Access to clean cooking technologies in Uganda: Model analysis based on empirical data

ausgeführt zum Zweck der Erlangung des akademischen Grades
eines Doktors der technischen Wissenschaften

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Wien, April 2017

Abstract

Energy deeply influences people's lives and is an engine for social development and economic growth. Limited access to energy, and therefore energy services, contributes significantly to poverty. In sub-Saharan Africa, in spite of growing economies, the rate of those gaining access to clean cooking technologies (e.g. cooking with modern fuels) continues to be outpaced by population growth.

In energy transition evaluations, models are often developed to analyse scenarios and pathways. However, because most energy models are designed in industrialised countries that have long overcome the energy access issue, the transition mechanisms from biomass fuels to modern fuels in cooking, a crucial step in energy access development, are often been overlooked in energy models.

The core objective of this thesis is to answer the following question: How can the determinants of household cooking technology choices be modelled, especially in Uganda, such that the choices made by heterogeneous consumers can be better represented, and the model results be used to quantitatively assess policies to achieve universal access to clean cooking technologies and the impacts of climate change policies?

In order to answer this question, a cooking technology choice model was developed, which generates cooking choice demand curves using the concept of revealed preference for household groups of different income levels and locations. The model contributes to filling the gap between existing cooking models and cooking situations in developing countries by adding consumer heterogeneity and cooking technology choice, reflecting both fuel and stove preferences in cooking energy transition analyses.

Analyses performed using the model indicate that with a combination of support to purchase modern fuels and clean stoves, universal access to clean cooking technologies in Uganda can be achieved by 2030. If the amount of support is provided based on the level of consumers' needs, universal access can be achieved for 8.14 billion USD, or about 550 million USD per year over 15 years. However, if a climate change policy limiting emissions is also implemented, increasing the price of LPG in Uganda by 0.23 USD/kg, the same policy would only achieve an access rate of 64%. Replacing the current technology of earth kiln by casamance kiln could reduce yearly firewood consumption in Uganda from 84 million tonnes to 52 million tonnes in 2030. Given this, it is recommended for Uganda to prioritise policies for improving charcoal production technology over policies increasing fossil fuel prices, which can limit deforestation and impacts on climate change without hindering cooking energy transition.

Kurzfassung

Der begrenzte Zugang zu Energie und damit Energiedienstleistungen trägt wesentlich zur Armut bei. Energie beeinflusst das Leben der Menschen tiefgreifend und ist ein Motor für soziale Entwicklung und Wirtschaftswachstum. Trotz wachsender Volkswirtschaften in Afrika südlich der Sahara wird die Rate derjenigen, die Zugang zu sauberen Kochtechniken erhalten (z. B. Kochen mit modernen Brennstoffen), weiterhin durch die Rate des Bevölkerungswachstums übertroffen.

Zur Bewertung von Energiesystemwandel werden häufig Modelle herangezogen, um Szenarien und Entwicklungspfade zu analysieren. Allerdings sind die meisten Energiemodelle für Analysen in Industrieländern konzipiert und betrachten deshalb implizit nur die Arten von Energiebedarf und Entscheidungen in diesen Regionen. Weil in den Industrieländer die Energiezugangsfrage längst gelöst ist, wurden die Übergangsmechanismen von Biomasse zu modernen Brennstoffen zum Kochen oft in Energiemodellen nicht berücksichtigt.

Die zentrale Frage dieser Arbeit ist nun, wie die Determinanten des Einsatzes von Haushaltskochgeräte mit einem Fokus auf Uganda, modellmäßig so erfasst werden können, so dass die Entscheidungen von heterogenen Verbrauchern besser abgebildet werden können und die Modellergebnisse zur qunatitativen Bewertung über Zugang zu sauberen Kochtechnologien und die Auswirkungen von Klimapolitik herangezogen werden können?

Um diese Frage zu beantworten, wurde ein Kochgeräteeinsatzmodell entwickelt, das basierend auf dem Konzept der offenbarten Präferenzen für Haushaltsgruppen unterschiedlicher Einkommensstufen und Standorte Kochgeräte-Nachfragekurven erzeugt. Das Modell trägt dazu bei, die Diskrepanz zwischen bestehenden Kochgeräteeinsatzmodellen und realen Kochsituationen in den Entwicklungsländern zu reduzieren, indem es die Heterogenität von Verbraucher und die Kochgeräten, sowohl in Bezug auf Brennstoff- als auch auf Herdpräferenzen bei der Analyse von Energiesystemwandel besser widerspiegelt.

Analysen, die mit dem Modell durchgeführt wurden, zeigen auf, dass mit einer Kombination von Unterstützung für den Kauf moderner Brennstoffe und sauberer Öfen der Zugang aller Menschen zu sauberen Kochtechniken in Uganda bis 2030 erreicht werden kann. Wenn die Höhe der Unterstützung sich auf der Grundlage der Bedürfnisse der Verbraucher berechnet, kann Zugang für alle Menschen für 8,14 Milliarden USD oder rund 550 Millionen USD pro Jahr über 15 Jahre erreicht werden. Auf der anderen Seite, wenn eine Klimapolitik den Preis von LPG in Uganda um 0,23 USD/kg erhöht, würde eine Zugangspolitik, die zuvor einen Zugang für alle Menschen erreicht hätte, nur eine Zugangsrate von 64% erreichen. Daher empfiehlt es sich, eine Politik zur Verbesserung

der Holzkohleproduktionstechnologie in Uganda anstatt einer Politik, die die Preise für fossile Brennstoffe addressiert, umzusetzen. Wenn die derzeitige Technologie des Erdofens durch Casamance ersetzt wird, kann der jährliche Verbrauch von Brennholz in Uganda im Jahr 2030 von 84 Millionen Tonnen auf 52 Millionen Tonnen reduziert werden, was den Umweltschutz unterstützt, ohne den Übergang zu modernen Kochgerätenzu behindern.

Acknowledgements

This dissertation could not have been completed without the great support that I have received from so many people over the years.

First, I would like to express my great appreciation for my advisor Univ.Prof. i.R. Dr. Dr.h.c. Nebojša Nakićenović for his support throughout this dissertation and for his patience, motivation and immense knowledge. Without his guidance and persistent help this dissertation would not have been possible.

I would like to thank my committee members, Dr. Keywan Riahi, Univ.Prof. Dipl.Ing. Dr. Reinhard Haas and Univ.-Prof. Dipl.-Ing. Dr. Arnulf Grübler for their encouragements and helpful inputs.

I wish to offer many thanks to the International Institute for Applied Systems Analysis (IIASA) for giving me an opportunity to conduct a part of my research at the institute. I express my heartfelt gratitude to Dr. Shonali Pachauri, Mr. Mathis Rogner, Dr. Shilpa Rao, Dr. Narasimha Rao, Dr. Sebastian Busch, Mr. Peter Kolp, Ms. Pat Wagner and all my colleagues in ENE and TNT groups, for supporting me through the research and providing me countless recommendations and suggestions to improve the quality of my work. You have not only been brilliant advisors and collaborators but also wonderful friends.

My appreciation goes also to Dr. Kenneth Arinaitwe and Mr. Godfrey Muhwezi at the Center for Integrated Research and Community Development Uganda (CIRCODU) for generously offering me feedback and support of this dissertation.

Lastly, I would like to thank my family for all their love and encouragement. For my parents and sisters who have supported me through this exciting and challenging journey. And most of all I give my sincere appreciation to my loving, supportive, encouraging, and patient wife Yui, whose support during the final stages of this dissertation is so appreciated. Thank you.

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Chapter 1. Introduction

1.1 Motivation

One of the greatest and most urgent development challenges facing the world today is poverty eradication. Although poverty has declined worldwide, as of 2015, 836 million people are still living in extreme poverty[1] (United Nations 2015a), and progress has been uneven as extreme poverty persists mainly in rural areas. Deteriorating ecosystems, unsustainable natural resource management, and climate change are disproportionally affecting low-income households, because people in poverty typically have the least resilience (FAO 2015). The goal of eradicating poverty will remain elusive, until these trends are halted and the situation in rural areas is treated with priority.

Economic development is a prerequisite for reducing and overcoming poverty, and energy services are at the core of economic growth. Energy deeply influences people's lives and is an engine for social development and economic expansion. Commercial energy facilitates productive activities including agriculture, manufacturing and commerce (UNDP 2000), and it has contributed to transforming societies, especially since the beginning of the industrial revolution. Energy is recognised to be an essential factor in combating poverty and achieving the Millennium Development Goals (Modi et al. 2005).

At a household level, having access to adequate and affordable energy is essential as basic services, such as cooking, lighting and communication technologies, all require energy input. Limited access to energy, and therefore energy services, contributes significantly to poverty. The poor cannot afford high quality energy delivered by modern fuels (e.g. electricity, LPG, natural gas), leaving them to settle for unhealthy forms of energy, such as firewood and charcoal, to meet their needs. The lack of access to modern fuels represents a bottleneck in improving living conditions (WHO 2006).

The importance of access to modern fuels has attracted increased attention in recent years. In 2011 the United Nations Secretary-General Ban Ki-moon's Advisory Group on Energy and Climate Change called for a major UN initiative, Sustainable Energy for All (SE4ALL), and one of its three objectives is to "ensure universal access to modern energy services" (i.e. energy services supplied by modern fuels) by 2030 (United Nations 2011). In July 2015, SE4ALL held a conference on financing for development, which lead to a report on concrete ways to boost financing for sustainable energy. Reflecting the increased attention and efforts of SE4ALL, the newly proposed Sustainable Development Goals (SDG) for post-2015 development included providing universal access to affordable, reliable, and modern energy services (United Nations 2015b).

[1] Extreme poverty applies to those living on less than 1.25 USD a day.

