -1.83   0.067    -.0093837    .0003247
  1.indwithpart |  -.0012678    .003215    -0.39   0.693    -.0075696     .005034
    1.tradstove |  -.0027794   .0066901    -0.42   0.678     -.015893    .0103342
    1.imprstove |   -.005059   .0071395    -0.71   0.479    -.0190534    .0089354
      1.ordjiko |  -.0028479   .0070004    -0.41   0.684    -.0165698    .0108741
     1.imprjiko |  -.0005671   .0070498    -0.08   0.936    -.0143857    .0132515
    1.kerostove |  -.0002444    .007026    -0.03   0.972    -.0140164    .0135277
    1.gascooker |   -.000104    .007595    -0.01   0.989    -.0149915    .0147834
      1.chimney |   .0031508   .0031329     1.01   0.315    -.0029901    .0092918
        1.rural |  -.0016339   .0015971    -1.02   0.306    -.0047644    .0014966
     1.brstfed6 |    .006098   .0043997     1.39   0.166    -.0025259     .014722
          _cons |   .0139111   .0071878     1.94   0.053    -.0001781    .0280004
----------------+----------------------------------------------------------------
lri             |
   1.ltichronic |   .0325847   .0187245     1.74   0.082     -.004118    .0692875
      expsmoke1 |  -9.61e-09   1.31e-07    -0.07   0.942    -2.66e-07    2.47e-07
    1.fireda514 |  -.0063391   .0038873    -1.63   0.103    -.0139588    .0012806
  1.charcoda514 |  -.0097213    .006777    -1.43   0.151    -.0230053    .0035627
    1.keroda514 |  -.0032938    .008785    -0.37   0.708    -.0205136    .0139261
     1.lpgda514 |   .0210633   .0132536     1.59   0.112    -.0049159    .0470424
       1.female |   .0022221   .0029472     0.75   0.451    -.0035549    .0079991
                |
       quintile |
              2 |  -.0095169   .0036048    -2.64   0.008    -.0165829    -.002451
              3 |  -.0067934   .0036671    -1.85   0.064    -.0139815    .0003946
                |
         1.grad |   .0190533    .021673     0.88   0.379    -.0234291    .0615358
         1.secs |  -.0031694   .0048518    -0.65   0.514    -.0126797    .0063409
        1.prims |  -.0021833   .0032039    -0.68   0.496    -.0084634    .0040968
  1.hsebungalow |  -.0011374   .0038398    -0.30   0.767    -.0086639    .0063892
       1.shanty |  -.0068716   .0080645    -0.85   0.394    -.0226791     .008936
         1.flat |  -.0076717   .0092163    -0.83   0.405    -.0257369    .0103936
   1.maisonnett |  -.0079194   .0150494    -0.53   0.599    -.0374184    .0215796
      1.swahili |  -.0064074   .0056609    -1.13   0.258    -.0175036    .0046888
    1.encdetchd |    .000912    .004478     0.20   0.839    -.0078655    .0096895
     1.encatchd |  -.0106686   .0060928    -1.75   0.080    -.0226113    .0012742
1.indwthoutpart |  -.0080718    .004812    -1.68   0.093    -.0175041    .0013604
  1.indwithpart |  -.0019521    .006247    -0.31   0.755    -.0141972     .010293
    1.tradstove |  -.0066009   .0129997    -0.51   0.612    -.0320822    .0188804
    1.imprstove |  -.0069077   .0138728    -0.50   0.619    -.0341004    .0202851
      1.ordjiko |  -.0026688   .0136027    -0.20   0.844    -.0293321    .0239945
     1.imprjiko |  -.0066018   .0136985    -0.48   0.630     -.033453    .0202493
    1.kerostove |   .0008495   .0136524     0.06   0.950    -.0259112    .0276102
    1.gascooker |   .0024861   .0147581     0.17   0.866    -.0264419    .0314141
      1.chimney |   .0010653   .0060876     0.17   0.861    -.0108673    .0129978
        1.rural |   .0007329   .0031033     0.24   0.813      -.00535    .0068158
     1.brstfed6 |   .0078585    .008549     0.92   0.358    -.0088989    .0246159
          _cons |   .0452586   .0139668     3.24   0.001     .0178816    .0726357
---------------------------------------------------------------------------------
```

Model 2:Multivariate regression for estimating health effects of IAP…Cont.

```
----------------+-------------------------------------------------------------------
eyes            |
   1.ltichronic |     .02086   .0074751     2.79   0.005     .0062078    .0355123
      expsmoke1 |  -3.64e-08   5.23e-08    -0.70   0.486    -1.39e-07    6.61e-08
    1.fireda514 |   .0017669   .0015519     1.14   0.255     -.001275    .0048088
  1.charcoda514 |  -.0043846   .0027055    -1.62   0.105    -.0096877    .0009186
    1.keroda514 |  -.0015173   .0035071    -0.43   0.665    -.0083917    .0053571
     1.lpgda514 |   .0082831    .005291     1.57   0.117    -.0020881    .0186543
       1.female |  -.0009177   .0011766    -0.78   0.435    -.0032239    .0013886
                |
       quintile |
             2  |  -.0000807   .0014391    -0.06   0.955    -.0029015    .0027402
             3  |   .0018747    .001464     1.28   0.200    -.0009949    .0047442
                |
         1.grad |   .0286799   .0086522     3.31   0.001     .0117203    .0456394
         1.secs |   .0009268   .0019369     0.48   0.632    -.0028698    .0047235
        1.prims |   .0001414    .001279     0.11   0.912    -.0023657    .0026485
  1.hsebungalow |  -.0026008   .0015329    -1.70   0.090    -.0056055    .0004039
       1.shanty |  -.0035737   .0032194    -1.11   0.267    -.0098843    .0027369
         1.flat |  -.0064308   .0036793    -1.75   0.081    -.0136427    .0007811
   1.maisonnett |  -.0092305   .0060079    -1.54   0.124    -.0210069    .0025459
      1.swahili |  -.0042392   .0022599    -1.88   0.061     -.008669    .0001906
    1.encdetchd |   .0011182   .0017877     0.63   0.532    -.0023858    .0046223
     1.encatchd |  -4.38e-06   .0024323    -0.00   0.999    -.0047721    .0047633
1.indwthoutpart |  -.0003321    .001921    -0.17   0.863    -.0040976    .0034334
  1.indwithpart |    .006001   .0024939     2.41   0.016     .0011126    .0108894
    1.tradstove |  -.0085011   .0051896    -1.64   0.101    -.0186735    .0016714
    1.imprstove |  -.0109224   .0055382    -1.97   0.049    -.0217781   -.0000667
      1.ordjiko |  -.0061348   .0054304    -1.13   0.259    -.0167791    .0045096
     1.imprjiko |  -.0089509   .0054686    -1.64   0.102    -.0196702    .0017685
    1.kerostove |  -.0047697   .0054502    -0.88   0.382    -.0154529    .0059135
    1.gascooker |  -.0087484   .0058916    -1.48   0.138    -.0202969        .0028
      1.chimney |  -.0014641   .0024302    -0.60   0.547    -.0062277    .0032996
        1.rural |   .0002091   .0012389     0.17   0.866    -.0022193    .0026375
     1.brstfed6 |   -.001867   .0034129    -0.55   0.584    -.0085568    .0048228
          _cons |    .013372   .0055757     2.40   0.016     .0024427    .0243013
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Model 3: Multivariate regression for estimating health effects of IAP

```
Equation          Obs  Parms        RMSE    "R-sq"          F        P
----------------------------------------------------------------------
uri             12809     31    .0857459    0.0037    1.57278   0.0241
lri             12809     31     .166632    0.0021   .8947553   0.6315
eyes            12809     31    .0665225    0.0035   1.510696   0.0363

--------------------------------------------------------------------------------------
                |      Coef.  Std. Err.        t   P>|t|     [95% Conf. Interval]
----------------+---------------------------------------------------------------------
uri             |
   1.ltichronic |  -.0074298    .009633    -0.77   0.441     -.026312    .0114523
      expsmoke1 |   2.45e-08   6.74e-08     0.36   0.716    -1.08e-07    1.57e-07
   1.fireda1549 |  -.0005493   .0017325    -0.32   0.751    -.0039452    .0028467
 1.charcoda1549 |   .0018344   .0028292     0.65   0.517    -.0037111      .00738
   1.keroda1549 |   .0016597   .0035782     0.46   0.643    -.0053541    .0086736
    1.lpgda1549 |   -.000531   .0057581    -0.09   0.927    -.0118177    .0107557
       1.female |   .0018233   .0015169     1.20   0.229    -.0011501    .0047967
                |
       quintile |
              2 |  -.0029532   .0018555    -1.59   0.112    -.0065902    .0006838
              3 |  -.0030794   .0018866    -1.63   0.103    -.0067774    .0006185
                |
         1.grad |  -.0089643   .0111545    -0.80   0.422    -.0308288    .0129002
         1.secs |  -.0031264   .0024973    -1.25   0.211    -.0080214    .0017686
        1.prims |  -.0031593   .0016483    -1.92   0.055    -.0063903    .0000717
  1.hsebungalow |  -.0007507   .0019754    -0.38   0.704    -.0046228    .0031214
       1.shanty |  -.0034792   .0041562    -0.84   0.403    -.0116259    .0046675
         1.flat |   .0159609   .0047483     3.36   0.001     .0066535    .0252684
   1.maisonnett |  -.0032667   .0077488    -0.42   0.673    -.0184555    .0119221
      1.swahili |   .0050567   .0029128     1.74   0.083    -.0006528    .0107661
    1.encdetchd |   .0010347   .0023049     0.45   0.654    -.0034833    .0055526
     1.encatchd |   .0004452   .0031345     0.14   0.887    -.0056989    .0065892
1.indwthoutpart |  -.0046064   .0024768    -1.86   0.063    -.0094612    .0002484
  1.indwithpart |   -.001389    .003218    -0.43   0.666    -.0076969    .0049188
    1.tradstove |   -.001865   .0066934    -0.28   0.781    -.0149851     .011255
    1.imprstove |  -.0042563   .0071395    -0.60   0.551    -.0182509    .0097382
      1.ordjiko |  -.0023299   .0069964    -0.33   0.739    -.0160439     .011384
     1.imprjiko |  -.0000366   .0070491    -0.01   0.996    -.0138538    .0137807
    1.kerostove |  -.0001665   .0070261    -0.02   0.981    -.0139388    .0136057
    1.gascooker |   .0000544   .0075983     0.01   0.994    -.0148393    .0149481
      1.chimney |   .0031601   .0031341     1.01   0.313    -.0029832    .0093033
        1.rural |  -.0016827   .0015969    -1.05   0.292    -.0048129    .0014475
     1.brstfed6 |   .0057809   .0043974     1.31   0.189    -.0028386    .0144004
          _cons |   .0132691   .0072024     1.84   0.065    -.0008488    .0273869
----------------+---------------------------------------------------------------------
lri             |
   1.ltichronic |   .0335659   .0187201     1.79   0.073    -.0031283    .0702601
      expsmoke1 |  -1.68e-08   1.31e-07    -0.13   0.898    -2.74e-07    2.40e-07
   1.fireda1549 |  -.0030039   .0033668    -0.89   0.372    -.0096033    .0035955
 1.charcoda1549 |  -.0080611    .005498    -1.47   0.143     -.018838    .0027157
   1.keroda1549 |  -.0025738   .0069537    -0.37   0.711     -.016204    .0110564
    1.lpgda1549 |  -.0039881   .0111898    -0.36   0.722    -.0259219    .0179456
       1.female |   .0023286   .0029479     0.79   0.430    -.0034497    .0081069
                |
       quintile |
              2 |  -.0094665   .0036058    -2.63   0.009    -.0165344   -.0023987
              3 |    -.00662   .0036662    -1.81   0.071    -.0138063    .0005664
                |
         1.grad |   .0184884   .0216768     0.85   0.394    -.0240014    .0609781
         1.secs |  -.0032523    .004853    -0.67   0.503    -.0127648    .0062603
        1.prims |  -.0022766   .0032033    -0.71   0.477    -.0085554    .0040023
  1.hsebungalow |  -.0009227   .0038388    -0.24   0.810    -.0084474    .0066019
       1.shanty |  -.0060583   .0080768    -0.75   0.453      -.02189    .0097734
         1.flat |  -.0066747   .0092275    -0.72   0.469     -.024762    .0114127
   1.maisonnett |  -.0065955   .0150584    -0.44   0.661    -.0361122    .0229212
      1.swahili |   -.005817   .0056604    -1.03   0.304    -.0169123    .0052784
    1.encdetchd |   .0010788   .0044791     0.24   0.810     -.007701    .0098585
     1.encatchd |  -.0103297   .0060913    -1.70   0.090    -.0222695    .0016101
1.indwthoutpart |  -.0079444   .0048131    -1.65   0.099    -.0173788    .0014901
  1.indwithpart |  -.0016187   .0062537    -0.26   0.796    -.0138768    .0106395
    1.tradstove |  -.0079724   .0130074    -0.61   0.540    -.0334689    .0175241
    1.imprstove |  -.0082841   .0138744    -0.60   0.550      -.03548    .0189118
      1.ordjiko |  -.0036566   .0135962    -0.27   0.788    -.0303072     .022994
     1.imprjiko |  -.0075173   .0136986    -0.55   0.583    -.0343687    .0193341
    1.kerostove |   .0003558    .013654     0.03   0.979    -.0264082    .0271198
    1.gascooker |     .00196   .0147659     0.13   0.894    -.0269833    .0309033
      1.chimney |   .0010998   .0060905     0.18   0.857    -.0108386    .0130381
        1.rural |    .000823   .0031033     0.27   0.791      -.00526     .006906
     1.brstfed6 |   .0079218   .0085455     0.93   0.354    -.0088287    .0246724
          _cons |   .0461682   .0139966     3.30   0.001     .0187327    .0736037
--------------------------------------------------------------------------------------
                |
```

Model 3:Multivariate regression for estimating health effects of IAP…Cont.

```
-----------------+----------------------------------------------------------------
eyes             |
    1.ltichronic |   .0206204   .0074734     2.76   0.006     .0059714    .0352694
       expsmoke1 |  -3.46e-08   5.23e-08    -0.66   0.508    -1.37e-07    6.79e-08
    1.fireda1549 |  -.0012963   .0013441    -0.96   0.335    -.0039309    .0013383
  1.charcoda1549 |  -.0005035   .0021949    -0.23   0.819    -.0048058    .0037988
    1.keroda1549 |  -.0017658    .002776    -0.64   0.525    -.0072072    .0036757
     1.lpgda1549 |   .0038696   .0044672     0.87   0.386    -.0048867     .012626
        1.female |    -.00091   .0011769    -0.77   0.439    -.0032168    .0013968
                 |
        quintile |
              2  |  -.0001241   .0014395    -0.09   0.931    -.0029457    .0026976
              3  |   .0018547   .0014636     1.27   0.205    -.0010142    .0047236
                 |
          1.grad |   .0285715   .0086538     3.30   0.001     .0116088    .0455342
          1.secs |   .0009202   .0019374     0.47   0.635    -.0028774    .0047178
         1.prims |   .0000714   .0012788     0.06   0.956    -.0024353     .002578
   1.hsebungalow |  -.0026831   .0015325    -1.75   0.080     -.005687    .0003209
        1.shanty |  -.0035916   .0032244    -1.11   0.265    -.0099119    .0027287
          1.flat |  -.0064293   .0036838    -1.75   0.081    -.0136501    .0007916
    1.maisonnett |  -.0088869   .0060116    -1.48   0.139    -.0206706    .0028967
       1.swahili |  -.0042614   .0022598    -1.89   0.059    -.0086908    .0001681
     1.encdetchd |   .0011363   .0017881     0.64   0.525    -.0023688    .0046413
      1.encatchd |   .0000384   .0024317     0.02   0.987    -.0047282     .004805
 1.indwthoutpart |  -.0003536   .0019215    -0.18   0.854    -.0041201    .0034128
   1.indwithpart |   .0059399   .0024966     2.38   0.017     .0010462    .0108336
     1.tradstove |  -.0082793   .0051928    -1.59   0.111    -.0184579    .0018994
     1.imprstove |  -.0108036   .0055389    -1.95   0.051    -.0216607    .0000535
       1.ordjiko |  -.0062901   .0054279    -1.16   0.247    -.0169295    .0043493
      1.imprjiko |  -.0090936   .0054687    -1.66   0.096    -.0198132    .0016259
     1.kerostove |  -.0048961   .0054509    -0.90   0.369    -.0155807    .0057886
     1.gascooker |  -.0089589   .0058948    -1.52   0.129    -.0205136    .0025958
       1.chimney |  -.0014133   .0024314    -0.58   0.561    -.0061793    .0033527
         1.rural |   .0001938   .0012389     0.16   0.876    -.0022347    .0026222
      1.brstfed6 |  -.0020932   .0034115    -0.61   0.540    -.0087803     .004594
           _cons |   .0140132   .0055877     2.51   0.012     .0030605     .024966
-----------------+----------------------------------------------------------------
```

Model 4: Multivariate regression for estimating health effects of IAP

```
Equation          Obs  Parms        RMSE    "R-sq"          F        P
----------------------------------------------------------------------
uri             12809     31    .0857325    0.0040   1.706541   0.0094
lri             12809     31    .1665827    0.0027   1.147228   0.2648
eyes            12809     31    .0665267    0.0034   1.457137   0.0509

----------------+------------------------------------------------------------------
                |      Coef.  Std. Err.        t   P>|t|      [95% Conf. Interval]
----------------+------------------------------------------------------------------
uri             |
   1.ltichronic |  -.0062938   .0096472    -0.65   0.514    -.0252037     .0126161
      expsmoke1 |   2.46e-08   6.74e-08     0.36   0.715    -1.08e-07     1.57e-07
     1.fireda50 |  -.0050827   .0029762    -1.71   0.088    -.0109165      .000751
   1.charcoda50 |  -.0055648   .0052626    -1.06   0.290    -.0158803     .0047507
     1.keroda50 |  -.0045512   .0070181    -0.65   0.517    -.0183078     .0092054
      1.lpgda50 |  -.0095977   .0116407    -0.82   0.410    -.0324152     .0132198
       1.female |   .0018456   .0015168     1.22   0.224    -.0011275     .0048187
                |
       quintile |
              2 |  -.0029346   .0018553    -1.58   0.114    -.0065713     .0007022
              3 |  -.0030884   .0018866    -1.64   0.102    -.0067864     .0006096
                |
         1.grad |  -.0088239   .0111528    -0.79   0.429    -.0306851     .0130374
         1.secs |  -.0030755    .002498    -1.23   0.218     -.007972      .001821
        1.prims |  -.0031132   .0016483    -1.89   0.059     -.006344     .0001177
  1.hsebungalow |  -.0006433   .0019751    -0.33   0.745    -.0045147     .0032281
       1.shanty |  -.0034544   .0041476    -0.83   0.405    -.0115843     .0046754
         1.flat |   .0163649   .0047449     3.45   0.001     .0070642     .0256656
   1.maisonnett |  -.0031334   .0077374    -0.40   0.686    -.0182998      .012033
      1.swahili |   .0052643   .0029114     1.81   0.071    -.0004426     .0109711
    1.encdetchd |   .0009819   .0023045     0.43   0.670    -.0035353     .0054992
     1.encatchd |   .0004161   .0031351     0.13   0.894    -.0057292     .0065613
1.indwthoutpart |  -.0046462   .0024763    -1.88   0.061       -.0095     .0002077
  1.indwithpart |  -.0013131   .0032148    -0.41   0.683    -.0076147     .0049884
    1.tradstove |  -.0021905   .0066836    -0.33   0.743    -.0152914     .0109103
    1.imprstove |  -.0045459   .0071352    -0.64   0.524    -.0185319     .0094402
      1.ordjiko |    -.00234   .0069949    -0.33   0.738     -.016051     .0113709
     1.imprjiko |  -.0001887   .0070473    -0.03   0.979    -.0140024     .0136251
    1.kerostove |  -.0000988   .0070277    -0.01   0.989    -.0138741     .0136765
    1.gascooker |  -.0000989   .0075978    -0.01   0.990    -.0149917     .0147939
      1.chimney |   .0032071   .0031326     1.02   0.306    -.0029333     .0093475
        1.rural |  -.0017062    .001597    -1.07   0.285    -.0048366     .0014242
     1.brstfed6 |   .0057391   .0043972     1.31   0.192    -.0028801     .0143584
          _cons |   .0140122   .0071741     1.95   0.051    -.0000501     .0280745
----------------+------------------------------------------------------------------
lri             |
   1.ltichronic |   .0302172   .0187449     1.61   0.107    -.0065257     .0669601
      expsmoke1 |  -1.45e-08   1.31e-07    -0.11   0.912    -2.71e-07     2.42e-07
     1.fireda50 |   .0156677   .0057829     2.71   0.007     .0043323      .027003
   1.charcoda50 |   .0129348   .0102255     1.26   0.206    -.0071088     .0329784
     1.keroda50 |  -.0009748   .0136366    -0.07   0.943    -.0277046      .025755
      1.lpgda50 |   .0278518   .0226185     1.23   0.218    -.0164838     .0721875
       1.female |   .0022567   .0029472     0.77   0.444    -.0035202     .0080336
                |
       quintile |
              2 |  -.0096071    .003605    -2.66   0.008    -.0166734    -.0025407
              3 |  -.0067609   .0036657    -1.84   0.065    -.0139463     .0004245
                |
         1.grad |   .0183384   .0216705     0.85   0.397    -.0241391     .0608159
         1.secs |  -.0032774   .0048537    -0.68   0.500    -.0127915     .0062367
        1.prims |  -.0023497   .0032027    -0.73   0.463    -.0086275     .0039281
  1.hsebungalow |  -.0011427   .0038376    -0.30   0.766    -.0086651     .0063796
       1.shanty |  -.0062553   .0080589    -0.78   0.438    -.0220521     .0095414
         1.flat |  -.0067827   .0092196    -0.74   0.462    -.0248544     .0112891
   1.maisonnett |  -.0064283   .0150341    -0.43   0.669    -.0358974     .0230408
      1.swahili |  -.0060759   .0056571    -1.07   0.283    -.0171646     .0050128
    1.encdetchd |   .0012094   .0044778     0.27   0.787    -.0075678     .0099866
     1.encatchd |  -.0101491   .0060917    -1.67   0.096    -.0220897     .0017915
1.indwthoutpart |  -.0076701   .0048115    -1.59   0.111    -.0171014     .0017612
  1.indwithpart |  -.0016537   .0062466    -0.26   0.791     -.013898     .0105906
    1.tradstove |  -.0078013   .0129866    -0.60   0.548    -.0332569     .0176542
    1.imprstove |  -.0080927    .013864    -0.58   0.559    -.0352683     .0190828
      1.ordjiko |  -.0038166   .0135914    -0.28   0.779    -.0304578     .0228245
     1.imprjiko |  -.0074681   .0136933    -0.55   0.585    -.0343089     .0193727
    1.kerostove |   .0005961   .0136551     0.04   0.965      -.02617     .0273622
    1.gascooker |   .0025662   .0147629     0.17   0.862    -.0263712     .0315037
      1.chimney |   .0010753   .0060869     0.18   0.860    -.0108558     .0130065
        1.rural |   .0009465   .0031031     0.31   0.760     -.005136      .007029
     1.brstfed6 |   .0082172    .008544     0.96   0.336    -.0085304     .0249648
          _cons |   .0428491   .0139396     3.07   0.002     .0155253     .0701729
----------------+------------------------------------------------------------------
```

Model 4:Multivariate regression for estimating health effects of IAP…Cont.

```
eyes             |
    1.ltichronic |   .0206814    .007486     2.76   0.006     .0060077    .0353551
       expsmoke1 |  -3.47e-08   5.23e-08    -0.66   0.507    -1.37e-07    6.78e-08
      1.fireda50 |   -.000431   .0023095    -0.19   0.852    -.0049579    .0040959
   1.charcoda50 |  -.0010146   .0040837    -0.25   0.804    -.0090192    .0069901
      1.keroda50 |   .0024723   .0054459     0.45   0.650    -.0082025    .0131472
       1.lpgda50 |  -.0044752    .009033    -0.50   0.620    -.0221811    .0132308
        1.female |  -.0009068    .001177    -0.77   0.441    -.0032139    .0014002
                 |
        quintile |
              2  |  -.0000845   .0014397    -0.06   0.953    -.0029066    .0027375
              3  |   .0019032    .001464     1.30   0.194    -.0009664    .0047727
                 |
          1.grad |   .0286911   .0086544     3.32   0.001     .0117272     .045655
          1.secs |   .0009113   .0019384     0.47   0.638    -.0028882    .0047109
         1.prims |   .0000813    .001279     0.06   0.949    -.0024258    .0025884
   1.hsebungalow |  -.0026794   .0015326    -1.75   0.080    -.0056835    .0003247
        1.shanty |  -.0033372   .0032184    -1.04   0.300    -.0096458    .0029714
          1.flat |  -.0063018   .0036819    -1.71   0.087     -.013519    .0009153
   1.maisonnett |  -.0086813    .006004    -1.45   0.148    -.0204501    .0030875
       1.swahili |  -.0043287   .0022592    -1.92   0.055    -.0087571    .0000997
     1.encdetchd |   .0011335   .0017883     0.63   0.526    -.0023718    .0046387
      1.encatchd |   .0000587   .0024328     0.02   0.981    -.0047099    .0048273
1.indwthoutpart |  -.0003456   .0019215    -0.18   0.857    -.0041121    .0034209
   1.indwithpart |   .0059719   .0024947     2.39   0.017      .001082    .0108618
     1.tradstove |  -.0085601   .0051863    -1.65   0.099    -.0187261    .0016058
     1.imprstove |   -.011048   .0055368    -2.00   0.046    -.0219009   -.0001951
       1.ordjiko |  -.0064123   .0054279    -1.18   0.237    -.0170518    .0042271
      1.imprjiko |  -.0092394   .0054686    -1.69   0.091    -.0199586    .0014798
     1.kerostove |  -.0049969   .0054533    -0.92   0.360    -.0156863    .0056924
     1.gascooker |  -.0089429   .0058957    -1.52   0.129    -.0204993    .0026136
       1.chimney |   -.001408   .0024309    -0.58   0.562    -.0061728    .0033568
         1.rural |   .0001939   .0012393     0.16   0.876    -.0022353     .002623
      1.brstfed6 |  -.0020346   .0034122    -0.60   0.551     -.008723    .0046537
           _cons |   .0137575    .005567     2.47   0.013     .0028454    .0246696
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Chapter 5 : **DEMAND FOR INDOOR AIR POLLUTION ABATEMENT INTERVENTIONS**

5.1 Introduction

Indoor air pollution (IAP) from household energy use affects household overall welfare, since it is known to be associated with poor health outcomes that have adverse consequences on an individual's productivity. Interventions aimed at reducing IAP correspondingly improve health, by for example diminishing the burden of respiratory diseases (Diaz, 2008). In rural Guatemala, use of improved stoves (*plancha*) significantly reduced the number of respiratory symptoms, especially the prevalence of wheezing, headache and eye discomfort and, after 18 months of use, it was also related with significantly better self-rated health (Pant, 2007). Furthermore, IAP abatement interventions have also been linked to reduced mortality rates (Zuk et al., 2006). Apart from health benefits, use of *plancha* also reduces firewood consumption, which is an environmental benefit with expected positive welfare effects as fewer resources are assigned to medical expenses and firewood collection increasing productivity (Adrianzen, 2010).

Ballard-Tremeer and Mathee (2000) discussed three different technical interventions that can reduce IAP. First, producing less smoke (targeting source of pollution) by use of improved stoves and fuels. Second, getting smoke out of the indoor (living) environment via chimneys, windows, doors, and modifying kitchen design. Lastly, reducing exposure to smoke (targeting behavioural changes) by reducing cooking time, fuel drying, using pot lids to conserve heat, proper maintenance of stoves and related appliances and keeping children away from smoke in other rooms.

In rural Kenya, it was observed that various energy and behavior based interventions can result in a 35–95 percent reduction in exposure to PM_{10} for different demographic subgroups (Ezzati and Kammen, 2002).

Transitioning to cleaner (modern) forms of energy is one intervention for abating IAP. Due to high prices, limited supply and access, modern forms of energy are not likely to be adopted in the near future (Kalpana et al., 2011). The most popular intervention for abating IAP has been the use of improved stoves. According to Budds, Biran, & Rouse (2001), the improved stoves assume different names in different localities and countries such as *upesi* (Kenya); *anagi* (Nepal), improved *chulha* (India), bucket stove (Thailand), *mirte* (Ethiopia) and *plancha* (Central America).

However IAP reduction levels from use of improved stove have not achieved expected target set by WHO air quality guidelines (Smith et al., 2007). An improved stove is one of the interventions that reduce levels of pollution in kitchens where previously open fires were used (Naeher, Leaderer, & Smith, 2000). Budds et al. (2001) found that the improved stove is less polluting compared to the traditional stove though with some exceptions. Ashley (1993) highlights that improved stoves have multiple aspects that are beneficial to general development such as health improvement, better safety, more time for productive activities, beneficial environmental impacts in terms of reduced emissions, hence the potential to alleviate poverty.

According to Budds et al. (2001), interventions to alleviate IAP in developing countries have generally focused on improved cooking stoves, despite the potential of other interventions such as smoke hoods (chimneys), cleaner fuels, modified kitchen, or house design to increase ventilation. The use of hoods (chimneys) in Kenya leads to higher dispersion of IAP, compared to use of windows as suggested by Gitonga (2001).

The levels of IAP can also be reduced through house modification that aims to increase ventilation via windows and door openings. According to Regional Wood Energy Development Programme-RWEDP (1993), lack of proper ventilation exacerbates the concentration of pollutants in homes through the low exchange of indoor air with outdoor air. Improving the kitchen location to reduce IAP is another intervention which forms part of the house design modification (RWEDP, 1993). Having a separate kitchen, cooking outdoors, and placing stoves near doors or windows may reduce the level of IAP (Budds et al., 2001).

Education programmes and behavioural changes can indirectly influence the reduction of IAP from energy use. They indirectly promote the reduction of IAP through adoption of various interventions. Through education, people could attain a higher level of knowledge about the relationships between energy use and health that could, in turn, facilitate the demand for and promote use of stoves (Pant, 2007; and Budds et al., 2001).

There are various behavioural measures as suggested by Bruce and Doig (2000), Budds et al. (2001), and Rouse (1999) that are used to abate the levels of IAP. These behavioural measures include soaking food before cooking, keeping children away from fire and smoke, drying wood before burning, cutting wood into small pieces, covering pots with lids when cooking, and putting off fire after cooking.

Although there are numerous interventions that can be adopted, there is inconclusive evidence on which ones are the most effective. However, use of modern energy is considered most effective in terms of abating IAP, and it was ranked highly as a long term project of about 15-30 years by Goldemberg (2000) as poor households can neither afford the fuel nor other complementary upfront costs such as gas cookers/electric cookers, gas (LPG) cylinders, cylinder valves and pipes.

Since biomass is a fuel choice for many households, the use of improved stoves is likely to be more effective than redesigning the kitchen location (Department for International Development-DFID, 1999). However, this is considered a short term measure of about five years (Goldemberg, 2000).The use of chimney or hoods provides consistent exit for smoke, and it is not dependent on improved stove (Bates and Doig, 2001). The use of chimney is regarded as a short term measure by WHO (2000). Ezzati et al. (2002), Ezatti (2002), Barnes et al. (1994) and Hosier and Dowd (1987) conclude that although the benefits of adopted interventions may be known, as illustrated by varying levels of success of different stove programmes, the factors that motivate households to adopt an intervention or suite of interventions and the required institutions are not clear.