Nevertheless, in spite of growing economies in sub-Saharan Africa (over 5% per year between 2000-2010), the rate of those gaining access to clean cooking technologies (e.g. cooking with modern fuels) continues to be outpaced by population growth (UNDP et al. 2009). As a result, the International Energy Agency (IEA) and the World Bank expect the number of people in the region without access to clean cooking technologies, which stood at 727 million as of 2012, to reach around 900 million by 2030 (World Bank 2012b, IEA 2013), while Riahi et al. (2012) in the Global Energy Assessment (GEA) and Pachauri et al. (2013) estimate that the number will reach over one billion without dedicated policies for energy access. "Current Policies Scenario", as called in the World Energy Outlook by IEA, is too slow to meet the sustainability goal of universal access to modern energy services by 2030.

In energy transition evaluations, models are often developed to analyse scenarios and pathways. Models can provide valuable information to assist in understanding transition paths that are suitable under different economic or fuel price conditions. However, most energy models are designed in industrialised countries and implicitly only assume types of energy demands and choices in first-world countries. Industrialised countries have overcome the energy access issue, and therefore, the transition mechanisms from biomass fuels to modern fuels in cooking had often been overlooked in energy models. Only a few energy models account explicitly for the dynamics of cooking technology choices of developing countries.

One of the key elements in developing and designing energy models is a reliable underlying dataset. In order to reflect the trend and behaviours of consumers and energy systems, both past and current data need to be utilised to adjust and calibrate models. Unfortunately, to develop a cooking technology choice model and analyse cooking energy transition, the dataset required includes not only fuel consumption but also types of stoves used, information that is not available in developing countries. Data collection for cooking also faces a unique problem in the energy sector, in that the markets for traditional fuels used for cooking (e.g., firewood and biomass) in developing countries are largely informal. This means that there are limited official or recorded statistics and records, which makes the tracing of transactions extremely difficult.

In light of these issues, Uganda's household survey (UBOS 2006b) is one of the rare cases where quality key data exists, including non-commercial fuel use. The survey also collects data on primary cooking stoves used, disaggregating between traditional stoves and improved cooking stoves. Combining this cooking data with dwelling location, income levels and household purchasing patterns, the detailed energy use portfolios for various household groups can be developed for cooking transition analyses.

Although access to clean cooking technologies by itself will not alleviate poverty, it is a necessary and important first step out of poverty and towards the expansion of local economies. Therefore, this dissertation focuses on the cooking situation among the low-income households and develops a cooking technology choice model to quantitatively investigate their cooking situation, in hopes that it will provide a base for more future analyses. It will particularly focus on Uganda, a country with a rare set of detailed household survey data on cooking fuels and stoves, as a first step to mapping the cooking energy transition of sub-Saharan Africa.

1.2 Aim of the dissertation

The research presented in this dissertation contribute to the body of research that investigates the transition to clean cooking technologies in developing countries by providing a deeper understanding of how social situations along with economic situations affect cooking choices in Uganda. The development of cooking technology choice model contributes to closing the gap of knowledge in consumer preferences and to better reflecting the situations of developing countries in energy models. It can also provide a well-informed input for energy access policies that could increase the rate of transition to clean cooking technologies.

The core objective of this PhD dissertation is to answer the research question:

> *How can the determinants of household cooking technology choices be modelled, especially in Uganda, such that the choices made by heterogeneous consumers can be better represented, and the model results be used to quantitatively assess policies to achieve universal access to clean cooking technologies and the impacts of climate change policies?*

To answer the question, the following secondary research questions are derived:

- How can heterogeneity in cooking choices be represented in a model?
- What are the key parameters affecting the future cooking technology choices?
- What kinds of policies can effectively promote a transition to clean cooking technologies?
- How would a climate change policy that increases modern fuel prices influence the transition to clean cooking technologies?

The current modelling approaches in energy models have major deficiencies in representing dynamic cooking energy transitions and the heterogeneity of consumer preferences in the types of fuels and technologies chosen for cooking. The cooking technology choice model developed in this dissertation contributes to filling the gap between the current cooking situations in developing countries and existing cooking models by adding 1) consumer heterogeneity, and 2) cooking technology choice reflecting both fuel and stove preferences. The cooking technology choice model incorporates preferences of heterogeneous consumers by creating end-use technology specific demand curves, which reflect social factors such as dwelling location, household size and income level, for different consumer groups. The model is used in the dissertation to make recommendations on financial policies to accelerate the transition to clean cooking technologies, and to analyse the impacts of climate change policies on such transition.

The dissertation focuses on the cooking situation in Uganda as a first step to mapping the energy transition of sub-Saharan Africa, with the hope that it will provide a base for more future analyses. To analyse household cooking technology choices in Uganda, a cooking technology choice model is developed, based on the household level data from a Ugandan survey on fuel purchasing patterns and types of cooking stoves used.

1.3 Thesis structure

This chapter, Chapter 1, provides a brief introduction of how access to modern forms of energy and cooking fuels is essential for poverty eradication and sustainable development, and further describes the research questions, motivations and objectives of the dissertation. Chapter 2 puts the objectives into a context, the connection between biomass consumption and development, along with past studies on cooking technology choice, is presented.

Chapter 3 explores the types of cooking fuels consumed and end-use cooking technologies used in sub-Saharan Africa. The understanding of available fuels and stoves provides a framework to explain where the current cooking energy use of sub-Saharan Africa stands. After getting an overview of the region, Chapter 4 explores the energy use and regional differences in the cooking energy situation of Uganda. It provides the current status and past policies to gain a better understanding of the choices that Ugandan consumers have in cooking technology.

Chapter 5 describes the concepts of a cooking technology choice model, its structure and the source of input parameters used in the model. Along with a literature review on energy models and cooking models, details of how the household survey data is organised and treated are explained.

The results of model analysis are presented in Chapter 6. Multiple sets of scenarios are analysed which include: fuel price support, credit access, climate change and charcoal price scenarios. The results are presented in scenario groups to bring out their policy implications.

Chapter 7 is the concluding chapter. The overall conclusion and the summary of model results and the policy implications drawn from them are presented. It also explains the strengths and limitations of this dissertation and suggests recommendations for future work.

Chapter 2. Biomass and development

2.1 Biomass consumption and poverty

In developing countries, particularly among the low-income households that struggle with the impacts of poverty, the main source of energy is traditional biomass. Traditional biomass such as wood, dung and agricultural residues can be collected from surroundings without cost, and simply burning them can provide basic needs such as lighting, cooking and heating at the same time. More than 2.6 billion people in the world are estimated to rely on traditional biomass as their main source of energy as of 2012 (WHO 2011, IEA 2014a). 95% of these people without access to modern fuels live in sub-Saharan Africa and South Asia, and most of them reside in rural areas. Asia has the most people without access at 1.88 billion (51%) people, but the share of population without access is the highest in Sub-Saharan Africa at 80% (727 million).

Among developing countries, this link between energy and poverty is demonstrated by energy source. Figure 2-1 shows the historical relationship between wood fuel production intensity per GDP versus GDP per capita in selected countries. There are regional and country differences in consumption rates, but a trend of shifting away from wood fuel with the increase in GDP is common throughout the world. The increase in effective resources from switching fuels could almost entirely be devoted to better satisfying basic needs for food, shelter, clothing, health, education and additional fuel (Reddy et al. 2000), meaning that substituting traditional biomass cooking with clean cooking technologies would grant considerable gains in purchasing power to low-income households. Thus, the cost-effective transition to modern energy services has a great potential to reduce poverty in many dimensions.

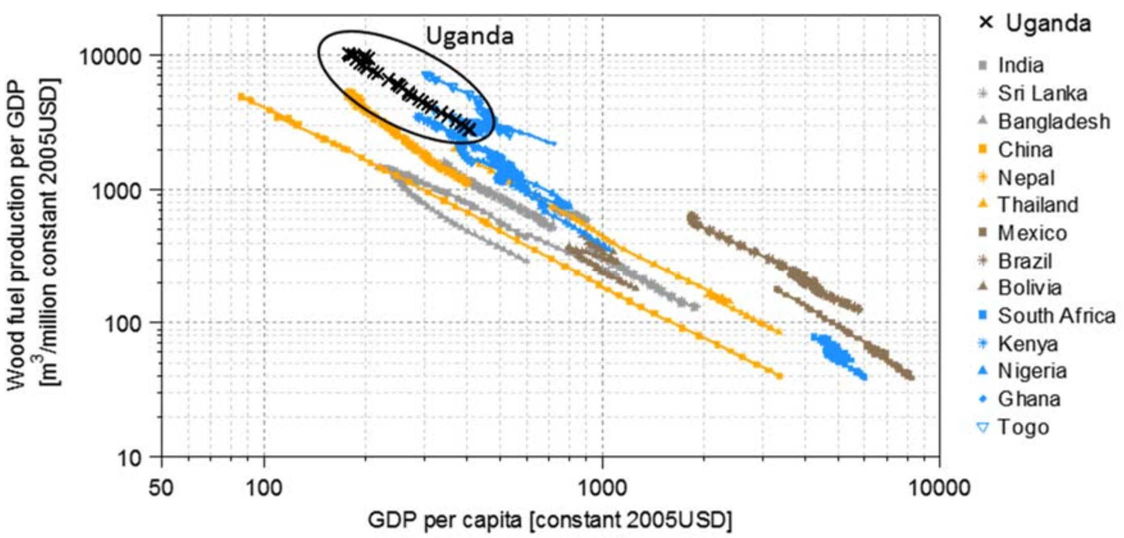

Figure 2-1. Wood fuel production intensity per GDP versus GDP per capita in 1961-2012 (FAO 2013, World Bank 2013)

2.2 Vicious cycle of biomass use

Low-income households are often trapped in using biomass as the main energy source, making it difficult to make the transition to more efficient fuel. Low-income households spend a significant amount of time collecting firewood, which deprives them of time for income generating activities. Lack of income limits their ability to make necessary upfront investments for more efficient and less harmful fuels and appliances. In addition, collecting firewood is typically performed by women and children, leaving the children with less time for education and trapping not just the current but also the future generations in the vicious cycle of biomass use.