For this reason, the third essay seeks to find out why households are not adopting interventions aimed at abating exposure to IAP, despite their positive implications for welfare.

Specifically, the objectives addressed in this essay are to:

a) Examine the demand for IAP abatement intervention;
b) Examine drivers of adoption of IAP abatement interventions; and
c) Draw policy implications for increasing adoption of IAP abatement interventions.

This essay makes three contributions to the literature on the demand for IAP abatement interventions. First, it provides empirical evidence from Kenya on the demand for IAP abatement interventions. The IAP abatement interventions are categorised into three: the use of improved stove, modern energy, and chimney. This categorization is important since the demand for abatement interventions may differ among the three IAP abatement interventions. Second, this essay uses the Heckman (selection) model as the best approach to address the potential sample selection bias associated with substantive dependent variable of interest. Third, the essay is among the first to estimate the demand for chimney as one of the key IAP abatement interventions.

The rest of the essay is organised as follows. Section 5.2 discusses the literature review on the demand for IAP abatement interventions. The methodology, data and description of variables are discussed in section 5.3 and section 5.4, respectively. Section 5.5 presents the results and discussion, while section 5.6 presents the conclusions and policy recommendations.

5.2 Literature review

5.2.1 Theoretical literature

The energy ladder and fuel stacking models, apart from explaining how households behave with regards to energy use, also seek to explain the demand for fuel and fuel stove appliance as interventions for reducing IAP (Masera, Saatkamp, & Kammen, 2000; Adol-Agyarko, 2009; and Duflo, Greenstone, & Hanna, 2008).

The energy ladder model embodies a three step phase where households are observed to switch or transit from use of traditional energy (firewood and charcoal) to modern energy (LPG and electricity) as income rises (Leach, 1992). The energy ladder model has also been used to rank cooking energy with regard to the level of IAP, development of technology, safety and ease of use (Barnes, 2005). Smith (1987) observes that as fuels become safer, they also increase in cost. Jebraj and Iniyan (2006) indicate that apart from the income factor that comes out strongly in the energy model, culture; social and behaviour factors are key in explaining use of household energy behaviour. In addition, the household energy use behaviour has been explained using the fuel stacking model. The fuel stacking model describes how households are observed to use multiple fuels, rather than completely switching to use modern energy (Masera et al., 2000).

Theories explaining the demand for IAP intervention such as the changes in living environment characteristic (house design and kitchen location design modification) and behavioural changes are either missing or not clearly build up. According to Larson and Rosen (2000), there has been little theoretical or empirical analysis on the household demand for IAP interventions.

According to Larson and Rosen (2002), the demand for IAP abatement interventions can be explained by willingness to pay concept. The economic rationale indicates that the demand for IAP abatement intervention by households should equal the willingness to pay for the IAP abatement intervention by households. For instance if the households willingness to pay captured by perceived net gains is larger than the cost, then adoption of the IAP abatement intervention will take place. Larson and Rosen (ibid) therefore concludes that for case of developing countries, the household willingness to pay for the existing IAP abatement interventions is lower than the estimated cost.

In developing countries households are faced with several risks including from pests, water, air, among others Dickie and Gerking (1991). Therefore when making valuations on how to reduce such risk, households are guided by other health risks which they face.

The demand for IAP abatement intervention is also explained by the welfare impacts of different policy intervention scenarios (Zhang, 2009). If the welfare impact of a certain IAP abatement intervention is positive, then it is expected that household demand for the intervention would increase, however the magnitude of this increase may depend on the policy intervention instituted. In order to measure the welfare impact, discrete choice models have been widely applied using the Compensating variation approach (Zhang, ibid).

Policy simulation is also another concept that seeks to explain the demand for IAP abatement interventions. Edwards and Langpap (2008) explains how policy simulation approach can evaluate different IAP policy interventions and propose policies that can accelerate adoption of IAP abatement intervention. IAP interventions with maximum benefits to households are identified after carrying out simulation process and populated for adoption.

Household demand for various interventions has been explained on the basis of perceived benefits and costs (Larson and Rosen, 2002; and Pant, 2007). However, in addition to economic reasons, social, culture, behaviour and environmental factors may explain why an intervention is adopted or not adopted.

5.2.2 Empirical literature

Empirical literature is discussed based on the demand of the intervention adopted. Three interventions are discussed: the first, relates to the choice of fuel adopted. The second and third interventions relate to the fuel stove appliances and change of living environment characteristics (that is, modifications of house and kitchen designs, improving ventilation and use of chimney).

Various factors influence adoption of fuel used. Several analyses on effects of costs and modern fuel adoption indicate that poor households find the cost of modern energy to be too high to consider adoption (ESMAP, 2000; & 2004).

Social cultural factors also drive the use of biomass because of the taste of food cooked (Pant, 2007). Kowsari and Zerriffi (2011) found other cultural factors including food type, lifestyle and cooking habit can affect demand on energy system. Likewise, Atanassov (2010) investigated the theoretical dimension of fuel transition in developing countries and assessed the role of socio-cultural factors as determinants of fuel choice at household level. Applying psycho anthropologic (that examines the relations of cultural and mental processes) research techniques to 402 households in Catembe, the study provides a framework for understanding the core factors responsible for household cooking energy choice. A series of qualitative and quantitative results indicate that factors such as taste and preferences, cooking practices, local cuisine, kitchen type, gender relations and fuel preferences are culturally determined, and significantly influence the adoption of modern cooking technologies. In addition, Joon, Chandra, & Bhattachanya (2009) concluded that the taste and culinary preferences had an important role in influencing the type of fuel used.

The gender of the household head is an important factor in determining the choice of fuel (Farsi, Filippini, & Pachauri, 2007; Schlag and Zuzarte, 2008; Gebreegziabher, Mekonnen, Kassie, & Kohlin, 2010; Chambwera, 2004; Pachauri, Mueller, Kemmler, & Spreng, 2004; and Howells et al., 2010). Malhotra, Neudoerffer, & Dutta (2004) argue that women and men do not bear the burden of environmental and health factors associated with biomass use, to the same extent. Women in many countries are responsible for the collection, transportation, processing and storing of fuels, as well as the cooking activities; while men typically make decisions of a financial nature (Malhotra et al., 2004; Schlag and Zuzarte, 2008; and World Health Organisation, 2006).

Lack of awareness, education and information play a crucial role in influencing the type of fuel adopted. Most households are not educated on the issues of IAP and associated health and welfare related consequences. In Ghana, for instance, women do not understand the problems linked to IAP exposure (McGranahan, 1994). According to Bruce et al. (2000), women in Kenya were unable to associate coughing to IAP as they did with red eyes. This is because coughing was considered habitual and widespread. Similarly, the low adoption of improved fuels can be explained by lack of information (Jack, 2006; and Schlag and Zuzarte, 2008). Generally, education was found important in determining fuel choice (Gebreegziabher et al., 2010; Chambwera, 2004; Pachauri et al., 2004; and Howells et al., 2010).

It is unclear whether households connected to the electricity grid are more likely than the unconnected to adopt use of modern energy. Heltberg (2004) found that those connected to electricity were more likely to use modern energy and less likely to use solid fuels than unconnected ones. Madubansi and Shackleton (2007) found contradictory results. In their study, connection to the grid was found to be an insignificant determinant of modern energy use.

There is a higher probability that households connected to tap water are more likely to use modern energy compared to those who are unconnected to tap water (Heltberg, 2004). Heltberg (ibid) found that availability of tap water inside the house enhanced fuel switching.

Ownership of clean and modern fuel appliance such as gas cooker/electric cooker is a key factor that drives the transition to modern energy. Gebreegziabher et al. (2010) examined the urban energy transition and technology adoption in Tigray, northern Ethiopia, as a way of reducing the pressure of urban centres on rural areas. Using a sample of 350 urban households, a bivariate probit model was estimated to determine the factors underlying the use of electric *mitad* cooking appliance, wood stoves and a household's choice of a specific fuel source. The results indicated that energy transition is conditioned on the adoption of appropriate cooking appliances or stove technologies by the majority of users. For instance, transition to electricity is affected by households adopting the electric *mitad* cooking appliance.

Household income has been found in several studies to play a key role in selecting the type of fuel used. Gebreegziabher et al. (2010); Chambwera (2004); Pachauri et al., (2004); Howells et al. (2010); and Oudejans (2011) have shown that when a household's income rises, the household tends to use multiple fuels, with consistent use of biomass fuel. The income factor was also observed to be important by Campbell, Vermeulen, Mangono, & Mabugu (2003) who found urban households with high income in Zimbabwe able to transit to modern cooking fuel sources such as kerosene and electricity rather than use woodfuel which is the dominant fuel among the lower income households. Likewise, when a household's income increases, the use of firewood reduces in Burkina Faso (Ouedraogo, 2006).

Household size, age and occupation of household head are important determinants of fuel choice (Gebreegziabher et al., 2010; Chambwera, 2004; Pachauri et al., 2004 and Howells et al., 2010). In cases where there are many members in one household, this triggers fuel stacking rather than fuel switching since larger households are more likely to use multiple fuels (Heltberg, 2004 and

Barnes, Kerry, & William, 2004). Different occupation categories result to different lifestyles and opportunity costs of time, which have consequences on fuel choices (Gundimeda and Köhlin, 2008). Mekonnen and Kohlin (2008) found that older household heads have a higher probability than younger household heads of selecting solid fuels (such as wood fuels, agriculture residue and animal residues). Similar results are found in Pundo and Fraser (2003) where older women, apart from showing their loyalty use firewood.

Fuel availability and climate also explain the choice of fuel. Kebede, Berkele, & Kedir (2002) investigated domestic energy demand pattern in 10 large cities and towns in Ethiopia. Availability of modern fuels is better for most urban areas than rural areas, while rural areas are mostly faced with problems of accessibility. Temperature and precipitation influenced households from warmer regions in the US to use electricity alone. Electricity use was seen as the only alternative for cooling purposes during summer, and was used for heating purposes since it has a high marginal cost but a low fixed cost during winter (Mansur, Mendelsohn, & Morrison, 2007). Government policies indirectly determine the type of fuel used through policies that inform the distribution and production of energy carriers such as fuels and stoves (Barnes et al., 2004).

Numerous factors were found to be important in determining the adoption of stoves. Key among these factors were costs and benefits. Pant (2007) estimated the health benefits of improved *chula* (improved cook stove) intervention that reduce the use of fuelwood leading to the protection of the forest. Pant observed that households invest in pollution reducing interventions on the basis of the costs and benefits they perceive. The full cost (minus subsidy, if any) is perceived by the rural households. However, not all the benefits, particularly the health benefits, are indirect and known to them. Han (2010) carried a cost-benefit analysis to compare the benefits and costs generated from the implementation of new biomass project in rural Guizhou. The study found greater benefits in terms of health improvement from use of new improved stove than traditional stove users.

Correspondingly, Oudejans (2011) analysed the factors that influence the transition to low carbon cooking technologies for the rural poor in India. The results indicate that biogas stoves require expensive biogas installations, which makes these technologies less suitable for the rural poor in India. The results also show that improved biomass stoves (IC's) are the best in terms of cost-benefits and carbon dioxide-emissions, and are available in natural draft stoves and forced draft stoves that include an electric battery.

Masera et al. (2000) showed the importance of cultural factors in adoption of the new stoves (LPG). The study demonstrated how people in Jaracuaro, rural Mexico, where a majority (57 %) of people depend on fuelwood for cooking, failed to abandon fuelwood use for LPG stoves. This was because LPG stoves were found inefficient for cooking the popular tortilla, since it was found to be distasteful. Oudejans (2011) also showed the effect of the cultural factors where adoption of solar cooker required a large shift in culture. Likewise, culture differences played a crucial role in adoption of jiko stove. In Kenya, the *jiko* stove was popular and widely accepted unlike in Tanzania where the design of the *jiko* had to be modified to meet the preferences of the locals (Barnes et al., 1993) and Budds et al., 2001).

The gender and education attainment of the household head also influence whether or not an improved stove will be adopted or not (Atanassov, 2010; Gebreegziabheret al., 2010; and Heltberg (2004). It is expected that education levels improve the choice of stoves attributes, tastes and preferences for better fuel stove appliances. Also women because of their cultural role in cooking are more likely to select modern technologies compared to men (Atanassov, 2010).

Lack of information on improved stoves is the reason for their non-adoption (Jack, 2006; and Schlag et al., 2008). According to Sclag et al. (2008), there are three ways in which limited information flow affects fuel switching. One, through the limited knowledge of specific patterns of household energy use that makes it difficult to assess the market demand and the potential for clean cooking fuel programmes in different areas of Sub-Saharan Africa. Second, this contributes to the limited information on alternatives to tradition fuels and the associated benefits available to consumers. Third, as a result of lack of detailed information on household energy, it is difficult to determine the commercial viability of different types of fuel.

Households engage in a variety of strategies to cope with IAP. Jaggernath (2013) evaluated the socio-economic and spatial aspects of the health implications emanating from air pollution in Richards Bay, KwaZulu-Natal. The study identified six different coping strategies that households used to deal with air pollution. These include closing windows and doors, leaving the home temporarily, cooking outdoors rather than indoors, using renewable energy sources such as solar energy, and purchasing better appliances such as stoves. The results also reveal that while middle/ upper income households adopt strategies (such as purchasing better appliances, procuring better health care and even feeling that they have an option to relocate), the poorer households rely almost exclusively on coping or survivalist strategies (closing doors, windows and cooking outdoors; leaving the home temporarily and use of masks). They do not have long-term strategies to change or anticipate conditions. However, the focus group discussion revealed that closing windows and doors can increase indoor pollution; particularly if fossil and biomass-based fuels are being used in the house.

The age of the household head and family size affect the type of stove adopted. Mekonnen et al. (2008) showed that older household heads are more likely than younger ones to choose solid fuels resulting from their habit. On the other hand non-solid fuels are more likely to be selected by the younger household heads than older household heads. Selecting solid fuels may imply lower chances of adopting modern fuel stove appliances.

The type of fuel stove appliance may be affected by the scarcity of fuels and whether or not fuels are purchased. Barnes (2005); Ramakrishna, Durgaprasad, & Smith (1989); and Barnes, Openshaw, Smith, & Van der Plas (1994) conclude that adoption of improved stoves is more likely when biomass fuels are purchased (people are motivated by cost savings for purchasing fuels) and when fuels are scarce (women are motivated by saving time in collecting less wood). Moreover, when the adoption rate of improved stoves is lower, this may be because some households freely collect biomass as they are too poor to afford maintenance of improved stove (Barnes, 2005).

There has been low adoption of house design modification aimed at improving ventilation. According to Budds et al. (2001), this could be because it is considered more difficult to modify house structures than to improve stoves or fuel design. Conversely, Bruce (1999) and Regional Wood Energy Development Programme-RWEDP (1993) argued that relatively cheap and simple changes can be made to housing in developing countries, for instance enlarging windows, opening eaves or raising roof height.

5.2.3 Summary of literature

Literature review has shown that much information is available on use of improved stoves and modern energy as potential intervention for reducing IAP (Gebreegziabher et al., 2010; Jaggernath, 2013; Masera et al., 2000 and Oudejans, 2011).However, little is known about the ventilation and improvements in kitchen designs interventions, and their drivers. In addition, Ezzati et al. (2002), Ezatti (2002), Barnes et al. (1994) and Hosier and Dowd (1987) acknowledge that despite known benefits of adopted interventions factors that motivate households to adopt any intervention or suite of interventions and the required institutions are still unclear.