It is common for households in rural areas to spend more than 10 hours per week collecting firewood (Figure 2-2). A study on firewood collection in Zimbabwe by Mehretu et al. (1992) found that each household devotes over 3.5 person trips per week, which takes 1.73 hours and covers a distance of 1.9 km on an average. In a small village of Matanya in Malawi, villagers would go to a nearby mountain to collect firewood two to three times a week, spending about 8 hours on each trip (Brinkmann 2005). However, the amount of time and distance covered in collecting firewood does vary greatly according to the local situation, such as vegetation types, weather and population density. For example, Gandar (1984) compared time and distance covered by people collecting firewood living in two vegetation types in Mahlabatini district of South Africa and found that the average distance walked in collecting one headload of firewood differed by almost 5 km between the two (3.6 km to 8.3 km). Even within the same area the time can differ. A survey study in Amatola Basin, South Africa by Bembridge et al. (1990) found that the respondents' range of collection time for a headload varied from 30 minutes to three hours with a mean time of two hours and five minutes. Although the degree of the problem is not the same across the board, all low-income households share the same problem of firewood collection being one of the time consuming activities necessary for survival.

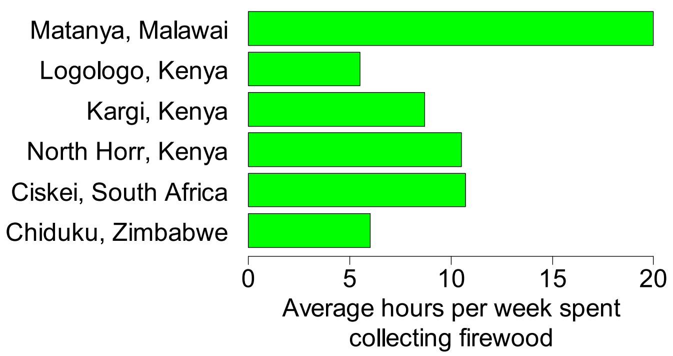

Figure 2-2. Average hours per week spent collecting firewood in various regions of sub-Saharan Africa (Bembridge et al. 1990, Mehretu et al. 1992, McPeak 2002)

The reason for the vicious cycle of reliance on biomass also lies on supply side. In rural areas, biomass has historically been a very accessible, reliable and inexpensive (or freely available) energy source. There are also many types of biomass that can be used as fuel. When firewood becomes scarce, low-income households often switch to dung or agricultural residues as their alternative fuel source. However, this switch makes the situation worse for the low-income households, as the use of agricultural residues or dungs as fuel source rather than fertilisers could lead to a reduced agricultural productivity, limiting their income generating opportunities.

The obstacle in switching to modern fuels also includes infrastructural problems, especially in rural areas. To gain access to LPG and electricity, access to infrastructure such as pipelines or transmission lines is required. However, for an investment in major infrastructure to become economical or profitable, a large amount of consumption is required. For communities in the developing stage, the consumption outlook is typically not high enough to justify the investment, leaving them on a low priority level for gaining access. The lack of investment in infrastructure is not limited to energy sectors; the same goes to basic infrastructure such as roads and communication lines. Underinvestments in infrastructure result in a lack of reliable supply chain, causing frequent shortages of LPG and electricity for the rare users in rural areas.

Collection of firewood causes another serious social issue especially in African countries, as the task of collecting firewood is performed mostly by female members of the household (daughters and wives). Mehretu et al. (1992) report that over 90% of the collection is made by women, and husbands contribute only 2.4% to the task. In the case of lowlands of Northern Kenya, a study found that female household members assumed the task of collecting firewood almost without exception (McPeak 2002). This leads to gender inequality, as female children receive less time for education. Carrying heavy loads of firewood also causes physical problems. In rural sub-Saharan Africa, many women carry 20 kg of firewood daily over a distance of 5 km (Muawya et al. 2012). Repeating this task can lead to long-term physical injuries, especially when the task is carried out frequently. In addition to physical issues, other risks such as from falls, snake bites or human assault also rise with collection distance (IEA 2002).

2.3 Biomass combustion and health

The use of traditional fuels and cookstoves can have significant direct and indirect effects on communities. Health issues among low-income households can be particularly overwhelming due to their lack of financial stability and can lead to relatively higher medical expenditure (Reddy et al. 2000).

Numerous studies have pointed out the significant health risks related to the burning of biomass fuels in stoves or open fire. Severe health implications, such as acute lower respiratory infections, chronic obstructive pulmonary disease, and lung cancer, to name a few, are reported to be caused by inhaling toxic fumes from the use of biomass (Perez-Padilla et al. 2001, Valent et al. 2004, Viegi et al. 2004, Bruce et al. 2006, Ceylan et al. 2006, Hutton et al. 2006). A risk assessment of the burden of diseases by Lim et al. (2012) estimates that 2.6-4.5 million deaths worldwide in 2010 are attributed to household air pollution from solid fuel burning. To put these numbers into context, deaths attributed to tobacco smoking in the same study was 4.8-6.4 million, and among women, the number of deaths attributed was higher for household air pollution from solid fuel burning (1.3-2.1 million) than for tobacco smoking (0.9-1.7 million). A study by Wilkinson et al. (2009) estimated that 240,000 deaths from acute lower respiratory infections and 1.8 million deaths from ischaemic heart diseases can be averted in 2020, if 87% of the Indian households were to gain access to clean cooking technologies.

Some of these health issues are exacerbated when used indoors, but the damage can be alleviated with the use of improved biomass stoves and ventilation, such as chimneys. Improved biomass stoves can reduce toxic fumes from combustion and can also reduce the amount of firewood required for cooking. However, improved biomass stoves typically cost more than 10 USD, which is a significant amount of money for those living in extreme poverty. For chimneys to be effective, they must be maintained and kept clean, and have no leakage to the indoors. Simply ventilating homes by opening doors and windows could also improve the situation, but it is unlikely to make a substantial difference in health effects (IEA 2010b).

2.4 Environmental issues

The continued use of traditional fuels and cookstoves in the current manner in sub-Saharan Africa can lead to significant impacts on the environment locally and globally. Biomass is a renewable fuel source that is carbon neutral and has limited environmental impacts, but this only applies when biomass is managed and used sustainably. If managed unsustainably, it can have negative environmental impacts on groundwater, soil and forests. Furthermore, when biomass is used under incomplete and inefficient combustion, it produces greenhouse gases such as carbon monoxide, methane and black carbon (BC), contributing to climate change.

The topic of firewood and environment first came into spot-light in the mid 1970s, when the total firewood consumption in developing countries was estimated for the first time (Maes et al. 2012). Based on the data, the growth in the consumption rate of firewood was estimated, which resulted in a higher number than the annual regrowth in forests. This fuelled the widely accepted idea that consumption of firewood in developing countries was a major cause of deforestation and that it would lead to a lack of supply in the near future. A study by de Montalembert et al. (1983) estimated that 920 million people suffered from a lack of easy access to firewood in 1980 and that this number could be two and half times higher, or 2.3 billion people, in 2000. While these concerns attracted many researchers, when the relationship between firewood consumption and deforestation was studied in detail (Arnold et al. 2003), the accumulated information from studies found that firewood consumption did not have a major impact on forestry. Firewood is typically collected outside of the forests, thus the impact was kept at a minimum level (Hiemstra-van der Horst et al. 2009). In fact the major sources of deforestation are often said to be agricultural expansion and other land use change rather than firewood use. While this is true in most parts of the world, the situation in Africa is quite different. A recent study by Hosonuma et al. (2012) shows that in the African continent, the collection of firewood and consumption of charcoal are the main drivers for deforestation, contributing to about 50% of the total.

In an area with a high population density, the high demand for firewood can lead to a local scarcity, causing localised environmental damages and forcing people to go farther to gather firewood of the same quality. A radar imagery of the Central African Republic shows deforestation along roads and tracks that lead out from villages, showing how people are going farther out to gather firewood for charcoal production, depleting forest resources around villages (IEA 2002). Furthermore, the use of charcoal in urban areas promotes deforestation, leading to scarcity and higher biomass prices, which further diminishes the living standards of the low-income households (Leach 1992, Dasgupta 1995).

In order to assess the environmental impact of charcoal use, it is important to consider the production method of the fuel. Despite the fuel efficiency advantages of using charcoal over using biomass for cooking, the lifecycle of charcoal may be far more damaging to the environment. If charcoal is produced using traditional methods of earth kiln, the conversion rate could be as low as 8% (World Bank 1991, Ferguson 2012). Furthermore, unlike firewood collection in the rural areas which is done on a daily basis, wood for charcoal production is often produced in bulk from forest resources from a selected area. Charcoal producers typically cut down trees in sizable batches without management or replanting. Such unsustainable forestry practices lead to land degradation (Kammen et al. 2005). In addition, charcoal is often made from trees that yield a dense and slow burning charcoal, but these species are slow growing and therefore particularly vulnerable to overexploitation (Girard 2002).

The environmental impact of biomass use also includes contribution to climate change from the release of BC through incomplete and inefficient combustion. Due to poor heat transferring efficiencies, traditional biomass stoves may emit more than 10% of their carbon as products of incomplete combustion, which include greenhouse gases such as carbon monoxide, methane and BC (Smith 1992). BC absorbs light and warms the atmosphere, and a study by Luoma (2010) reports that BC produced from open fire cooking along with diesel generators greatly contributes to climate change. Burning biomass is estimated to produce an average of 0.59 grams of BC per kilogram of dry biomass (Andreae et al. 2001) and accounts for 18.6% of global BC emissions (Bond et al. 2004).

BC is often not included in global carbon policies regarding emissions of pollutants, but it has a significant effect on the local as well as global climate (Bond 2007). A climate model study by Menon et al. (2002) has identified a strong correlation between high BC deposits and changes in regional climate patterns, and Menon et al. (2009) indicate that BC is responsible for the thinning of glacier over the Himalayas. EPA (U.S. Environmental Protection Agency) also estimates that BC could be the second largest contributor to climate change after carbon dioxide (EPA 2015).

2.5 Cooking technology choices

Cooking technology choice or fuel switching is a central concept in the energy transition process. A common concept used to describe household fuel choices in developing countries is the "energy ladder'' (Smith 1987, Reddy et al. 1994, Barnes et al. 1996). The concept of energy ladder implies that, as households gain socio-economic status, they move from reliance on inefficient, dirty fuels (e.g. dung, crop residues, firewood and charcoal) to more efficient and cleaner fuels (e.g. LPG, natural gas and electricity). This trend of switching to more efficient and convenient fuels with the increase in purchasing power can be observed from the current energy use and poverty level data, regardless of regions or country sizes, as shown in Figure 2-3.

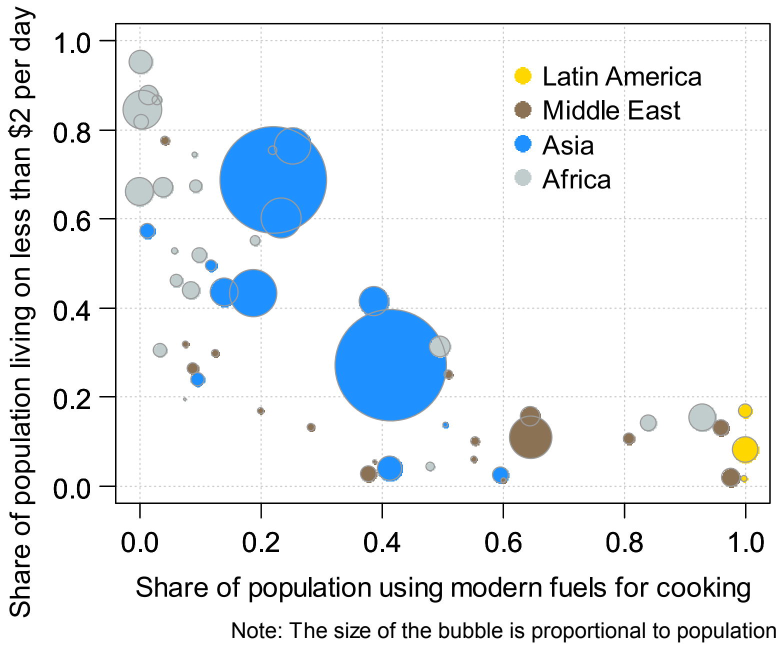

Figure 2-3. Household income and access to modern fuel in developing countries (IEA 2013, World Bank 2013)

The energy ladder is successful in capturing the income dependency of fuel choices, but it is not without criticism. For instance, the use of the word “ladder” has been criticised because it seems to suggest that one fuel is simply replaced by another, when in fact, fuel transitions are much more dynamic in reality. Many households continue using multiple fuels to satisfy their needs before completing the transition to higher quality fuels (Davis 1998, Masera et al. 2000). The more important criticism is that it puts too much emphasis on income alone to explain fuel switches and choices. Past empirical studies have confirmed a correlation between income and modern fuel consumption (Hosier et al. 1987, Davis 1998, Farsi et al. 2007). Hosier et al. (1987) tested the concept of the energy ladder in Zimbabwe and showed that households with higher incomes had higher probabilities in selecting modern fuels for cooking. However, studies by Arnold et al. (2006) and Cooke et al. (2008) estimated income elasticity of firewood consumption to be very low or even positive, where in some analyses a higher consumption of firewood is observed among high-income household groups, suggesting a weaker linkage between the two variables.

Taking on these criticisms, cooking analyses using logit model, a model well suited for studying the relationship between a predictor variable and a categorical outcome variable, were carried out to identify factors that influence fuel use patterns. Heltberg (2004) analysed household surveys from eight developing countries[2] and performed regression analyses to identify the parameters that correlate strongly to modern fuel use. The study showed a positive correlation between modern fuel use and per capita expenditure, electrification, tap water access, household size and education level. Pachauri et al. (2008) looked at household survey data from India and China to analyse energy use patterns in the two countries and found that expenditure rates, a proxy for income, are a strong driving factor for modern cooking fuel use in urban areas but much less so in rural areas. Similarly, Prasad (2008) used household survey data to analyse energy use in Africa and Latin America and found similar trends in income and the use of modern fuels for cooking. A study of cooking energy preferences in Burkina Faso found cooking frequency and types of local cereal eaten were also a factor in firewood adoption (Ouedraogo 2006). An analysis of fuel choices in Guatemala indicated that even ethnicity can be an influencing parameter in types of fuels likely to be used (Heltberg 2005).

The transition to clean cooking technologies is strongly influenced not only by economic situations but also social situations, which vary widely from region to region, country to country and household to household. However, logit model analyses have contributed in identifying that the economic factor, or income, is an influential factor in analysing

[2] Brazil, Nicaragua, South Africa, Vietnam, Guatemala, Ghana, Nepal, India

fuel use patterns while education, dwelling location, household size, ethnicity and cooking habits contribute to heterogeneity in cooking fuel choices.

Developing countries face different types of energy options and social issues when compared to industrialised countries. Given that current energy models are developed by industrialised countries without consideration of cooking energy transition, trying to fit consumer cooking choices of developing countries into these models would lead to inappropriate results. If energy models are going to be used to provide quantitative results on cooking fuel transition in developing countries, the models need to be designed based on data that reflect the social situations and consumer needs of developing countries. Socioeconomic situations and heterogeneity of consumers in developing countries must be taken into account to investigate and assess the transition to modern fuels.

Chapter 3. Cooking energy use in sub-Saharan Africa

This chapter looks at the state of residential energy use in sub-Saharan Africa, focusing especially on energy use for cooking. It looks into the types of fuels used, demands that energy services satisfy and the state of clean cooking technologies and policies in sub-Saharan Africa. It also compares the situation of sub-Saharan Africa with other continents, along with different situations within the region.

3.1 Introduction

The main energy services in the residential sector in developing countries are cooking, lighting and heating. The most basic form of providing energy, burning collected firewood in open fires, can provide all three of these basic demands. However, the use of collected firewood comes with hard labour; collecting firewood is time-consuming and physically demanding. Collected firewood has a high moisture content, especially during the wet season, which makes it difficult to start and maintain a fire. In addition, burning firewood indoors can lead to health problems such as respiratory diseases. Therefore, to avoid the inconvenience and the low quality of service associated with the use of collected firewood, the population shifts to more convenient modern forms of energy, such as gas and electricity, as economic development takes place.

According to the IEA's World Energy Outlook estimate (IEA 2013), 728 million people in sub-Saharan Africa depended on traditional biomass as their primary energy source in 2011, and by far the biggest source of biomass energy is firewood and charcoal. Nigeria alone has 122 million people (75% of the population) who still rely on biomass for cooking, and even in South Africa, one of the most developed countries in sub-Saharan Africa, 6 million people (6% of the population) still lack access to modern fuels.

Table 3-1. Primary energy supply in World, OECD and Africa for residential sector in 2005 (IEA 2012a)

2005	[unit]	World		OECD		Africa	
Biomass	[PJ]	30,906	58%	2,345	16%	8,805	85%
Charcoal	[PJ]	790	1%	13	0%	471	5%
Kerosene	[PJ]	2,248	4%	810	5%	179	2%
LPG	[PJ]	4,238	8%	1,370	9%	370	4%
Electricity	[PJ]	15,241	29%	10,227	69%	497	5%

Typical fuels used for cooking in sub-Saharan Africa are biomass (firewood, charcoal), kerosene, LPG and electricity. The ease of use increases in the respective order, going from solid, liquid, gas and finally to electricity. Some of the other less used fuels are jatropha oil, biogas, ethanol and gelfuel.

The desire to use modern forms of cooking energy is most often hindered by the lack of purchasing power and availability of fuels. The lack of finance options causes the consumers to veer toward more affordable choices; if fuels are not available the consumers need to settle for the second or the third best option available. Therefore, income, which affects available means to purchase fuels, and dwelling location, which affects availability of fuels, are key factors in the types of cooking fuel choices made.

In sub-Saharan Africa, where economic development has lagged behind other regions, more than 85% of the people living in rural areas still rely on biomass or solid fuel as their primary cooking fuel. Non-solid fuels, such as electricity, LPG or kerosene are hardly used for cooking. In urban areas, the situation is much better with over 40% of the population using non-solid fuels as their cooking energy source. Nevertheless, the number of solid fuel users is still high at over 50% with about a quarter of the population relying on heavily environmentally damaging charcoal as the main fuel. Figure 3-1 shows the share of cooking energy supplied with different types of fuels in sub-Saharan Africa and selected countries in 2007.