Larson et al. (2002) and Pant (2007) contributed to the missing literature on household demand for IAP intervention. However, the aspect of demand in their study was based on the perceived benefits to the household adopting the intervention.

The study aims at determining the demand for IAP abatement interventions. In addition to common interventions (use of modern energy and improved stoves), the study extends the analysis by including the demand for chimney. Apart from the benefits and costs, other factors such as culture, social and economic characteristics that influence the choice of particular IAP interventions are considered.

The knowledge on the factors that influence adoption of different interventions is important. It allows accurate forecast of the demand of the different interventions and modification of technology that widens the adoption rate of the different interventions.

5.3 Methodology

In the conceptual framework discussed in chapter 1, IAP abatement interventions include; use of living environment, modern energy and improved stoves. Factor influencing demand for these interventions includes cultural factors, household income, gender and education (Masera et al., 2000; and Ballard-Tremeer and Mathee, 2000). Reduced IAP may impact positively on human health and well-being as shown in the conceptual framework presented in chapter 1.

5.3.1 Theoretical model

This essay uses the indoor air quality production function (discussed in chapter 3) that has been modified from the health production function based on Grossman (1972) and applied by Gupta (2006); Adhikari, (2012); and Brandt and Hanemann (2003). Demand functions for averting activities are derived. Averting activities such as adopting improved cooking stove, modifying the living environment, and switching to modern energy are households averting behaviour aimed at reducing IAP.

The household maximises utility function defined as:

$$U = U\ (X, L, I) \tag{5.1}$$

where X is consumption of goods; $L,$ is leisure; and $I,$ IAP. The household derives utility from consumption of goods and leisure, while IAP results in disutility. The household produces unpolluted (clean) air by combining averting activities (such as adopting improved cooking stoves, modifying living environment characteristics and use of modern energy) with other socio-economic factors. The indoor air quality function is:

$$I = I\ (B, C, D, Z) \tag{5.2}$$

where I is a measure of IAP; B, adopting improved cooking stoves; C, modifying living environment; D, switching to the use modern energy; and Z, social economic factors.

The household budget constraint is specified as:

$$Y + W(T - L - \propto H) = P_x X + P_b B + \ P_c C + \ P_d D \tag{5.3}$$

where Y is non-wage income; W, wage rate; $(T - L - \propto I)$ time spent at work (T is total time; L, is leisure time; and, $\propto I$ is lost days of work due to self-nursing /attending to child with respiratory infection caused by IAP as defined in other essays earlier); X, consumption goods; and $B, C, and\ D$ are as defined above. P_b is the price per unit of adopting improved cooking stove; $P_{c,}$ price per unit of modifying living environment; $P_{d,}$ price per unit of switching to use modern energy; and P_x=1, price of the bundle of consumption goods normalised to one.

The household maximises the utility function (equation 5.1) with respect to X, L, B, C and D subject to the budget constraint (equation 5.3). The household utility maximisation problem is:

$$\text{Max} \quad U = U[X, L, I(B, C, D, Z)] \tag{5.4}$$

Subject to $X + P_b B + P_c C + P_d D = Y + W(T - L) - W \propto I(B, C, D, Z)$

The langragian function, where λ is the Langragian multiplier:

$$\mathcal{L} = \ U[X, L, I(B, C, D, Z)] + \lambda[Y + W(T - L) - W \propto I\ (B, C, D, Z) - (X + P_b B + P_c C + P_d D)] \tag{5.5}$$

The first order conditions are shown in equations (5.6a), (5.6b), (5.6c), (5.6d) and (5.6e).

$$\frac{\partial U}{\partial X} = \lambda \tag{5.6a}$$

$$\frac{\partial U}{\partial L} = \lambda W \tag{5.6b}$$

$$\frac{\partial U}{\partial I}\frac{\partial I}{\partial B} = \lambda\left[W \propto \frac{\partial I}{\partial B} + P_b\right] \tag{5.6c}$$

$$\frac{\partial U}{\partial I}\frac{\partial I}{\partial C} = \lambda\left[W \propto \frac{\partial I}{\partial C} + P_c\right] \tag{5.6d}$$

$$\frac{\partial U}{\partial I}\frac{\partial I}{\partial D} = \lambda\left[W \propto \frac{\partial I}{\partial D} + P_d\right] \tag{5.6e}$$

Simplifying and re-arranging equations (5.6c), (5.6d) and (5.6e) yields:

$$\frac{\partial U}{\partial HI} / \frac{\partial U}{\partial X} = W \propto + \frac{P_b}{\frac{\partial I}{\partial B}} \tag{5.7a}$$

$$\frac{\partial U}{\partial I} / \frac{\partial U}{\partial X} = W \propto + \frac{P_c}{\frac{\partial I}{\partial C}} \tag{5.7b}$$

$$\frac{\partial U}{\partial I} / \frac{\partial U}{\partial X} = W \propto + \frac{P_d}{\frac{\partial I}{\partial D}} \tag{5.7c}$$

The solution to the utility maximisation problem yields these demand functions for averting activities that is adopting improved cooking stoves, modifying living environment and switching to use modern energy, respectively.

$$B = B(P_a, P_b, P_c, P_d, W, Y + WT, Z) \tag{5.8}$$

$$C = C(P_a, P_b, P_c, P_d, W, Y + WT, Z) \tag{5.9}$$

$$D = D(P_a, P_b, P_c, P_d, W, Y + WT, Z) \tag{5.10}$$

5.3.2 Empirical model

Using the household utility function (equation 5.1), IAP interventions targeting emission abatement can reduce health costs, reduce the effects of respiratory diseases and other related health problems, and increase human productivity which is considered welfare improving. These interventions include; adopting improved stoves, changing living environment characteristics, and switching to modern fuel use. In the model, households are assumed to maximise their utility subject to indoor air quality function, time and budget constraints and other exogenous factors.

In this essay, three policy interventions are proposed and modeled: use of improved fuel stove appliance, change of living environment (use of chimney), and switching to modern energy. The empirical specifications for demand for improved stove appliance, chimney and modern energy respectively, are:

$$S_h = \propto_o + \propto_1 \ M_h + \propto_2 \ N_h + \propto_3 \ D_h + \varepsilon_{\ h} \tag{5.11}$$

$$L_h = \beta_o + \beta_2 M_h + \beta_3 D_h + \varepsilon_{\ h} \tag{5.12}$$

$$A_h = \gamma_o + \ \gamma_1 P_h + \ \gamma_2 N_h + \gamma_3 D_h + \varepsilon_{\ h} \tag{5.13}$$

where $h = \ 1 \ldots..$ H indexes households, $S, L, \ and \ A$ denotes demand for improved fuel stove appliance, chimney and modern energy respectively. $\propto_o, \propto_1, \propto_2, \propto_3, \propto_4, \beta_o, \ \beta_1$ and $\gamma_o, \gamma_1, \gamma_3, \gamma_4$ are coefficients to be estimated; $P_{h,}$ a vector of fuel stove appliance (traditional stove, improved stove, ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker); $M_{h,}$ a vector of alternative fuel types (firewood, charcoal, kerosene, LPG, and electricity); $N_{h,}$ a vector of living environment (type of dwelling, kitchen location and presence of chimney); $D_{h,}$ a vector of socio-economic variables (age, education levels, employment, households size and gender); and $\varepsilon_{h,}$ the error term.

Estimating the outcome (event) of equations (5.11), (5.12) and (5.13) using ordinary least square (OLS) estimator, results in sample selection bias. Sample selection bias or the problem of selectivity bias occurs when characteristics that influence the sample selection also influence the event or the outcome equation (Puhani, 2000). When OLS is used, the assumption made is that the sample is chosen randomly from the whole population, which is not the case here. The outcome equations violate the assumptions of OLS: first, the sample used to analyse the event represents a fraction of the whole population and second, the sample is not randomly selected.

The outcome equations (5.11), (5.12) and (5.13) may be subjected to sample selection because the event equations (household demand for improved fuel stove appliance, demand for chimney and demand for modern energy, respectively) is not representative of all households. This is because those who have not adopted correspondingly the use of improved stove appliance, use of chimney and use of modern fuel are not part of sample for the outcome/event equation.

In addition, for each event or outcome equation, the decision on whether or not to adopt a specific intervention aimed at abating the levels of IAP is made by individual household, and those that have not adopted a particular intervention may constitute a self-selected sample. It may be possible that those who have not adopted a particular intervention (captured by missing data) might have been influenced by various factors, among them the high cost of adopting an intervention.

To address the problem of sample selection bias the Heckman selection model is used to estimate equations (5.11), (5.12) and (5.13) (Heckman, 1974 & 1979). The Heckman model corrects estimation biases as a result of non-random selected samples. Also, the Heckman selection model allows information from the non-users of various IAP abatement interventions to improve the estimates of the parameters in the outcome (event) equation to be used. The Heckman model provides consistent, asymptotically efficient estimates, for all the parameters in the model. The Heckman model is implemented using the two stage approach or the maximum likelihood approach. The two stage procedure is also known as the Heckit model.

The first stage is the selection/participation model, where the probit regression model on the use or adoption of a particular intervention (use of improved stove appliance, use of chimney and use of modern fuel) is estimated. The second stage is an outcome/event model which involves correcting for self-selection, by incorporating a transformation of a specific adopted intervention selection probability as an additional explanatory variable in the outcome equations (5.11), (5.12) and (5.13).

In the first stage of the Heckman selection model, households decide whether to adopt a particular intervention or not. There are three interventions that are analysed; adopting the use of improved stoves, use of chimney and use of modern energy. The first stage regression model is given in equation (5.14) and estimated using a probit model as defined in equation (5.15).

$$V_h^* = X_h^{'}\beta + \mu_h \qquad (5.14)$$

$$\Pr(V_h = 1|X) = \Phi\left(X_h^{'}\beta\right) \qquad (5.15)$$

where V_h is 1, if the h^{th} household uses or adopts a particular intervention (where the latent variable $V_h^* > 0$ shows the unobserved propensity of using a particular intervention) or 0 otherwise. β is a vector of parameter to be estimated; and $X_h^{'}$, is a vector of explanatory variables which includes a set of alternative fuel stove appliances, set of fuel types alternatives, living environment characteristics and socio-economic variables. μ_h is the error term. Φ is the cumulative distribution function of the standard normal distribution. The maximum likelihood estimate of equation (5.15) is then used to compute the inverse mill's ratio[25] for each household h, and is derived as:

$$\lambda_{\ h} = \frac{\phi\, X_h^{'}\beta)}{\Phi\ (X_h^{'}\beta)} \tag{5.16}$$

where ϕ and Φ are the standard normal density and cumulative distribution functions respectively. The inverse mill's ratio is then used as an additional variable in the second stage. The expected demand models for improved fuel stove appliance, chimney and modern energy that were estimated are given as;

$$E(Z|U_h = 1) = W_h^{'}\beta + \rho\sigma_\varepsilon \lambda \left(X_h^{'}\beta\right) \tag{5.17}$$

If $\rho\sigma_\varepsilon = \beta_{\ \lambda}$ then equation (5.17) becomes

$$E(Z_h|V_h = 1) = W_h^{'}\beta + \beta_{\ \lambda} \lambda \left(X_h^{'}\beta\right) \tag{5.18}$$

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[25] The inverse of mills ratio is the probability density function to the cumulative distribution function.

Where $Z_h = W_h^{'}\beta + \varepsilon_h$ is observed if $V_h = 1$ for households that choose to adopt an intervention, and 0 if not. $W_h^{'}$ and $X_h^{'}$are vectors of covariates; $\beta,$ a vector of parameters; $\rho,$ is the correlation between unobserved determinants of propensity to adopt an intervention and unobserved determinants of outcome/event regression equation; ε (obtained from the outcome model in equation (5.17); $\sigma_{\varepsilon,}$ the standard of error ε;, and λ, the inverse mills ratio derived after estimating equation (5.16).

The coefficient for inverse mill's ratio (λ) is used to show whether there is sample selection or not. When the coefficient for inverse mill's ratio is different from 0 (or the coefficient is statistically significant), it implies that there is sample selection bias (Karpaty and Kneller, 2005). According to Khitarishvili (2009) the coefficient for inverse mills ratio (λ) is a product of ρ times σ. In turn, ρ is the correlation coefficient between ε and u, and σ is the standard deviation of ε.

The exclusion restriction is imposed in order to identify the parameters of this model (Greene, 2003). Same variables included in the first stage (probit model) are excluded in the second stage (outcome/substantive model). However, the Heckman two step estimators also allow the model to be identified without exclusion restrictions, in order to facilitate the model identification and address multicollinearity among explanatory variables and correlation between error terms. The use of valid exclusion restriction, the inverse mills ratio and explanatory vectors in the substantive equation are proposed (Bushway, Johnson, & Slocum, 2007). Exclusion restrictions in current study are; log of income, traditional stove and middle and high household incomes categories for use of improved stove, chimney and modern energy.

According to Greene (2003), the marginal effects of the regressors on outcome variable, Z_h, in the observed sample consist of two components. There is the direct effect (from the outcome equation) on the mean of Z_h which is β; and an indirect effect (from selection equation) through λ_h for a particular independent variable, if it appears in the probability that U_h^* is positive. From equation (5.18), the full effect of changes in a continuous regressor (X_{hk}) that appears in both X_h and W_h on Z_h is

$$\frac{\partial E[Z_h|U_h^*>0]}{\partial X_{hk}} = \beta_k - \frac{\gamma_k}{\sigma_u}\beta_{\lambda}\,\delta_h \qquad (5.19)$$

where

$$\delta_h = \lambda_h(\propto_u)[\lambda_h(\propto_u) - \propto_u] \text{ and } \propto_u = -\gamma' W/\sigma_u \qquad (5.20)$$

Equation (5.19) is the conditional marginal effects of a continuous variable (X_{hk}), while equation (5.21) is the conditional marginal effects of a discrete variable (X_{hk}) going from 0 to 1.

$$E(\Delta Z_h|U_h = 1) = \beta_k + \beta_{\lambda}\,\Delta\,\lambda \qquad (5.21)$$

$$\text{where } \Delta\,\lambda = \frac{\phi\left(\gamma'\overline{X}_{(1)}/\sigma_u\right)}{\Phi\left(\gamma'\overline{X}_{(1)}/\sigma_u\right)} - \frac{\phi\left(\gamma'\overline{X}_{(o)}/\sigma_u\right)}{\Phi\left(\gamma'\overline{X}_{(0)}/\sigma_u\right)} \qquad (5.22)$$

$Z_h$is the natural logarithm of expenditure on interventions, the conditional marginal effect of equations (5.18) or (5.21) corresponding to a relative change in earnings. The estimated percentage change in earnings due to a unit increase in (X_{hk}) is $[\exp(C) - 1]100$, where C is the estimated value of the conditional marginal effect.

The unconditional relative marginal effect of a continuous variable (X_{hk}) on the expected expenditure on interventions using equation (5.18) is:

$$\frac{\partial}{\partial X_{hk}} \ln E(g_h) = \beta_k - \frac{\gamma_k}{\sigma_u} \beta_{\lambda} \, \delta_h + \left[\Phi \left(\frac{\gamma' X_h}{\sigma_u} \right) \right]^{-1} \emptyset \left(\frac{\gamma' X_h}{\sigma_u} \right) \frac{\gamma_k}{\sigma_u} \tag{5.23}$$

The first part of the right hand side ($e_{a.}$) is the effect associated with a change in expenditure for those who have adopted interventions and the second part (e_{II}) is the effect associated to a change in the probability of adopting an intervention.