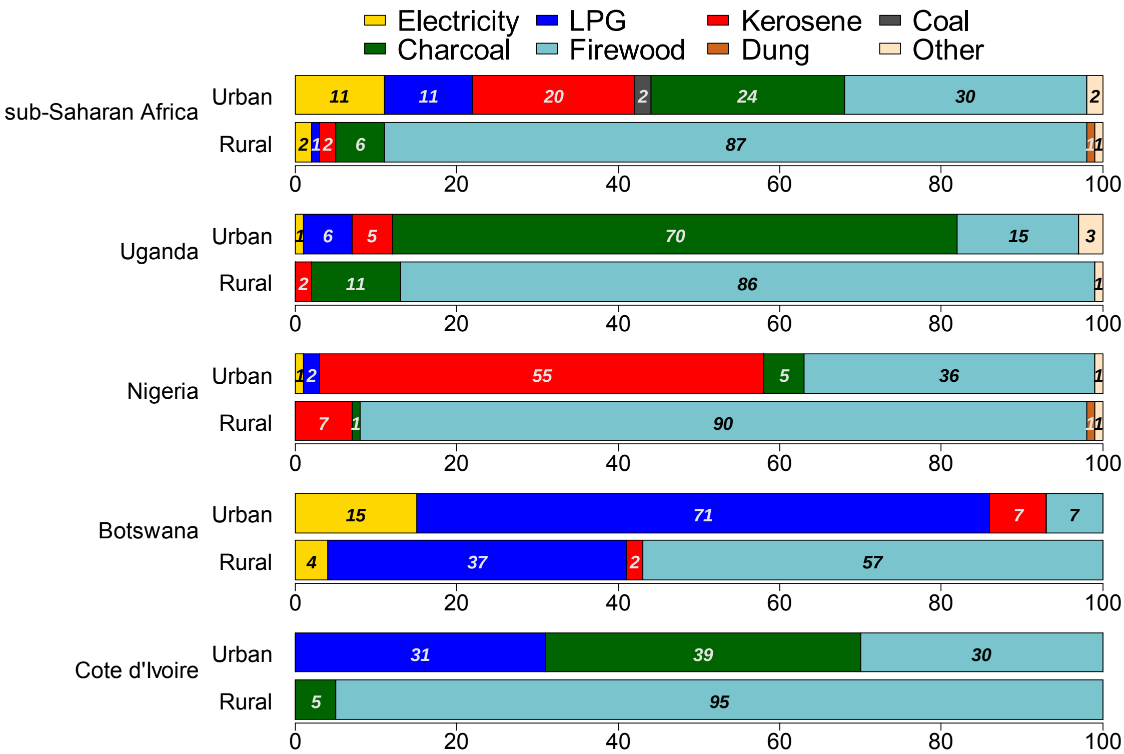

Figure 3-1. Shares of different types of cooking fuels used
in rural and urban areas of sub-Saharan Africa (Legros et al. 2009)

Types of fuels used and the relative difference in access to fuels vary among countries. Nevertheless, the overall trend of an increasing use of more convenient, modern fuels in correlation with an increase in purchasing power and a higher use of those fuels in urban areas is common in sub-Saharan countries (Legros et al. 2009). To gain a better understanding of the various fuels and cooking technologies, the typical use and current status of each fuel in sub-Saharan countries are explained in the following sections, and the types of cooking technologies are explained in Section 3.5.

3.2 Traditional cooking fuels

3.2.1 Traditional biomass

Traditional biomass is typically used with cooking devices such as open fire, metal plate stoves or ceramic stoves. Because the same combustion process can also provide lighting and heating, in many rural areas biomass is the main source of energy form for all energy services. The biomass economy is mainly informal, making the tracing or accounting processes extremely challenging. In many cases biomass is simply collected in dwelling areas or traded through barter systems.

Over three quarters of sub-Saharan Africa's population, or over 700 million people, use traditional biomass as the main fuel for cooking (WHO 2010, IEA 2012b, IEA 2013). The use of wood for energy has been a major contributor to wood removal in Africa, which was estimated to be 90% of the total African wood consumption between 1980-1994 (Amous 1999). According to the Energy Balances of IEA, close to 90% of the biomass consumption for energy in Africa is being used for the residential sector (including the use for charcoal production), and this ratio has been consistent over the last 40 years.

Table 3-2. Share of biomass use in primary energy by sectors in Africa (IEA 2012a)

	1971	1980	1990	2000	2010
Residential	89%	89%	89%	89%	89%
Industry	8%	8%	8%	9%	9%
Others	3%	3%	3%	2%	2%

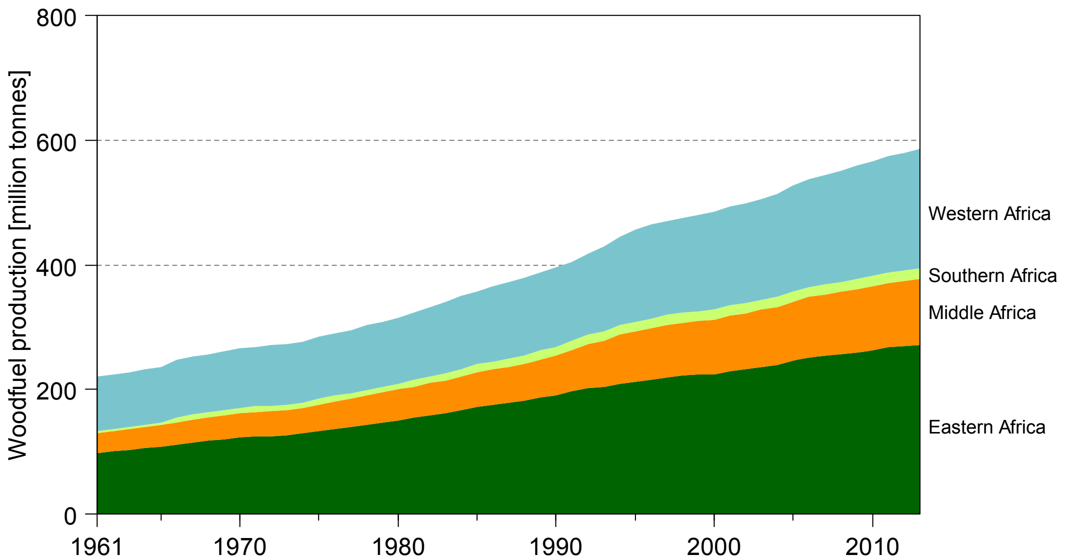

Figure 3-2. Woodfuel production in sub-Saharan Africa from 1961-2013 (FAO 2013)

3.2.2 Charcoal

Charcoal is a wood product made by heating wood in the absence of sufficient air. Heating releases the wood's volatile compounds and leaves a lightweight and cleaner burning fuel that is 70-90% carbon as a product. Charcoal is the primary urban fuel in most of sub-Saharan Africa, and the production, transport and combustion of charcoal contribute greatly to the economic cycle of many developing nations. However, it can have affect economy negatively, when charcoal trade is inadequately regulated. According to FAO, Africa accounted for nearly 60% of the world's charcoal production in 2012, which was estimated to be 29 million tonnes.

Charcoal is normally preferred over other biomass fuels such as firewood, residues and dung. Charcoal is smokeless, has a higher energy density, and can be stored without fear of insect problems. The fuel can be easily extinguished and reheated, and also burns evenly for a long time, allowing the user to take on other tasks while they cook. In contrast, to sustain the fire from firewood, the use needs to regularly attend to and feed the fire. The convenience of charcoal is one of the reasons why the fuel is still desired for grilling even in industrialised countries, such as in the USA.

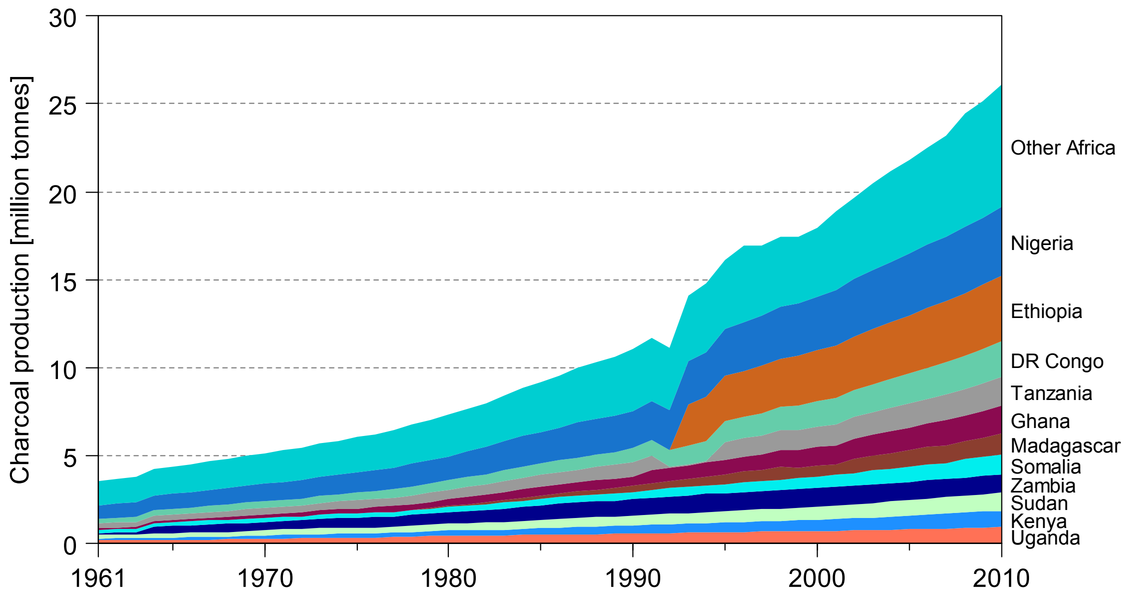

Figure 3-3. Charcoal production in sub-Saharan Africa from 1961-2010 (FAO 2013)

Methods of charcoal production remain highly wasteful with traditional methods achieving conversion efficiencies as low as 8-15% (World Bank 1991, Ferguson 2012). Once the earth kiln is lit, continuous attention is required for 3 to 15 days depending on the size of the production (Seidel 2008). Since much of the production is done at an individual level by rural low-income inhabitants, methods that are more efficient yet capital intensive, such as casamance kiln, have been difficult to diffuse. Since the average conversion efficiency for casamance kiln is in the range of 20-30%, a shift could potentially reduce the wood requirement by half.

Table 3-3. Historical charcoal consumption in industry and residential sectors in Africa (IEA 2012a)

	[unit]	1971	1980	1990	2000	2010
Industry	[%]	1%	1%	1%	0%	0%
Residential	[%]	96%	96%	96%	96%	96%
Industry	[kt]	69	88	113	37	93
Residential	[kt]	5,978	7,669	10,686	14,435	18,844
Total consumption	[kt]	6,242	8,003	11,125	15,071	19,682

Although most of the consumption take place in urban areas, charcoal is one of the major income generating industries in many rural areas. It is estimated that about 2.5 million people are economically dependent on charcoal production, transport, and trade in Kenya (Mutimba 2005). Charcoal production is mostly in the informal sector and almost exclusively in rural areas, especially in districts well connected to big urban centres. Due to the distance the charcoal must be transported, transport costs are estimated to be a major factor in determining the price of charcoal, possibly accounting for 25% of the final price (FAO 1983, Teplitz-Sembitzky et al. 1990, Kambewa et al. 2007).

3.2.3 Kerosene

Kerosene is a petroleum-based fuel that has a hydrocarbon mix similar to aviation jet fuel with carbon chain in the C_{12} to C_{15} range. It is most commonly used for lighting in the residential sector where electricity is unavailable or unstable, which is the case in most sub-Saharan Africa countries besides South Africa. Due to the strong need of kerosene for lighting, the fuel is available in most areas even in the rural areas. This fuel is quick and easy to use, and it can also be used for cooking and heating. Kerosene usage for cooking varies greatly among and within nations. The fuel is more commonly used for cooking in urban areas, reaching over 40% in countries like Kenya, Nigeria, Eritrea and Djibouti (WHO 2010). Although kerosene is considered to be an improvement over traditional biomass, it produces soot and other toxic fumes when burned. In addition, kerosene has been cited to be particularly dangerous for children, accounting for about 60% of paediatric poisonings in Kenya and South Africa (de Wet et al. 1994, Lang et al. 2008).

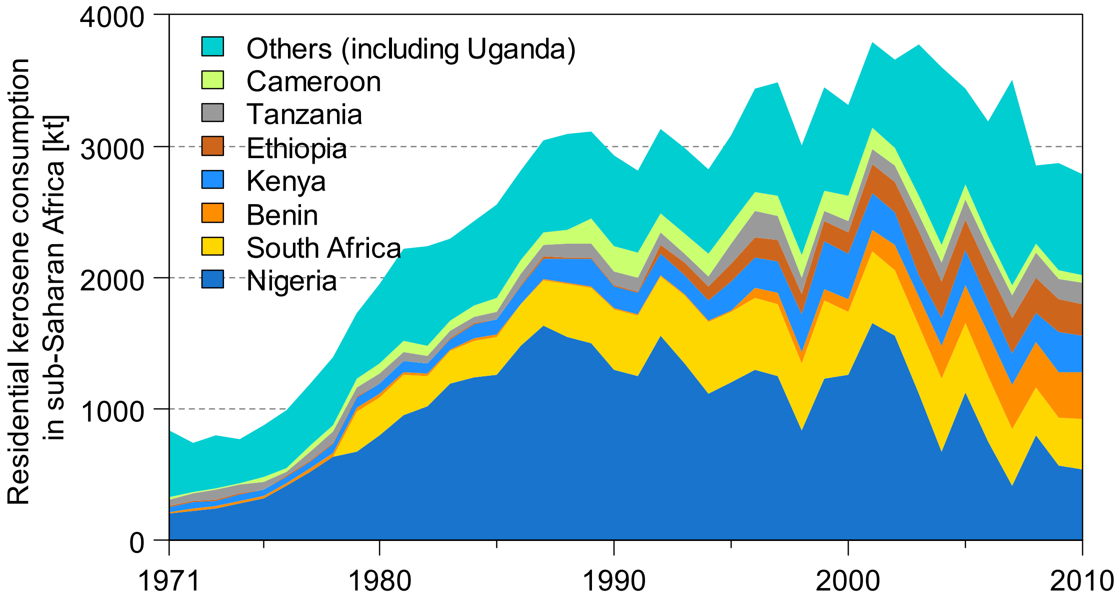

Figure 3-4. Residential kerosene consumption in sub-Saharan Africa from 1971-2010 (IEA 2012b)

3.3 Modern cooking fuels

3.3.1 LPG (liquefied petroleum gas)

LPG is a petroleum-based fuel, which is mainly made of two liquefiable hydrocarbon gases, propane (C_3H_8) and butane (C_4H_{10}). Commercial LPG is generally a varying mixture of the two gases and is most often used for cooking although it can also be used for lighting. LPG is considered to be one of the cleanest fuels for cooking as it burns efficiently and emits few pollutants (Smith et al. 1993). The fuel became popular due to the high energy content, efficiency, convenience and portability (Bizzo et al. 2004).

Due to the infrastructural issues to deliver LPG, the usage is mostly limited to urban areas in sub-Saharan Africa. The fuel is commonly used for cooking in Angola, Gabon, Senegal and Botswana (WHO 2010), but in many of the Eastern African nations the market for LPG is almost non-existent. Uganda is no exception and has a low percentage of LPG users at around 12% even in the capital of Kampala (UBOS 2010c).

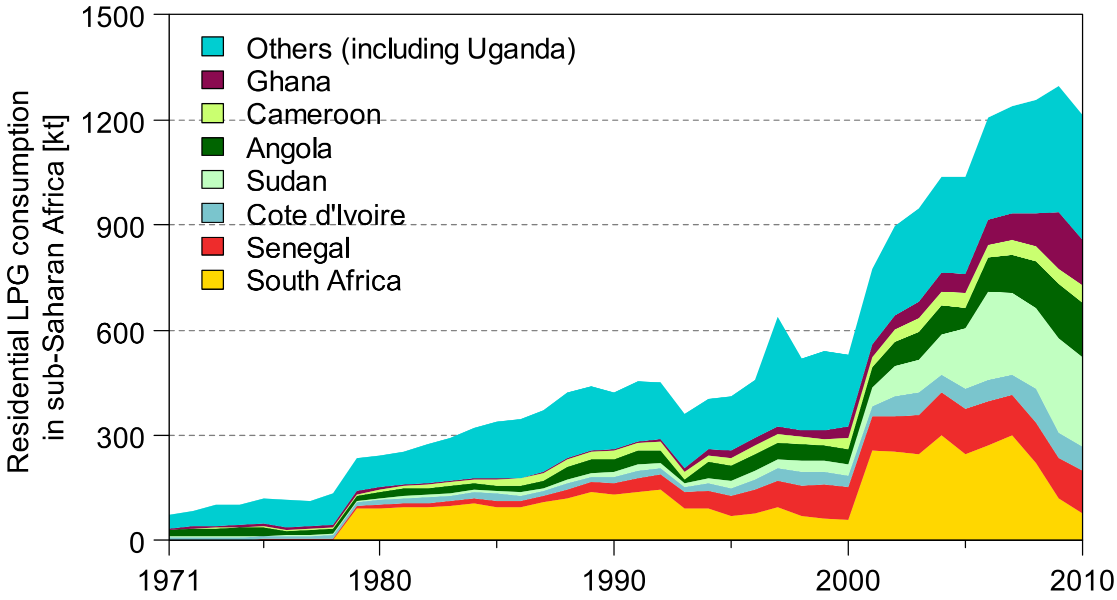

Figure 3-5. Residential LPG consumption in sub-Saharan Africa from 1971-2010 (IEA 2012b)

3.3.2 Electricity

Electricity is one of the cleanest and most efficient energy carriers, but because the grid in most sub-Saharan countries is poorly developed, limited households have access to it. The electrification process in sub-Saharan Africa has been painstakingly slow. With the regional access still standing at 32% in 2010, 589 million people (114 million in urban and 474 million in rural) are still without access to electricity (IEA 2012b).

Southern Africa is the only sub-Saharan region with a substantial share of the population using electricity for cooking. In countries such as South Africa, Zimbabwe and Namibia, more than half of the urban population cooks with electricity (WHO 2010). This is no surprise, as these countries account for over 50% of the residential electricity consumption in the entire sub-Saharan Africa.