Therefore, the percentage change in earning due to a unit increase in X_{hk} is $[\exp(Ce_I + e_{II}) - 1]100$. If X_{hk} is a discrete variable, the unconditional marginal effect when moving from 0 to 1 is given as:

$$\Delta \ln E(g_h) = \Delta \ln E(g_h | U_h^* > 0) + \Delta \ln \Phi \, (-\propto_u) \tag{5.24}$$

where the first part of the right hand side ($e_{1.}$) and the second part (e_{II}) are already defined above. However, Hoffman and Kassouf (2005) argue that better estimates of marginal effects come from calculating the conditional and unconditional marginal effects when applying Heckman's procedure.

5.4 Data and description of variables

The data used for analysis is drawn from the Kenya Integrated Household Budget Survey (KIHBS) 2005/6. The KIHBS clusters sampled in each district were selected with equal probability from the NASSEP-IV frame, where a total of 13,430 households were targeted.

Specific details are discussed in section 3.4 of chapter three. Variables description and measurement of the variables used are as follows.

Three intervention models are estimated in equations (5.11), (5.12) and (5.13). The dependent variables for these equations are in logarithmic form and capture the monthly expenditure or cost related to use of improved stove, chimney and modern energy. Estimated house rent[26] was used as a proxy for chimney expenditures.

Energy used (iap): It is the type of fuel used for cooking. It is represented by five dummy variables, each of which captures a particular type of household energy used. The types of household energy include; firewood, charcoal, kerosene, LPG and electricity. It is equal to 1, if a specific type of household energy is being used; and 0, otherwise. Households using modern energy are also expected to automatically use modern fuel stove.

Fuel stove appliance (appliance): It is the type of stove used to burn fuel. It is captured by eight dummy variables including; traditional three stone stove (*tradstove*), ordinary jiko (*ordjiko*), improved jiko (*imprstove*), kerosene stove (*kerostove*), gas cooker (*gascooker*), electric cooker (*eleccooker*), and other stove (*otherstove*). When one fuel stove appliance is considered, it takes a value of 1, while the other fuel stove appliance takes a value of 0. Type of stove is likely to influence modifications of living environment such as introducing windows and chimney in dwellings. However, the type of stove already dictates the type of household energy used.

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[26] If the house was rented, the amount paid to rent the dwelling in Kenya shillings per month was used. Alternatively if the house was not rented, then an estimate of the amount received/paid in Kenya shillings per month if the dwelling or one exactly like it was rented to another person was used.

Uptake of modern energy is conditioned to household ownership of modern clean and modern fuel stove appliance (Gebreegziabher et al., 2010)

Type of kitchen: It is the place/area used for cooking and is captured by six dummy variables. They include: outdoor-kitchen (*outdoor-kitchen*), enclosed detached kitchen (*encdet-kitchen*), enclosed attached kitchen (*enc-ata*), indoor without partition kitchen (*indwout-kitchen*), indoor-with-partition kitchen (*indwith-kitchen*), and other floor (*other-kitchen*). It takes the value 1 and 0 otherwise, when one type of kitchen is observed. It is expected that those who cook outside are unlikely to adopt any of the three interventions.

Chimney: It is a type of ventilation captured by a dummy variable that takes the value 1, if presence of chimney is observed, and 0, otherwise. Dwellings with chimneys are expected to have positive expenditures on house design modifications.

Age of the household head: The age of the household head in years is categorized into four dummies: age 0–4 years (*dage04*), age 5-14 years (*dage04*)514, age 15–49 years (*dage1549*), and age above 50 years (*dage50*). When a particular age group is observed, it takes the value 1, and 0, otherwise. Younger household heads when compared to older household heads are more likely to adopt modern energy (Mekonnen et al., 2008).

Education: This is the education level of the household head and is represented by four dummy variables each representing a specific level of education. They include: head with primary education (*hdprims*), head with secondary education (*hdsec*), head with graduate education (*hdgrad*), and head with no education (*hdnosch*). When one education level is considered, it takes a value of 1, and 0, otherwise. It is expected that those who are educated are more concerned about their indoor air quality. Lack of education has contributed to low levels of adopting modern energy and improved stoves (Jack, 2006; Sclag et al., 2008; Gebreegziabher et al., 2010; Pachauri et al., 2004; and Chambwera, 2004).

Location (*location*): This is the geographic location of the residence and is captured by a dummy variable which equals 1, when it is a rural location, and 0, if urban.

Household expenditure (*income*): It is defined as the total amount spent by households per month. It is used as a proxy for income. Adoption of modern energy and improved fuel stove are influenced by level of household income (Gebreegziabher et al., 2010; Pachauri et al., 2004; Chambwera, 2004; and Jaggernath, 2013).

Household size: This is the total number of members in a given household. It is not clear how a large or small household size influences adoption of IAP abatement interventions.

Employment (empy): It is a dummy variable that captures those household heads on paid employment. It takes the value 1, when the household head is on a paid employment, and 0, otherwise. Household heads on paid employment are expected to adopt avertive actions that reduce the level of IAP.

Chimney expenditures (costchimney) – It is defined as the total amount spent monthly on chimney by households. Chimney costs represent a portion of the total house cost which is indicated by the amount paid as rent. These costs differ by type of dwelling. For the house owners, the amount received if the house was rented was used instead as rent. Chimney expenditures may also incorporate maintenance cost associated with occasional cleaning of the chimney. The rent per month is used as a proxy for chimney expenditures.

Improved stove expenditures (*newstovecost*) - It is the total amount spent monthly on improved stoves by households. The use of improved stove is complemented by the use of firewood. Improved stove expenditure is captured by costs associated with firewood use.

Modern energy expenditures (*costmodernfuels*) - It is the total amount spent monthly on improved stoves by households. The modern energy expenditures constituted the costs associated with LPG and electricity use.

This information can be represented in a table, similar to the one presented in section 3.4.

5.5 Results and discussion

This section discusses the descriptive and regression results that address objective three which aims at determining the demand for IAP abatement interventions. Section 5.5.1 discusses the descriptive statistics, while section 5.5.2 discusses the regression results.

5.5.1 Descriptive statistics

Table 5.1 presents the summary statistics for the various variables used in estimating the outcome and selection equation for the three interventions. It presents information on the number of observations, mean, standard deviation, minimum and maximum statistics for each variable. The missing values, either as a result of non-response, omission and commission during data entry, may explain the differences in the number of observations for most of these variables. There are three binary dependent variables based on the type of intervention: improved stoves, chimney and modern energy expenditures.

Out of about 13, 212 households, the use of improved stove, chimney and modern energy interventions have been adopted by 978, 990 and 648 households, respectively. An estimate of 72 percent of households that adopted improved stove intervention use firewood, while only 51 percent of those who use firewood have adopted chimney intervention.

Majority (54%) of the households dwell in bungalows. An approximate of 64 percent of households living in bungalows have adopted the improved stove intervention, while 76 percent and 38 percent have adopted the use of chimney and modern household energy, respectively.

Among the educated households' heads with education, household heads with primary education (46 %) form the largest population. Fifty three percent of household heads with primary education have each adopted the use of improved stove and chimney, while 48 percent have adopted the use of modern household energy intervention.

The rural location comprises about 64 percent of the total population. Among the rural population, 57 percent, 75 percent and 68 percent use improved stove, chimney and modern household energy IAP abatement interventions, respectively.

Household's heads on paid employment represented about 69.4 percent. Household's heads that are on paid employment may use more than one intervention, those using improved stove, chimney and modern energy interventions were 70.7 percent, 71.9 percent and 76.1 percent, respectively.

Table 5.1: Descriptive statistics of variables explaining demand for IAP abatement interventions

	Full Sample		**Improved Stove Intervention Sample**		**Chimn Intervention**
Variables	N	Mean	N	Mean	N
Type of household energy					
Kerosene (=1 if household energy used is kerosene/paraffin, 0 otherwise)	12,989	0.1090	977	0.0727	980
Electricity (=1 if household energy used is electricity, 0 otherwise)	12,989	0.0082	977	0.0010	980
Lpg (=1 if household energy used is LPG, 0 otherwise)	12,989	0.0417	977	0.0205	980
Charcoal (=1 if household energy used is charcoal, 0 otherwise)	12,989	0.1820	977	0.1740	980
Firewood (=1 if household energy used is firewood, 0 otherwise)	12,989	0.6460	977	0.7190	980
Type of appliance					
Traditional stove (=1 if appliance used is traditional stove, 0 otherwise)	12,989	0.5800	978	0	990
Improved stove(=1 if appliance used is improved stove, 0 otherwise)	12,989	0.0753	978	1	990
Ordinary jiko (=1 if appliance used is an ordinary jiko, 0 otherwise)	12,989	0.1000	978	0	990
Improved jiko (=1 if appliance used is improved jiko, 0 otherwise)	12,989	0.0859	978	0	990
Kerosene jiko (=1 if appliance used is kerosene jiko, 0 otherwise)	12,989	0.1050	978	0	990
Gas cooker (=1 if appliance used is gas cooker, 0 otherwise)	12,989	0.0402	978	0	990
Electric cooker (=1 if appliance used is electric cooker, 0 otherwise)	12,989	0.0059	978	0	990
Type of dwelling					
Bungalow house (=1 if dwelling is bungalow house, 0 otherwise)	12,989	0.5460	978	0.6380	990
Flat house (=1 if dwelling is mansionette house, 0 otherwise)	12,989	0.0360	978	0.0020	990
Mansionette house (=1 if dwelling is mansionette house, 0 otherwise)	12,989	0.0116	978	0.0020	990
Swahili house (=1 if dwelling is swahili house, 0 otherwise)	12,989	0.1170	978	0.0348	990
Shanty house (=1 if dwelling is shanty house, 0 otherwise)	12,989	0.0399	978	0.0194	990
Manyatta house (=1 if dwelling is manyatta/traditional house, 0 otherwise)	12,989	0.2090	978	0.2570	990

Source: Authors computation based on KIHBS 2005/06

	Full Sample		**Improved Stove Intervention Sample**		**Chimn Intervention**
Variables	N	Mean	N	Mean	N
Kitchen location					
Outdoor (=1 if kitchen location is outdoor, 0 otherwise)	12,991	0.1730	978	0.2380	990
Enclosed and detached (=1 if kitchen location is enclosed and detached, 0 otherwise)	12,991	0.3170	978	0.3430	990
Enclosed and attached (=1 if kitchen location is enclosed and attached, 0 otherwise)	12,991	0.1170	978	0.0695	990
Indoor with partition (=1 if kitchen location is outdoor, 0 otherwise)	12,991	0.2940	978	0.2600	990
Indoor with partition (=1 if kitchen location is outdoor, 0 otherwise)	12,991	0.0930	978	0.0900	990
Education					
Head graduate (=1 if education level completed is graduate , 0 otherwise)	13,212	0.0098	196	0.0051	182
Head secondary (=1 if education level completed is secondary , 0 otherwise)	13,212	0.1530	196	0.1530	182

Head primary (=1 if education level completed is primary, 0 otherwise)	13,212	0.4590	196	0.5260	182
Head with no education (=1 if education level completed is graduate , 0 otherwise)	13,212	0.0232	196	0.0102	182
Other characteristics					
Chimney (=1 if there is presence of chimney, 0 otherwise)	12,988	0.0762	978	0.1370	990
Gender (=1 if gender is female, 0 otherwise)	13,212	0.2970	196	0.3470	182
Head age	13,212	44	196	44	182
Head age square	13,212	2212	196	2196	182
Household size with less or equal to 5 members	66,725	0.1190	978	0.1100	990
Household size between 6-12 members	66,725	0.0775	978	0.0900	990
Household size between 13-29 members	66,725	0.0017	978	0.0000	990
Rural (=1 if residing in rural area, 0 otherwise)	13,158	0.6440	969	0.5700	987
Income	13,118	3602	977	4586	990
Improved stove expenditures per month	975	744	975	744	134
Modern fuels expenditures per month	646	689	21	769	100
Chimney expenditures per month	964	13158	130	3051	964
Employed (=1 if in employment, 0 otherwise)	4,303	0.6940	75	0.707	64

Source: Authors computation based on KIHBS 2005/06

5.5.2 Regression results

The results for the use of improved stove, chimney and modern household energy interventions are discussed in section 5.5.2.1, 5.5.2.2 and 5.5.2.3, respectively.

5.5.2.1 Improved stove intervention

Table 5.2 (Appendix Table C.1) presents the results for improved stove intervention, equation (5.11). The table reports parameter estimates for improved stove expenditure equation, marginal effects of selection (probit) equation for adoption of improved stove, and conditional and unconditional marginal effects using Heckman two-stage method. The coefficient of inverse mills ratio helps to detect the presence or absence of sample selection. In this case, the coefficient of the inverse mill's ratio variable (lambda), obtained from the probit equation, was -6.802 and statistically significant at 1 percent. This implies that there is sample selection bias whose effect is controlled by inclusion of the inverse mill's ratio.

The demand for improved stove intervention was proxied by household expenditures related to the use of improved stove. The first stage of the Heckman two-stage method is the selection model, which estimates the adopting drivers for improved stove intervention; and the second stage of the Heckman two-stage method is the outcome model, which estimates the demand for improved stove intervention.

Table 5.2: Heckman sample selection estimation results for improved Stove Intervention

	Improved stove expenditure model		Marginal effects for probit model		Conditional marginal effects		Unconditio marginal e
charcoal (d)	0.219	(0.276)	-0.003	(0.005)	0.040	(0.385)	-0.018
paraffin (d)	0.725+	(0.407)	-0.013+	(0.007)	0.027	(0.565)	-0.074
lpg (d)	1.017	(0.677)	-0.019+	(0.010)	-0.053	(0.946)	-0.110
electricity (d)	3.754+	(1.917)	-0.049**	(0.011)	-0.787	(3.053)	-0.291*
rural (d)	1.026**	(0.289)	-0.023**	(0.005)	-0.070	(0.356)	-0.138*
chimney (d)	-3.082**	(0.631)	0.092**	(0.014)	0.084	(0.725)	0.547**
enclosed detached-kitchen (d)	1.188**	(0.334)	-0.021**	(0.005)	0.045	(0.438)	-0.123*
enclosed attached-kitchen (d)	3.401**	(0.674)	-0.046**	(0.004)	0.125	(0.820)	-0.265**
indoor without partition-kitchen(d)	1.261**	(0.341)	-0.020**	(0.005)	0.200	(0.453)	-0.106+
indoor with partition-kitchen (d)	1.324**	(0.468)	-0.022**	(0.006)	0.009	(0.627)	-0.131+
flat house (d)	6.555**	(1.350)	-0.059**	(0.004)	-0.301	(2.023)	-0.345**
swahili house(d)	3.321**	(0.692)	-0.047**	(0.004)	-0.065	(0.839)	-0.277**
shanty house(d)	1.950**	(0.698)	-0.033**	(0.007)	-0.259	(0.952)	-0.199*
Otherdwelling (d)	-0.430	(0.520)	-0.002	(0.010)	-0.509	(0.726)	-0.038
manyatta/tradition house (d)	-0.273	(0.263)	0.002	(0.005)	-0.150	(0.366)	0.005
mansionette house(d)	6.941**	(2.326)	-0.056**	(0.004)	-0.191	(3.390)	-0.329**
log income			0.015**	(0.002)	0.748**	(0.114)	0.130**
mills(lambda)	-6.802**	(1.082)					
N	12733						
Censored	11827						
Uncensored	906						
wald chi2(25)	37.22						
prob>chi2	0.0020						

Marginal effects; Standard errors in parentheses
(d) for discrete change of dummy variable from 0 to 1
+ p<0.10 * p<0.05 **p<0.01

Determinants for adoption of improved stove

The rural location variable was found to be negative and significant at 1 percent level, indicating that households that live in rural areas were less likely to adopt an improved stove compared to those in urban areas. This result is similar to what is provided in the literature. It indicates that rural households, because of cultural factors such as food type, lifestyle, cooking habit, taste preferences, local cuisine, kitchen type, gender relations and fuel preferences, are less likely to adopt improved stoves (Barnes, Openshaw, Smith, & Van der Plas, 1993; Budds et al., 2001; Masera et al., 2000; and Oudejans, 2011). In addition, the socio-economic differences between urban and rural locations could explain why urban population is adopting improved stoves.

Presence of chimney variable had a positive coefficient significant at 1 percent level as expected. This means that households with chimneys had a higher likelihood of adopting improved stove than those without chimneys. However, a high proportion of households chimneys come from those who own traditional stove fuel appliance (20.9%) compared to those with own improved stove fuel appliance (13.5%).

The variables for enclosed detached, enclosed attached, indoor with partition and indoor without partition kitchen location had a negative coefficients and were significant at 1 percent level. This showed that households that cook indoors (whether in enclosed detached, enclosed attached, with partitioned or without partitioned) had a lower probability of adopting an improved stove than those cooking from outdoors. ITDG (2002) found that households are unwilling to adopt improved stoves. Those who cook indoors may do so to exacerbate the levels of smoke that acts as mosquito repellant and also provides warmth during cold seasons (ITDG, ibid).

The coefficients for flat, swahili, shanty and mansionette types of dwelling variables were negative and significant at 1 percent level. This implied a lower probability for adopting improved stove by households living in such dwelling types, compared to those in bungalows. This may be because of their social status which makes these households less associated with use of traditional fuels along with their complimentary stoves (i.e. traditional three stone fire and improved stoves), and be more associated with use of modern energy and fuel stove appliances. For example, only 1.3 percent and 8.7 percent of households used firewood in flat and swahili houses, respectively.

The coefficient for paraffin/kerosene and LPG variables was negative and significant at 10 percent level. This means that households that use such type of energy were less likely to adopt improved stove intervention relative to those that used firewood. Households that use paraffin/kerosene may be unwillingly to adopt improved stove because they want to maintain an already attained social economic status. According to Masera (2000) those households with such modern technology are considered prosperous.

Income variable had a positive coefficient as expected and was significant at 1 percent level. This implied that households with high income are more likely to adopt improved stove expenditures. Income was identified as an important factor for adoption of improved stove by Jaggernath (2013). According to literature, as income increases, households are likely to adopt better fuels and fuel stove appliance technologies.

Determinants for improved stove expenditures

The estimation results for log of improved stove expenditure model forms the second stage of the Heckman two-stage method. The estimated results for the demand of improved stove intervention are shown in Table 5.2 (Appendix Table C.1). The demand is proxied by household expenditures associated with use of improved stove.

Rural location variable had a positive coefficient and was significant at 5 percent level. The coefficient implies that households in rural areas had higher expenditures than household in urban areas. The high expenditures from use of improved stoves may be explained by high market costs of acquiring firewood which is a complementary good for use of improved stoves.

The coefficients for paraffin/kerosene and electricity variables were positive and significant at 10 percent. This means that households who use paraffin/kerosene had higher expenditures relative to household who use firewood. The use of improved stove as earlier indicated is complemented by use of firewood. It could be that those households who use either electricity or kerosene in addition to firewood are considered to have high incomes and this could explain why they have higher improved stove expenditures compared to those households who use firewood alone. In this case, the use of firewood is considered a normal good (an increase in income causes an increase in demand and vice versa).

The variable for presence of chimney had negative coefficient and was significant at 1 percent level. This means that households who use chimney intervention had lower improved stove expenditures than household who do not use chimney intervention. It could be that the use of chimney and the use of improved stove interventions are more of substitute products. For instance it may mean that when income increases to a certain level, the use of chimney dominates that of improved stove intervention. In this case it could be that households who had achieved a particular level of income were more able to substitute the use of improved stove for chimney and this may explain the observed low expenditures for improved stove interventions.

The coefficient for indoor cooking location variables (enclosed attached, enclosed detached, indoors with partition and indoors without partition) was positive and significant at 1 percent level. This means that households cooking indoors had higher improved stove expenditures than household who cooked outdoor. Given that the use of improved stove intervention is supplemented by use of firewood. It could be that households who cook from indoors use more firewood compared to those who cook outdoors as a result of other factors such as speed of combustion.

The swahili, shanty, flat and mansionette dwelling variables had positive coefficients significant at 1 percent level. This means that households living in such dwelling had higher improved stove expenditures than household who dwell in bungalow house. The expenditures may be high, especially where firewood fuels are purchased compared to where there are zero/no costs as a result of using free firewood. It could be that households who dwell in the swahili, shanty, flat and mansionette are located in the urban areas where firewood fuels are purchased compared to those who dwell in bungalow houses (who are mainly located in rural areas with possibility of free access to firewood). For instance, in this study, the bungalow house is the main type of dwelling among rural households (56 %). Only 4 percent of flat and shanty house, 1 percent of mansionette house and 12 percent of swahili house are located in rural areas.

The exclusion restriction variables are expected to affect adoption of improved stoves but not expenditure on improved stoves. The exclusion restriction variable appears in the adoption of improved stove (selection) equation of the Heckman model as an instrument for correcting sample selection (Puhani, 2000). In this case, the log of income, which was the exclusion restriction, was significant at 1 percent implying that income affects the adoption of improved stove, but not the expenditure on improved stoves.

Table 5.4 (Appendix Table C.1) also indicates the conditional and unconditional marginal effects of various explanatory variables, after carrying out the Heckman two-stage method for improved stove. Conditional marginal effects are based on the household sample of those who adopt improved stoves, while unconditional marginal effects are based on the total household sample of those who do and do not adopt improved stove. The conditional and unconditional marginal effects for both discrete and continuous regressors appearing in both outcome and selection equations can be obtained.

Explanation is similar for both continuous and discrete variables. For example, the traditional house variable, considering all explanatory variables at their mean value, a unit increase in traditional house will lead to a 27.3[27] percent drop in improved stove expenditures, for those who use improved stove; and a 0.155[28] percent increase in the proportion of households that adopt improved stove intervention. This corresponds to a 31.2[29] percent fall in total improved stove expenditures.

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[27] The coefficient for traditional/manyatta house from the improved stove expenditure model.

[28] The differences between unconditional and conditional marginal effects for traditional/manyatta coefficients.

[29] The sum of the differences between unconditional and conditional marginal effects for traditional/manyatta house coefficients, the difference between marginal effects for probit model and conditional marginal effects for traditional/manyatta house coefficients, and the coefficient for traditional/manyatta house from marginal effects for probit model.

5.5.2.2 Chimney intervention

Table 5.3 (Appendix Table C.2) reports the results for chimney intervention as shown in equation (5.12). The table reports parameter estimates for chimney expenditure equation, marginal effects of selection (probit) equation for adoption of improved stove, and conditional and unconditional marginal effects of using Heckman two-stage method. The coefficient of inverse mills (lambda), obtained from the probit equation, was -1.888 and was statistically significant at 10 percent level. This meant that there is presence of sample selection bias, whose effect can be addressed by use of the inverse mill's ratio.

The demand for chimney intervention was proxied by household expenditures related to the use of chimney. The first stage of the Heckman two-stage method is the selection model, which estimates the adopting drivers for chimney intervention; and the second stage of the Heckman two-stage method is the outcome model, which estimates the demand for chimney intervention.

Table 5.3: Heckman sample selection estimation results for chimney intervention

	Chimney Expenditure Model		**Marginal Effects Probit Model**		**Conditional Marginal Effects**		**Unconditional Marginal Effect**	
rural (d)	-0.430**	(0.109)	0.021**	(0.003)	0.009	(0.130)	0.150**	(0.0
log income	0.033	(0.045)	-0.001	(0.001)	0.021	(0.051)	-0.004	(0.0
charcoal (d)	-0.011	(0.117)	-0.005	(0.004)	-0.121	(0.145)	-0.043	(0.0
paraffin (d)	-0.107	(0.138)	0.008	(0.006)	0.046	(0.169)	0.062	(0.0
lpg (d)	-0.124	(0.185)	0.006	(0.008)	-0.013	(0.230)	0.042	(0.0
improved stove (d)	-1.479**	(0.190)	-0.0002	(0.007)	-1.484**	(0.239)	-0.058	(0.0
ordinary jiko (d)	-1.010**	(0.163)	-0.009	(0.006)	-1.206**	(0.213)	-0.103*	(0.0
improved jiko (d)	-0.866**	(0.158)	-0.012*	(0.005)	-1.132**	(0.210)	-0.118**	(0.0
kerosene stove (d)	-0.714**	(0.166)	-0.016**	(0.005)	-1.085**	(0.218)	-0.143**	(0.0
mansionette house(d)	1.054**	(0.254)	0.022	(0.015)	1.415**	(0.320)	0.245+	(0.1
flat house (d)	0.834**	(0.197)	-0.025**	(0.004)	0.146	(0.251)	-0.174**	(0.0
swahili house (d)	0.424*	(0.188)	-0.029**	(0.003)	-0.372+	(0.223)	-0.215**	(0.0
Otherdwelling (d)	-0.216	(0.226)	-0.007	(0.007)	-0.365	(0.276)	-0.062	(0.0
enclosed detached-kitchen (d)	-0.407+	(0.221)	0.054**	(0.009)	0.461+	(0.256)	0.412**	(0.0
enclosed attached-kitchen (d)	-1.354**	(0.347)	0.274**	(0.024)	0.830*	(0.367)	2.175**	(0.2
indoor without partition- kitchen (d)	-0.395+	(0.219)	0.001	(0.007)	-0.373	(0.261)	-0.006	(0.0
indoor with partition- kitchen n (d)	-0.808**	(0.295)	0.156**	(0.020)	0.729*	(0.321)	1.243**	(0.1
traditional stove (d)			-0.091**	(0.010)	-1.478**	(0.125)	-0.751**	(0.0
mills (lambda)	-1.888**	(0.225)						
N	12,793							
Censored	12,793							
Uncensored	11,842							
wald chi2(17)	202.64							
prob>chi2	0.0000							

Marginal effects; Standard errors in parentheses
(d) for discrete change of dummy variable from 0 to 1
+ p<0.10 * p<0.05 **p<0.01

Determinants for adoption of chimney

Rural location variable had a positive and statistically significant coefficient at 1 percent level. This implied that living in a rural location increases the likelihood of adopting chimney intervention compared to an urban one. In rural areas, the main type of dwelling is the bungalow which accounts for 56.3 percent, followed by traditional and swahili dwellings with 18.9 percent and 12.1percent, respectively. Flat, shanty and mansionette houses account for 3.8 percent, 3.7 percent and 1.03 percent, respectively. The design factors for bungalows may allow easy erection of chimneys compared to flats and shanties. The percentage of bungalows with chimney was about 76 percent compared to swahili (6.8%) and traditional (1.2%) dwellings.

The variables for traditional stove, improved jiko and kerosene stove fuel appliances had negative coefficients and were significant at 1 percent, except for improved jiko with 5 percent significance level. Those households which use this appliance are less likely to adopt the use of chimneys compared to those using electricity cookers. The use of chimney provides an opening that allows passage of smoke outside the dwelling. Absence of chimney, use of traditional stove and improved jiko fuel appliances imply presence of smoke indoors that may act as mosquito repellant.

The variables for flats and swahili houses had negative coefficient and were significant at 1 percent. This showed that households that live in flats and swahili dwellings were less likely to adopt chimney interventions compared to those in traditional houses. Apart from cultural factors, the design of the type of dwelling and social economic status may play a key role in influencing whether or not chimney intervention is adopted. For instance, designs for flats and shanties do not, in most cases, consider erection of chimneys. In the case of swahili and traditional dwellings, the spacing left between the roof and the wall acts as a ventilation avenue that may limit the use of chimney. In fact, because of social economic status associated with flats and mansionettes, the use of clean and modern technologies implies less smoke, making the use of chimney unnecessary.

The coefficients for enclosed attached kitchen, enclosed detached kitchen, and indoor with partition kitchen variables were positive and statistically significant at 1 percent level. This means that cooking in these areas increases the probability of adopting chimney intervention. It may be possible that households that cook indoors and those that cook in enclosed kitchens may have bungalows as the main type of dwelling. About 62 percent of households that cook indoors and in enclosed kitchen live in bungalows. As discussed earlier, those that live in bungalows are more likely to have erected a chimney, explaining their higher likelihood to adopt the chimney intervention.

Determinants for chimney intervention expenditures

The estimation results of chimney expenditure equation are reported in Table 5.3 (Appendix Table C.2). The variables for improved stove, ordinary jiko, improved jiko, kerosene stove and traditional stove type of fuel appliance had a negative coefficient and were also statistically significant at 1 percent. This means that households who use improved stove, ordinary jiko, improved jiko and kerosene stove had lower chimney expenditures than household who use electric cooker. The type of dwelling (which captures wealth) may explain why households who used improved stove, ordinary jiko, improved jiko and kerosene stove had lower expenditures than those who used electric cooker. It could be that the high chimney expenditures among households who use electric cooker are observed by wealthy households who mainly dwell in bungalow, flat and mansionettes houses.

The variables for mansionettes and flats dwellings had a positive coefficient and were significant at 1 percent level. The swahili dwelling also had a positive coefficient and was significant at 5 percent level. This implies that households who dwell in mansionettes, flats and swahili type of dwellings had higher chimney expenditures than household who dwell in bungalow. As explained earlier, the limited use of chimneys may be attributed to the design aspects of the dwelling type. It may be difficult and costly to incorporate the chimney detail, especially in mansionettes, flats and swahili houses and this could explain why they have higher chimney expenditures.

The coefficients for households that cook indoors were all negative. The variables for enclosed detached and indoor without partition kitchen were significant at 10 percent level, while enclosed attached and indoor with partition kitchen were significant at 1 percent level. This may mean that household who cook from indoor kitchen had lower expenditures relative to those households who cook outdoors. The reason could be that it may be easier and cheaper to erect a chimney for an indoor kitchen than outdoor kitchen and this may explain why households who cook from an indoor kitchen had lower expenditures than those who cooked outdoors.

The coefficient for rural location variable was negative and significant at 1 percent level. This implied that household in rural areas had low chimney expenditures than households in urban areas. The low chimney expenditures among households in rural areas could be because of either the costs incurred in constructing a dwelling unit erected with chimney are lower or the demand for such dwelling units is low. The exclusion restriction variable in the model is the traditional stove, which was found to be significant at 1 percent level. This implies that the traditional stove is expected to affect adoption of chimney, but not expenditures on chimney.

Table 5.3 (Appendix table C.2) provides the conditional and unconditional marginal effects of various explanatory variables, after carrying out the Heckman two-stage method. Interpretations of both discrete and continuous variables follow similar explanations as done earlier in section 5.5.2.1

5.5.2.3 Modern energy intervention

Table 5.4 (Appendix Table C.3) reports the results for modern energy intervention. The table presents parameter estimates for modern energy expenditure equation, marginal effects of selection (probit) equation for adoption of modern energy, and conditional and unconditional marginal effects of using Heckman two-stage method.

The coefficient of the inverse mill’s ratio variable (-5.703), obtained from the probit equation, is statistically significant. As earlier explained, the significance implies there is a sample selection, and inclusion of the inverse mill’s ratio is important to avoid sample selection bias.