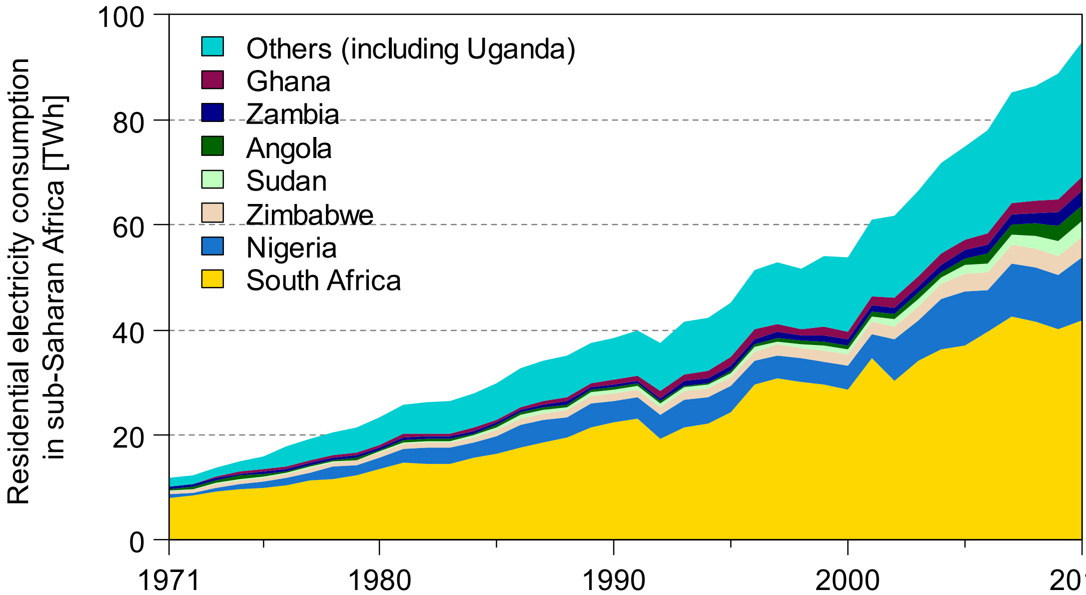

Figure 3-6. Residential electricity consumption in sub-Saharan Africa from 1971-2010 (IEA 2012b)

Because of the tremendous additional capital investment still needed to develop grids, it is unlikely that electricity will come to account for a significant proportion of cooking energy in sub-Saharan Africa in the near future. In fact, on the contrary, in South Africa there is a movement by the national electricity company, Eskom, to switch people from using electricity to LPG for cooking because the electricity supply capacity is in shortage (Eskom 2010).

3.4 Other fuels

3.4.1 Other liquid fuels

Jatropha curcas is a species of plant that has gained some attention in recent years due to its characteristic of being able to grow in semi-arid land. The plant originates in Central America, but today it can be found in many parts of southern and eastern Africa. The oil extracted from its seed can be used as cooking fuel or biodiesel. Jatropha is attractive because it can be grown locally even in tough arid regions, but the amount of pollutants from the use of jatropha oil for cooking is much worse than that of gas stoves.

Ethanol is mainly produced for use in the transportation sector by mixing with petroleum. Ethiopia, Kenya, Malawi and Zimbabwe use ethanol at a significant scale (Schlag et al. 2008). When ethanol is converted to gelfuel, it offers more advantages than the liquid form. For example, Brazil has banned liquid ethanol for safety reasons but has allowed gelfuel to be marketed.

3.4.2 Biogas

Biogas is another fuel that is considered to be an alternative option to using charcoal and firewood. In Africa it was installed as early as the 1950's in Kenya and South Africa, and it is currently used not only in the residential sectors but also in the commercial sectors (Schlag et al. 2008). One of the important features of biogas is that it can be produced in rural areas. Biogas can be produced through the fermentation processes of organic matter using residue available in most places, such as dung, crop residue and kitchen waste, and can be considered to be renewable. Through anaerobic digestion, these biomasses can be turned into a highly usable form of energy, biogas, which is typically around 60% methane, 38% carbon dioxide and 2% trace gases (CREEC 2011). The combustion of gas is very clean and reduces or eliminates indoor air pollution. Since biogas system uses materials produced locally, it can often improve resource efficiency and reduce environmental impacts such as eutrophication and air pollution (Lantz et al. 2007).

Biogas systems typically require a high upfront investment, which is out of reach for most of the rural population in sub-Saharan Africa. Therefore, the dissemination of the system has been very limited, and the system has only seen a small success. In addition to cost, the lack of knowledge and maintenance are also hurdles in implementations. Some biogas systems have been successful, but they were often community based and not made for households.

The typical types of biogas designs are fixed dome and floating drum. The fixed dome design, sometime called a "Chinese" digester, is simple and has no moving parts, allowing for an easy maintenance, though its construction is labour intensive. It is typically built underground. In some countries with clustered housings such as Nigeria, a large fixed drum digester is constructed to serve 10-20 households in a community (Rajendran et al. 2012). The floating drum design, sometimes called an "Indian" digester, has an inverted drum placed on a cylindrical or well-shaped digester. The drum floats directly in the slurry and collects gas for storage. The advantage of floating drum digesters is that it provides gas at a constant pressure and the amount of gas stored is observed easily from the position of the drum.

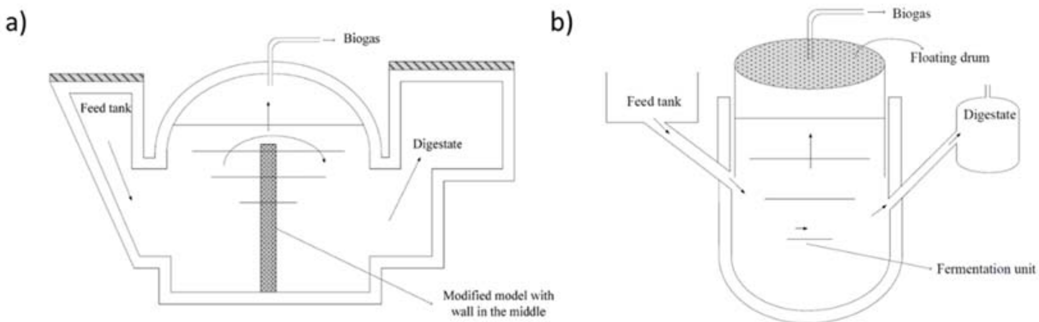

Figure 3-7. Schematic sketches of a a) fixed dome digester b) floating drum digester (Rajendran et al. 2012)

3.5 Cooking stoves

3.5.1 Stoves using biomass fuels

The most common cooking method in sub-Saharan Africa is the use of a three stone stove shown in Figure 3-8. The method requires no investments, as stones and biomass used to burn are collected from the surroundings However, the thermal efficiency is quite low, typically in the range between 10-15%, and to sustain fire a constant care of adding fuel is required. The stove contains no chimney or cover, thus the emission rates of incomplete combustion products are very high, resulting in the most negative health impacts among all stoves.

Figure 3-8. An example of a three stone stove and a mud stove (USAID 2007, CREEC 2011)

Charcoal is typically used with metal plate stoves, shown in Figure 3-9. Compared to three stone stoves, the burning area is more enclosed, allowing higher thermal efficiency and causing much less indoor air pollution. However, it is usually made from scrap metal with no regulations, so the efficiency varies from stove to stove. The stove usually costs about 3-5 USD, which is affordable for many of the urban residents, and the availability is typically not an issue in any country.

Figure 3-9. Examples of metal plate stoves used commonly with charcoal (Clough 2012)

In contrast to traditional cooking stoves, improved cooking stoves normally have a combustion chamber and a layer of insulation to reduce heat loss by guiding more heat directly to the cooking pan. Some stoves have additional health measures such as a chimney that channels the hazardous smokes away from the cook. Improved biomass stoves and improved charcoal stoves are similar in characteristics except that they use different fuels. Since the gain in efficiency switching from a three stone stove to an improved biomass stove is greater than the gain in efficiency switching from a metal plate stove to an improved charcoal stove, improved biomass stoves typically provide more incentive for switching.

One key problem with the term “improved” cooking stoves is its lack of clear definition; any stove with some insulation can be called “improved”. Thus, to secure confidence from the consumers, it would help to have a marketing name or a brand name to ensure some quality. This was the case in Kenya, where the ceramic stove, called Kenya Ceramic Jiko, was able to gain familiarity among the consumers, which allowed for a greater distribution of the product.

Figure 3-10. An example of a Kenya Ceramic Jiko stove used in Kenya (Clough 2012)

3.5.2 Stoves using non-solid fuels

Two common types of stoves are used for cooking with kerosene: wick stoves and pressurised stoves. Both have high total energy efficiencies between 40% and 60% and are simple to use (Bailis 2004). Wick stoves have a series of wicks, usually made of twisted cotton, which are placed in a holder with a control knob to adjust the power.

Kerosene is stored at the bottom, where the wicks get the fuel. Kerosene fuelled wick lamps, similar to wick stoves, are known to produce a significant amount of black carbon. A study by Lam et al. (2012) reported that 7-9% of kerosene consumed is converted to particulate matter that is nearly pure black carbon. The use of kerosene is much easier compared to solid fuels, but from the health point of view, it is difficult to categorise wick stoves as a modern, clean cooking technology. Pressurised stoves have a fuel tank and a vapour burner. Vaporised kerosene mixes with air to burn, which normally provides a more powerful fire than wick stoves. However, due to a more complex design and lighting technique required, it is more expensive and also more prone to accidents. Since kerosene is fossil fuel based, its combustion leads to a net carbon emission. Due to its lower efficiency, the net negative health impact is worse than that from LPG, but kerosene stoves are still much cleaner than traditional stoves fuelled by firewood.

Gas stoves have a burning ring, a pan support and a cylinder to hold gas. There are many types, and complex ones could have multiple ring stoves combined with an oven. Gas stoves have a high efficiency between 45% and 60% (Bailis 2004), but they cost around 30 USD (Afrane et al. 2012, Global Village Energy Partnership et al. 2012c). In addition, the fuel is sold in bottles, for which one must also purchase a cylinder to store the gas. Different sizes typically ranging from 3 kg to 50 kg are offered, but large cylinders can be as expensive as the stove itself in many cases. In Uganda, a 13 kg cylinder costs roughly 40 USD (142,000 Ugandan Shilling) according to GVEP International (Global Village Energy Partnership et al. 2012c). The cost of a cylinder is a major hurdle in the dissemination of gas stoves. A smaller cylinder does help to overcome the initial barrier of the high upfront cost, but the reduced size requires frequent refills decreasing the convenience of using a gas stove.

Figure 3-11. Examples of LPG cylinders and gas stoves (Wana Energy Solutions 2013)

One of the big advantages of using LPG cooking stoves is the reduced amount of pollutants during the usage. The fuel is non-toxic, and with a specialised stove, it requires only a few steps before the fire starts. According to a study by Smith et al. (2000), gas burning stoves emit up to 50 times fewer pollutants than biomass stoves.