Table 5.4: Heckman sample selection estimation results for modern energy intervention

	Modern Energy Expenditures		**Marginal Effects for Probit Model**		**Conditional Marginal Effects**		**Unconditiona Marginal Eff**	
improve stove (d)	-0.311	(0.434)	0.007	(0.008)	0.174	(0.660)	0.047	(0
ordinary jiko (d)	-1.737**	(0.522)	0.040**	(0.009)	0.383	(0.640)	0.255*	(0
improved jiko (d)	-1.542**	(0.484)	0.028**	(0.009)	0.069	(0.633)	0.167+	(0
kerosene stove (d)	-3.074**	(0.713)	0.077**	(0.013)	0.309	(0.797)	0.477**	(0
gas cooker (d)	-4.125**	(0.945)	0.138**	(0.023)	0.461	(1.035)	0.876**	(0
electric cooker (d)	-4.673**	(1.255)	0.170**	(0.048)	0.335	(1.474)	1.056*	(0
chimney (d)	-0.361	(0.371)	0.005	(0.005)	0.015	(0.517)	0.032	(0
enclosed detached- kitchen (d)	-0.425	(0.369)	0.006	(0.006)	-0.015	(0.557)	0.032	(0
enclosed attached- kitchen (d)	-1.530**	(0.487)	0.023*	(0.009)	-0.157	(0.663)	0.124	(0
indoor without partition- kitchen (d)	-1.513**	(0.418)	0.017**	(0.007)	-0.362	(0.580)	0.085	(0
indoor with partition-kitchen (d)	-1.298**	(0.468)	0.012	(0.008)	-0.501	(0.666)	0.051	(0
flat house (d)	-1.922**	(0.560)	0.045**	(0.011)	0.305	(0.686)	0.282*	(0
mansionette house(d)	-2.826**	(0.841)	0.082**	(0.024)	0.475	(1.028)	0.533*	(0
swahili house (d)	-0.716*	(0.343)	0.015**	(0.006)	0.252	(0.465)	0.098+	(0
shanty house (d)	-2.663**	(0.703)	0.075**	(0.015)	0.510	(0.807)	0.488**	(0
manyatta house (d)	1.097**	(0.356)	-0.011*	(0.004)	0.152	(0.543)	-0.063	(0
Other dwelling (d)	-0.015	(0.497)	0.001	(0.007)	0.040	(0.719)	0.006	(0
rural (d)	-0.336	(0.238)	0.007*	(0.003)	0.178	(0.330)	0.044	(0
middle income			0.164**	(0.055)				
high income			0.301**	(0.054)				
mills (lambda)	-5.703**	(1.022)						
N	12,901							
Censored	12,295							
Uncensored	606							
wald chi2 (8)	31.16							
prob>chi2	0.0276							

Marginal effects; Standard errors in parentheses
(d) for discrete change of dummy variable from 0 to 1; and `+ p<0.10 * p<0.05 **p<0.01`

Determinants for adoption of modern energy

Different types of fuel stove appliances were found to be significant. Ownership of ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker, each, had a positive coefficient and they were all significant at 1 percent level. This showed that households that owned ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker had a higher probability of adopting modern energy compared to traditional stoves; as expected. Due to complementarity between the type of fuel and stove, adoption of one influences the use of the other. In this case, adoption of ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker acted to promote the use of modern energy. However, the coefficients for electricity cooker (0.170) and gas cooker (0.138) were higher, followed by kerosene stove (0.077), ordinary jiko (0.040) and improved jiko (0.028). Similar results were also obtained by Gebreegziabher et al. (2010)

The coefficients for enclosed attached and indoor without partition kitchen were positive and significant at 5 percent and 1 percent level, respectively. This implied that households that cook from enclosed attached kitchen and indoor without partition kitchen, are more likely to adopt modern energy compared to those who cooked from outside. About 42 percent of the households that cook from indoor without partition kitchen and 24 percent of the households who cook from enclosed attached kitchen made use of modern energy. The adoption of modern energy may also be explained by usage/ownership of modern fuel appliance. For example, 49 percent of households cooked in enclosed attached kitchen used modern energy (gas cooker and electricity cooker), compared to 18 percent of households that cooked indoors without partition.

The type of dwelling such as flats, mansionettes, swahili and shanty dwellings had positive coefficients and were significant at 1 percent level. This means that households living in flats, mansionettes, swahili and shanties had a higher likelihood of adopting modern energy when to those who live in bungalows. The coefficient for mansionette was high at 0082, followed by shanty (0.075), flat (0.045), swahili (0.015) and manyatta (-0.011). The high coefficient for shanty type of dwelling may be explained by high proportion of households using modern fuel at about 11.3 percent, compared to 3.6 percent of households using traditional fuels. The high levels of modern energy adoption for flats and mansionettes may be driven by social economic status.

Manyatta or traditional dwellings had a negative coefficient and were significant at 5 percent level. This means that living in traditional type of dwelling reduces the probability of adopting modern fuel interventions, compared to living in bungalows. Unobserved cultural factors for those living in traditional dwellings could be the reason behind low adoption of modern energy. These cultural factors include food type, lifestyle, cooking habit, taste preferences, local cuisine, gender relations and fuel preferences.

Rural location had a positive coefficient and was significant at 5 percent level. This indicated that households in rural location were more likely to adopt modern energy intervention compared to urban ones. Being employed implies having access to disposable income for acquisition of modern fuel and fuel stove appliances. In this case, the rural households formed a larger proportion of people who are employed, with 66 percent.

The coefficient for middle and upper income households was positive and significant at 1 percent. Therefore, when compared to the low income households, those households with middle and high income are more likely to adopt modern energy as hypothesised. Similar results were achieved by Gebreegziabher et al. (2010); Pachauri et al. (2004); Chambwere (2004); and Jaggernath (2013).

Determinants for modern energy intervention expenditure

The estimation results of modern energy expenditure equation are reported in Table 5.4 (Appendix Table C.3).

The type of fuel stove appliance like; the use of ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker each had a negative coefficient and was significant at 1 percent level. The coefficient implies that households who use ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker have lower modern energy expenditures than household who use traditional stoves. It could be that the use of ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker are considered to be more efficient (less fuel less is used) compared to traditional fuels.

The coefficient for enclosed attached, indoor without partition, and indoor with partition kitchen had negative coefficients and were significant at 1 percent level. This implies that households who cook from either enclosed attached kitchen, indoor without partition kitchen, or indoor with partition kitchen had lower modern energy expenditures than households who cook from outdoors. It could be that household who cook indoors are more likely to use modern energy than those who cook outdoors. About 13 percent, 24 percent and 43 percent of households cooking in enclosed attached kitchen, indoor without partition kitchen and indoor with partition kitchen respectively, were observed to be using modern energy compared to 6 percent of those who cooked from outdoors. This may suggest that households that cook from such types of kitchen and who use modern energy may in turn benefit from lower modern fuel expenditures.

The coefficient for flats, mansionettes, swahili and shanty dwellings each had a negative coefficient and was significant at 1 percent level, except for swahili dwelling which had 5 percent significance level. This implies that households who live in flats, mansionettes, swahili and shanties houses had lower modern energy expenditures than a bunglalow house. Cultural factors such as food type, taste and fuel preferences, cooking habits and local cuisine could be the reason whether or not; modern energy is adopted, hence influencing the level of modern energy expenditures. It is more likely for the rural households to observe their culture than the urban households. Among the households who lived in rural areas, majority lived in bungalow houses (56 %) compared to only 4 percent of households who lived in flat and shanty house, 1 percent of households who lived in mansionette house and 12 percent of households who lived in swahili house are located in rural areas. It could be that due to cultural factors, when compared to households who live in bungalows, those households who live in mansionettes, flats, swahili and shanty dwellings are more likely to adopt modern energy that translates to lower modern fuel expenditures.

The exclusion restriction variables in the model are the income quintiles. Being in the middle and high incomes quintiles influences the adoption of modern energy but not expenditures on modern fuel interventions.

The conditional and unconditional marginal effects are reported in Table 5.6 (Appendix Table C.3). Interpretations of both discrete and continuous variables apply similar explanations as discussed earlier.

5.5.3 Conclusions and policy implications

5.5.3.1 Conclusions

The results from the Heckman two-stage method indicate that factors driving adoption of improved stoves are; use of firewood, cooking outdoors, having a chimney, residing in a bungalow house, and having high incomes. Households who live in rural areas, those who use kerosene or electricity, those who cook indoors and those that dwell in swahili, shanties, flats or in mansionettes were likely to have higher improved stove expenditures while household who have chimney are more likely to have lower improved stove expenditures. The demand for improved stove interventions, therefore, was influenced by geographical location, type of household energy used, cooking place/area, type of dwelling, income and whether households had a chimney or not.

Households in rural areas, those who use electricity cooker, those who dwell in traditional houses, and those who cooked from indoor with partition, enclosed attached and detached kitchen were more likely to adopt the chimney intervention.

Households who use improved stove, ordinary jiko, improved jiko or kerosene stove, those that cooked from indoor kitchen had lower chimney expenditures and those that reside in rural areas are more likely to have lower chimney expenditures. Households who dwell in mansionettes and flats houses are more likely to have higher chimney expenditures. The geographical location, type of dwelling, kitchen location, type of fuel appliance used were key factors influencing the demand for chimney interventions.

The selection of modern energy intervention was driven: by ownership of ordinary jiko, improved jiko, kerosene stove, gas cooker and electricity cooker; by households who cook from enclosed attached and indoor without partition kitchen location; by households who live in flats, mansionettes, swahili, and shanty dwellings, by households who live in rural areas and by those having middle and high incomes.

Households who use ordinary jiko, improved jiko, kerosene stove, gas cooker or electric cooker; those who cook from either enclosed attached kitchen, indoor without partition kitchen or indoor with partition kitchen; and those who dwell in flat, mansionette, swahili and shanty houses have lower modern energy expenditures. Overall, the factors influencing demand for modern fuels are; type of fuel stove appliance, cooking area, type of dwelling, geographical location and income.

5.5.3.2 Policy implications

Presence of chimney aims at reducing the levels of IAP. The government should not only enhance the adoption of chimney but also encourage construction of dwellings with inbuilt chimney.

Ownership of modern fuel appliances like gas cooker and electric cooker was a requirement for use of modern energy intervention; however households did not adopt it. The reason for non-adoption was the high expenditures fueled by high market transactions costs (especially for rural households), low incomes and the type of dwelling. The government can enhance rural market access for both modern energy and fuel stove appliances. This can be done by strengthening local artisan and retailers to engage in production and sale of modern energy technologies. Engaging in such entrepreneurial activities provides households with income. Also, this will increase the market penetration of modern energy technologies and also with time it will reduce the cost of such technologies. The government should educate the poor on the selection and investments made on fuel stove appliance. Investments made, on type of fuel stove appliance, automatically dictates the type of energy used.

5.5.4 Areas of further research

This study successfully analysed the three major IAP abatiement interventions; use of modern energy, improved stoves and chimney. Behavioural intervention which aims at abating IAP by focusing on behavior change was identified in the study to be important; however the study was not able to estimate it. Further studies are needed to analyse the impact of adopting behavioral change on human health. In addition studies should estimate the demand for behavioral changes such as reducing cooking time, fuel drying, using pot lids to conserve heat, proper maintenance of stoves and related appliances and keeping children away from smoke in other rooms.

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APPENDIX

Appendix Table C.1: Improved stove intervetion

```
Heckman selection model -- two-step estimates   Number of obs      =     12733
(regression model with sample selection)        Censored obs       =     11827
                                                Uncensored obs     =       906

                                                Wald chi2(16)      =     37.22
                                                Prob > chi2        =    0.0020

------------------------------------------------------------------------------
                 |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------+------------------------------------------------------------
lognewstovecost  |
        charcoal |    .219171   .2757759     0.79   0.427    -.3213399    .7596819
        paraffin |   .7250844   .4074003     1.78   0.075    -.0734054    1.523574
             lpg |   1.017309   .6766175     1.50   0.133    -.3088367    2.343455
     electricity |   3.754328   1.916955     1.96   0.050    -.0028351    7.511491
           rural |   1.026326   .2886557     3.56   0.000     .4605714    1.592081
         chimney |  -3.081679   .6311191    -4.88   0.000     -4.31865   -1.844708
       encdetchd |   1.187725   .3342806     3.55   0.000     .5325467    1.842902
        encatchd |   3.400835   .6740412     5.05   0.000     2.079739    4.721932
   indwthoutpart |   1.260541   .3414165     3.69   0.000     .5913768    1.929705
     indwithpart |    1.32368    .467531     2.83   0.005     .4073364    2.240024
            flat |   6.555292    1.35018     4.86   0.000     3.908988    9.201597
         swahili |   3.321227   .6915805     4.80   0.000     1.965755      4.6767
          shanty |   1.950329   .6976394     2.80   0.005     .5829804    3.317677
   otherdwelling |  -.4298026   .5202565    -0.83   0.409    -1.449487    .5898815
manyattatradhse  |  -.2727192   .2634328    -1.04   0.301    -.7890381    .2435997
      maisonnett |   6.940596   2.325509     2.98   0.003     2.382681    11.49851
           _cons |   16.82498   1.769099     9.51   0.000      13.3576    20.29235
-----------------+------------------------------------------------------------
s1               |
        charcoal |  -.0306492   .0461612    -0.66   0.507    -.1211235    .0598251
        paraffin |   -.119311   .0665682    -1.79   0.073    -.2497822    .0111602
             lpg |  -.1823269   .1118523    -1.63   0.103    -.4015534    .0368995
     electricity |  -.7575362   .3869127    -1.96   0.050    -1.515871    .0007988
           rural |  -.1887899   .0359346    -5.25   0.000    -.2592204   -.1183594
         chimney |   .5572854   .0642631     8.67   0.000     .4313321    .6832388
       encdetchd |  -.1956204   .0482346    -4.06   0.000    -.2901584   -.1010824
        encatchd |  -.5527484   .0773633    -7.14   0.000    -.7043778   -.4011191
   indwthoutpart |  -.1815568   .0507773    -3.58   0.000    -.2810785    -.082035
     indwithpart |  -.2239195   .0705624    -3.17   0.002    -.3622192   -.0856198
            flat |  -1.133509   .2414826    -4.69   0.000    -1.606807   -.6602122
         swahili |  -.5711119   .0785619    -7.27   0.000    -.7250905   -.4171333
          shanty |  -.3737794   .1081281    -3.46   0.001    -.5857067   -.1618522
   otherdwelling |  -.0135655   .0867809    -0.16   0.876    -.1836529     .156522
manyattatradhse  |   .0210157   .0436148     0.48   0.630    -.0644679    .1064992
      maisonnett |  -1.175545   .3941267    -2.98   0.003    -1.948019   -.4030707
       logincome |    .128366   .0194787     6.59   0.000     .0901885    .1665435
           _cons |  -2.116852   .1600996   -13.22   0.000    -2.430641   -1.803062
-----------------+------------------------------------------------------------
mills            |
          lambda |  -6.801877   1.082204    -6.29   0.000    -8.922959   -4.680795
-----------------+------------------------------------------------------------
             rho |   -1.08219
           sigma |  6.2852961
------------------------------------------------------------------------------
```

Appendix Table C.2: Chimney intervention

```
Heckman selection model -- two-step estimates   Number of obs      =     12793
(regression model with sample selection)        Censored obs       =     11842
                                                Uncensored obs     =       951

                                                Wald chi2(17)      =    202.64
                                                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logcostchimney |
       rural |  -.4297917   .1094277    -3.93   0.000     -.644266   -.2153173
   logincome |   .0328743   .0446334     0.74   0.461    -.0546056    .1203542
    charcoal |  -.0110865   .1174811    -0.09   0.925    -.2413453    .2191723
    paraffin |  -.1073143   .1377385    -0.78   0.436    -.3772767    .1626481
         lpg |  -.1238052   .1845559    -0.67   0.502    -.4855281    .2379177
   imprstove |  -1.479243     .18964    -7.80   0.000    -1.850931   -1.107556
     ordjiko |  -1.009918   .1625029    -6.21   0.000    -1.328418   -.6914178
    imprjiko |  -.8658817   .1577533    -5.49   0.000    -1.175072    -.556691
   kerostove |  -.7137936   .1656564    -4.31   0.000    -1.038474   -.3891131
  maisonnett |    1.05393   .2535206     4.16   0.000     .5570384    1.550821
        flat |   .8341611    .197303     4.23   0.000     .4474543    1.220868
     swahili |   .4239266   .1878491     2.26   0.024     .0557491    .7921041
otherdwelling |  -.2159612   .2257679    -0.96   0.339    -.6584582    .2265358
    encdetchd |  -.4068045   .2214539    -1.84   0.066    -.8408462    .0272371
     encatchd |  -1.353814   .3471834    -3.90   0.000    -2.034281   -.6733475
indwthoutpart |  -.3954784    .218954    -1.81   0.071    -.8246204    .0336635
  indwithpart |  -.8080709   .2945338    -2.74   0.006    -1.385346   -.2307953
       _cons |    12.0453   .7541914    15.97   0.000     10.56712    13.52349
-------------+----------------------------------------------------------------
s3           |
       rural |   .2659232   .0425355     6.25   0.000     .1825552    .3492913
   logincome |  -.0072392   .0145031    -0.50   0.618    -.0356647    .0211863
    charcoal |  -.0667782    .051668    -1.29   0.196    -.1680456    .0344891
    paraffin |   .0934295   .0598187     1.56   0.118    -.0238129     .210672
         lpg |   .0672672   .0843262     0.80   0.425    -.0980091    .2325435
   tradstove |  -.9063676   .0774374   -11.70   0.000    -1.058142   -.7545931
   imprstove |  -.0029306   .0883497    -0.03   0.974    -.1760929    .1702316
     ordjiko |  -.1185427   .0827992    -1.43   0.152    -.2808263    .0437408
    imprjiko |  -.1612429   .0832069    -1.94   0.053    -.3243255    .0018397
   kerostove |  -.2244463   .0854458    -2.63   0.009    -.3919171   -.0569756
  maisonnett |   .2216732    .121446     1.83   0.068    -.0163565    .4597029
        flat |  -.4130288   .0920377    -4.49   0.000    -.5934194   -.2326382
     swahili |  -.4776032   .0716701    -6.66   0.000    -.6180739   -.3371324
otherdwelling |  -.0903758   .0956693    -0.94   0.345    -.2778841    .0971325
    encdetchd |   .5326366   .0790066     6.74   0.000     .3777865    .6874867
     encatchd |   1.410555   .0807224    17.47   0.000     1.252342    1.568768
indwthoutpart |   .0136923   .0861272     0.16   0.874     -.155114    .1824985
  indwithpart |   .9731752   .0848684    11.47   0.000     .8068362    1.139514
       _cons |   -1.66582   .1549198   -10.75   0.000    -1.969458   -1.362183
-------------+----------------------------------------------------------------
mills        |
      lambda |   -1.88769   .2245583    -8.41   0.000    -2.327816   -1.447564
-------------+----------------------------------------------------------------
         rho |   -0.96684
       sigma |  1.9524319
------------------------------------------------------------------------------
```

Appendix Table C.3: Modern energy intervention

```
Heckman selection model -- two-step estimates   Number of obs      =     12901
(regression model with sample selection)        Censored obs       =     12295
                                                Uncensored obs     =       606

                                                Wald chi2(18)      =     31.16
                                                Prob > chi2        =    0.0276

--------------------------------------------------------------------------------------
                   |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------------+------------------------------------------------------------------
logcostmodernfuels |
         imprstove |  -.3111962   .4343021    -0.72   0.474    -1.162413    .5400204
           ordjiko |  -1.737357   .5221684    -3.33   0.001    -2.760789   -.7139261
          imprjiko |  -1.542406   .4842614    -3.19   0.001    -2.491541   -.5932716
         kerostove |  -3.074443   .7125315    -4.31   0.000    -4.470979   -1.677907
         gascooker |  -4.125087   .9446364    -4.37   0.000     -5.97654   -2.273634
        eleccooker |  -4.673032   1.255467    -3.72   0.000    -7.133702   -2.212361
           chimney |  -.3608309   .3705898    -0.97   0.330    -1.087174    .3655118
         encdetchd |  -.4249021   .3693928    -1.15   0.250    -1.148899    .2990944
          encatchd |  -1.530241   .4871365    -3.14   0.002    -2.485011   -.5754711
      indwthoutpart |  -1.513143   .4183044    -3.62   0.000    -2.333005   -.6932818
       indwithpart |  -1.298066   .4675045    -2.78   0.005    -2.214358   -.3817738
              flat |   -1.92185   .5596187    -3.43   0.001    -3.018683   -.8250178
        maisonnett |  -2.826158   .8405833    -3.36   0.001    -4.473671   -1.178645
           swahili |   -.715919   .3425273    -2.09   0.037     -1.38726   -.0445778
            shanty |  -2.663498   .7026441    -3.79   0.000    -4.040655   -1.286341
   manyattatradhse |   1.096915   .3563553     3.08   0.002     .3984714    1.795359
      otherdwelling |  -.0148809   .4966868    -0.03   0.976    -.9883691    .9586073
             rural |  -.3363359   .2381332    -1.41   0.158    -.8030684    .1303966
             _cons |   20.84113   2.736646     7.62   0.000     15.47741    26.20486
-------------------+------------------------------------------------------------------
s2                 |
         imprstove |   .0971063   .0998345     0.97   0.331    -.0985657    .2927782
           ordjiko |   .4289103   .0758141     5.66   0.000     .2803174    .5775032
          imprjiko |   .3249288   .0830855     3.91   0.000     .1620842    .4877733
         kerostove |   .6907758   .0748091     9.23   0.000     .5441528    .8373989
         gascooker |   .9525974     .09218    10.33   0.000      .771928    1.133267
        eleccooker |   1.049757   .1728716     6.07   0.000     .7109345    1.388579
           chimney |    .075082   .0723045     1.04   0.299    -.0666322    .2167961
         encdetchd |   .0819553   .0832117     0.98   0.325    -.0811367    .2450472
          encatchd |   .2761601   .0911273     3.03   0.002     .0975539    .4547664
      indwthoutpart |   .2304651   .0807771     2.85   0.004     .0721448    .3887853
       indwithpart |   .1598333    .095491     1.67   0.094    -.0273256    .3469922
              flat |   .4517766   .0818637     5.52   0.000     .2913268    .6122265
        maisonnett |   .6775788   .1257261     5.39   0.000     .4311603    .9239974
           swahili |   .1942043   .0634025     3.06   0.002     .0699378    .3184709
            shanty |    .649401   .0835427     7.77   0.000     .4856604    .8131416
   manyattatradhse |  -.1877342   .0810357    -2.32   0.021    -.3465613   -.0289072
      otherdwelling |   .0109368    .103658     0.11   0.916    -.1922293    .2141028
             rural |   .1025263   .0453915     2.26   0.024     .0135607     .191492
                   |
          quintile |
                 2 |   .1640849   .0554197     2.96   0.003     .0554643    .2727054
                 3 |   .3007776   .0538994     5.58   0.000     .1951367    .4064186
                   |
             _cons |  -2.494354   .0883287   -28.24   0.000    -2.667475   -2.321233
-------------------+------------------------------------------------------------------
mills              |
            lambda |  -5.703332   1.021892    -5.58   0.000    -7.706203   -3.700461
-------------------+------------------------------------------------------------------
               rho |   -1.08953
             sigma |  5.2346886
--------------------------------------------------------------------------------------
```

Chapter 6 : **SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

6.1 Summary and conclusions

This thesis had four objectives addressed in three essays. The first objective was to determine the factors that influence the levels of Indoor Air Pollution (IAP) from household energy use. This objective was addressed using the Conditional Mixed Process (CMP) ordered probit model that addresses endogeneity issues. The levels of IAP were categorised into five: very high, high, medium, low and very low. The results indicate that about 70.1 percent of households that owned traditional stoves (and used firewood) had very high levels of IAP compared to 2.7 percent of households that owned electricity cooker (and used electricity). Living environment characteristics such as use of chimney is associated with low levels of IAP. Only 6.0 percent of households using firewood had very high levels of IAP.

The factors that influence the levels of IAP were education, income and the type of dwelling. Households' heads who were graduates and households with high incomes were associated with high levels of IAP. About 25.9 percent of households living in manyatta houses were associated with very high levels of IAP compared to 0.5 percent living in mansionettes. Majority of the households in manyatta houses were influenced by easy access of wall and roof building materials.

The second objective aimed at investigating the association between households energy use and illness using multivariate regression analysis. The results show that about 60.2 percent, 67.9 percent and 68.4 percent of households using firewood were associated with upper respiratory infection, lower respiratory infection and eye illness, respectively. However, for those who used electricity; only 2.0 percent, 0.26 percent and 1.75 percent are associated with upper respiratory infection, lower respiratory infection and eye illness, respectively.

The results show that households who are likely to manifest upper respiratory, lower respiratory and eyes infections use firewood fuels and traditional stove appliances. Also households who are highly associated with upper respiratory infection are those with members below 50 years, children especially between age 0-4 years, those living in flats and swahili houses, and those who cook from indoor without partition kitchens. There is a higher probability of being predisposed to1ower respiratory infection for households ages 5-49 years, those who cooked from enclosed attached and indoor without partition kitchen. Households who suffer from chronic illness, those who cook from indoor with partition kitchen and those with graduate education were likely to manifest eyes illness.

The third objective was to estimate the health cost and productivity effects of households energy use. The study utilised the cost of illness approach. The results show that an average of 20 work days and 22 school days annually are lost due to IAP related illness. The costs for upper-respiratory illness, lower-respiratory illness and eyes illness were Kshs 87,754; Kshs 119,572.66; and Kshs 119, 000.00, respectively. About Kshs 5,434.58 and Kshs 6,610.45 per household annually can be saved, if households adopted the use of improved stoves, for the case of lower-respiratory infection and eyes illness, respectively.

Finally, the fourth objective was to analyse the demand for IAP abatement interventions. The Heckman two step approach was used. The results show low adoption levels for IAP abatement interventions. About 7.49 percent, 7.40 percent and 4.90 percent of households used improved stove, chimney and modern energy interventions, respectively. The key factors that influenced demand for IAP abatement interventions were geographical location, type of energy households use, cooking place/area, type of dwelling, income and whether households had a chimney or not. The ownership of modern fuel appliances like gas cooker and electric cooker dictated whether the use of modern energy intervention is adopted or not. Further, the type of dwelling for households influenced whether any IAP abatement intervention will be taken up or not.

6.2 Recommendations

Education is found to affect the levels of IAP (Pant et al. 2008) and also influences whether any IAP abatement intervention will be adopted or not (Jack, 2004; Sclag et al., 2008; Gebreegziabher et al., 2010; Pachauri et al., 2004; and Chambwera, 2004). Through the soft policies such as educational programs and public awareness campaigns, the government can enhance household adoption of modern energy technologies that are associated with low levels of IAP, conserved environment and hence better health outcomes. These programs will enhance household awareness and create understanding on the significant savings they could make annually by reducing the health costs and increasing their productivity through reduced work days lost associated with IAP related illness. The government should also educate the public on the selection and investments made on fuel stove appliance. Investments made, on type of fuel stove appliance, automatically dictates the type of energy used.

Strengthening the soft policies by introducing the hard policies is equally important. Since modern energy technologies are expensive to most households. Hard policies may include providing mechanism that addresses the ability to pay for improved energy technologies among households. The government can partner with local banks to draw plans that will allow household to acquire these technologies and pay for them over a period of time either through monthly installments.

The types of dwelling play a key role in determining the levels of IAP. According to Adhikari (2012), the type of dwelling is a proxy for wealth and the ability to take avertive actions. Policies directed towards abatement of IAP should target more at those households living in manyatta/traditional houses because they are manifested with high levels of IAP. Encouraging households and residential developers to adopt construction materials that are more permeable, affordable and easily accessible is equally important. Permeable construction materials allow easy flow of air which implies that polluted air can easily move and not be trapped. Through both private and public partnership, awareness creation can be enhanced by building low cost exhibition houses to serve as best practices for households to emulate. The design of these houses should also consider erection of chimney to reduce the level of IAP. Therefore energy planners should work with architects to incorporate the chimney aspects when developing building designs. It is also important to discourage building of traditional houses that limit household's use of modern energy.

Income also drives the level of IAP and influences an individual is likely to associated with IAP related illness (Bukalassa, 2011). Households with high incomes are able to purchase modern energy technologies that have lower emissions (Gebreegziabher et al., 2010; Pachauri et al., 2004; Chambwera, 2004; and Jaggernath, 2013). For instance promoting of local artisans and retailers to engage in production and distribution of modern energy technologies not only enhances uptake of these technologies but also households are able to earn income

6.3 Contribution of the thesis

This thesis contributes to knowledge in various aspects. First, the thesis examines the determinants of IAP. Other than biomass which is the dominant household energy investigated, this study considers other household energies including kerosene, LPG and electricity. Second, the population of interest not only covers the rural, but also the urban. Third, factors studied emphasise on the type of household energy used and fuel stove appliance, however this thesis discusses the living environment characteristics such as use of chimney and modifying the type of dwelling in the Kenyan context. Fourth, in terms of methodology, this study addresses endogeneity by utilising the Conditional Mixed Process (CMP), a novelty estimator proposed by Roodmans (2011). Fifth, the study is able to distinguish the illness by not only putting focus on lower and upper respiratory infection, but also eye illness, which have not been previously studied and compared in a single study. Sixth, the study also gives focus to eye illness as one of the ill health from using household energy, an illness that has not been widely examined. Seventh, to the best of author’s knowledge, it is the first to compute the health cost and productivity associated with household energies in Kenya. Eighth, this study compares the different IAP abatement interventions that can be adopted, unlike other studies which have investigated only one intervention. Lastly, it is among the first studies to examine the adoption of chimney as one of the interventions to reduce IAP.

6.4 Areas of further research

Further studies should be directed to investigate the health cost of specific illnesses, for example bronchitis and pneumonia. Such studies should also estimate the health cost savings from mitigating activities taken up by households. Further research should focus on identifying the chemicals found in the indoor air that affects health adversely. The study also should identify which consumer products are associated with such harmful chemicals that affect health negatively.

It is also important if future studies are directed to investigate and compare the health effects of energy generation and conversion from different energy sources such as nuclear, coal, geothermal among others.

Due to data limitations, behavioral change as an IAP was not analysed. Further research should examine the impact of behavioral change on health and most important to establish the demand and factors that drives adoption of behavioral change intervention.

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APPENDIX

The Data Used

The Kenya Integrated Household Budget Survey (KIHBS) 2005-2006 was carried out by the Kenya National Bureau of Statistics. It was the first survey to be done on the living standards measurements study. The KIHBS was designed to update and strengthen the Consumer Price Index (CPI), poverty and inequality; and the System of National Accounts (SNA).

The data collection exercise took a year and covered the whole country. The data was represented at different levels: national, urban/rural, provincial and district. The KIHBS was based on the National Sample Survey and Evaluation Programme (NASSEP-IV) sampling frame. It comprises 1,800 clusters selected with probability proportion to size (PPS) from a set of all Enumeration Areas (EA) used during the 1999 Population and Housing Census. The data was collected from all eight provinces in the country. The KIHBS clusters sampled in each district now county were selected with equal probability from the NASSEP-IV frame, where a total of 13,430 households were targeted. The survey was conducted in 1,339 sampling units/clusters across all districts in Kenya, and comprised 857 rural and 482 urban clusters.

The survey collected information on demographics; education; health, fertility and mortality; employment; labour; child health and nutrition; housing; water, sanitation and energy use; food consumption and expenditures; non-food consumption; ownership of durable goods; agricultural holdings, activities and outputs; livestock; household economic enterprises; transfers; income; credit; and recent shocks to household welfare.