This is the main reason why studies consider LPG to be an example of a modern, clean cooking technology. Other comparable clean fuels include natural gas and electricity.

3.5.3 International and domestic stove programmes

Efforts are being made to expand access to clean cooking technologies. The Global Alliance for Clean Cookstoves (GACC) has a plan to disseminate 100 million clean cookstoves by 2020 and to start clean cooking stove programmes in over 50 countries. The organisation has prioritised six countries[3] as a starting point for their action. ECOWAS Centre has also formed an alliance called West African Cooking Alliance (WACCA) during the ECOWAS High Level Energy Meeting in Ghana in October 2012 to promote clean cooking. The alliance aims to ensure that 100% of the West African population has access to clean and sustainable cooking energy by 2030. The World Bank in collaboration with the Africa Energy Group (AFTEG) has also launched an initiative called the Africa Clean Cooking Energy Solutions (ACCES) initiative to support the dissemination and adoption of clean cooking technologies. At a country level, the government of Ghana has launched "The Rural Liquefied Petroleum Gas (LPG) Promotional Programme" in 2014 and plans to distribute 350,000 stoves and cylinders over the next three years.

One of the most successful programmes to disseminate clean cooking stoves was Senegal's butanisation programme. It was first introduced in the 1970s to reduce the consumption of biomass. The programme started with removing import duties on LPG cooking related equipment. Although it led to an increase in LPG consumption, a large-scale success did not occur until fuel subsidy, along with the introduction of small fuel cylinders, was introduced. The consumption of LPG in Senegal was merely 10 ktonnes in 1980, but it had reached over 100 ktonnes by 2003 (Figure 3-12). A ten-fold increase over 23 years equates to an annual increase of more than 10% on average. As of 2006, the LPG use in urban areas was about 74% (WHO 2010), and the rate is over 90% in the capital city of Dakar (Sarr et al. 2008). However, the success was limited to urban areas; close to 75% of the rural population still rely on traditional biomass.

[3] Six countries are Uganda, Bangladesh, China, Ghana, Kenya and Nigeria.

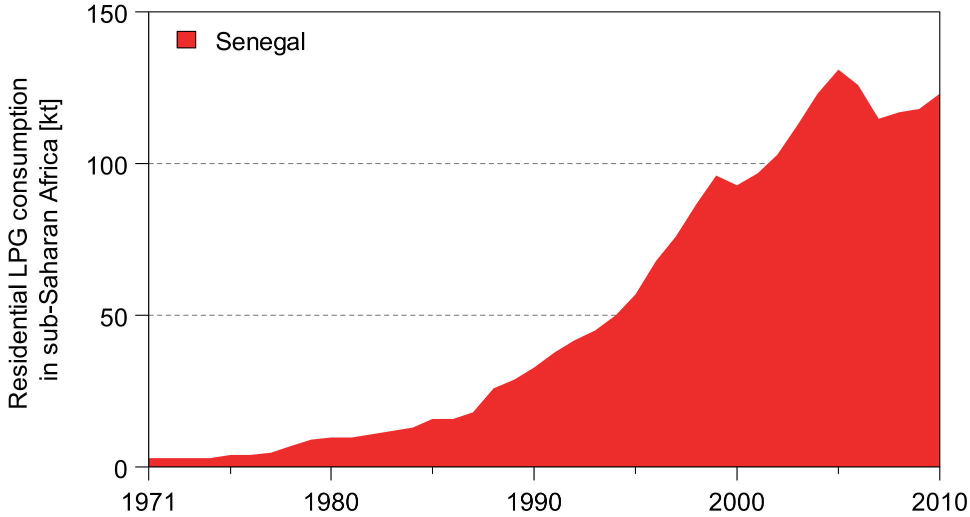

Figure 3-12. Residential LPG consumption in Senegal from 1971-2010 (IEA 2012b)

Chapter 4. The state of cooking energy use and households in Uganda

This chapter looks closely at Uganda, a country of focus for the cooking technology choice model developed in Chapter 5, due to the availability of rare sets of survey data on non-commercial fuels. The chapter first provides basic information about Uganda, then looks at the nation's overall energy use situation. It concludes with the status of cooking energy use of the country.

4.1 Country overview

Uganda is a landlocked country located in sub-Saharan Africa and bordering Kenya to the East, the Democratic Republic of Congo to the West, Tanzania and Rwanda to the South, and South Sudan to the North. The country boasts a surface area of 241,550 km^2 with the capital city of Kampala lying on the shore of the largest freshwater lake in Africa, Lake Victoria. The official language of the country is English, but being an ethnically diverse country, many people speak other languages as well such as Luganda, Nilo-Saharan and Swahili.

Figure 4-1. Map of Uganda (UBOS 2012)

The estimated population in 2011 was over 34 million (UNSD 2013). It has a very young population with over 50% of the population below the age of 14 years old (UBOS 2010c).

The population is growing at a rapid rate of roughly 3.5% per year, which was fifth-highest population growth rate in the world in 2012. The population lives predominantly in rural areas, with one of the lowest urbanisation rate in the world at only 15%, way below the world average of 52.1% and lower than the eastern African average of 23.7% (UN DESA 2013). About 85% of the population are Christians (Catholic, Protestant and Pentecostal) and 12.5% are Muslims. The overall literacy rate among children aged 10 years and above was 73% in 2009/10, and only 6% of the population have an educational background above the secondary level (UBOS 2010c). However, signs of improvement can be seen: in 2007, Uganda became the first country in sub-Saharan Africa to implement free secondary education.

Table 4-1. Population demographics of Uganda (World Bank 2013)

		1970	1980	1990	2000	2010
Population	[million]	9.45	12.66	17.70	24.21	33.42
rural	*[million]*	*8.82*	*11.71*	*15.74*	*21.29*	*28.36*
urban	*[million]*	*0.63*	*0.95*	*1.96*	*2.93*	*5.07*
Population growth rate	[%]	3.10	3.03	3.51	3.06	3.21
Life Expectancy	[years]	49.86	50.07	47.36	46.09	53.61

Uganda's gross domestic product (GDP) in 2012 was 20 billion USD (50 trillion USh) which equals 550 USD per capita, and it has sustained a relatively high growth rate of about 7% per year over the last decade (World Bank 2013). However, this growth is accompanied also by population growth, making the per capita growth to be only 3.5% per year. The major trading partners of Uganda are Sudan, Kenya, Rwanda, India and China. The main export commodities include coffee, fish, and tea, while import commodities include medicines, motor vehicles, electrical apparatus and petroleum oils (UN Comtrade 2013). Agriculture, forestry, and fishing account for nearly 23% of Uganda's total GDP, and 66% of the working population are engaged in the agricultural sector (UBOS 2012).

Uganda's System of National Accounts (SNA) reports that forestry had constituted approximately 3.5% of the GDP or about 500 million USD (2005 USD) in the period of 2008-2012. Production data recorded by the Uganda Bureau of Statistics (UBOS) consists of sawn timber, poles, firewood, and charcoal. From the late 1980s to 2002, the forestry sector showed a robust growth, averaging about 6% per year. Since 2004, however, the sector growth has declined to under 4%, and was estimated to be about 2.3% in FY2009-10[4]. The downward trend relates to declining forest stocks as a result of the conversion of degraded forest land to agricultural use and the overharvesting of forest areas for firewood, charcoal production, and other forest products.

[4] Fiscal year in Uganda start on 1 July and ends on 30 June.

Table 4-2. GDP information of Uganda (World Bank 2013)

		1970	1980	1990	2000	2010
GDP (current US$)	[billion]	1.26	1.24	4.30	6.19	17.20
GDP growth rate	[%]	*NA*	*NA*	6.47	3.14	5.90
GDP per capita (current US$)	[US$]	133	98	243	256	515
GDP per capita, ppp (2005 int. US$)	[US$]	*NA*	*NA*	563	774	1149
GDP per capita growth rate	[%]	*NA*	*NA*	2.80	0.03	2.55
Inflation, consumer prices	[%]	*NA*	*NA*	33.12	3.39	3.98
GDP Composition						
agriculture	*[%]*	*53.78*	*72.03*	*56.58*	*29.38*	*24.25*
industry	*[%]*	*13.71*	*4.49*	*11.06*	*22.90*	*25.47*
services	*[%]*	*32.52*	*23.48*	*32.36*	*47.72*	*50.28*

Uganda ranked 161st out of 186 in the 2013 Human Development Index (HDI) of the United Nations Development Programme (UNDP) (Malik 2013). Although the proportion of the population living below the poverty line has decreased from 31% in 2005/06 to 25% in 2009/10, the Gini coefficient[5] of the regions has stayed relatively unchanged between 0.40-0.45 over the last decade and actually increased from 0.408 in 2005/06 to 0.426 in 2009/10 (UBOS 2010c). The majority of those below the poverty line are engaged in the agricultural sector.

Regionally, economic development is the highest in the central area, which includes the capital city of Kampala, followed by western and eastern regions. The average expenditure of urban dwellers in the northern region is less than half that of the central region at 520.4 USD per year or barely over 1.75 USD per day, as shown in Table 4-3. The rural areas are much worse off, with the average expenditure of about 0.80 USD per day, which is below the World Bank's poverty measure of 1.25 USD per day. The northern districts (Gulu, Amuru, Kitgum, Pader, Moroto and Nakapiripirit Districts) are the poorest. Due the long term conflict and internal displacement, the northern region has suffered the most from the lack of economic development and has a poverty level of more than 46% (CREEC 2011). Lower poverty levels are encountered in southwest and central Uganda, typically attributed to factors such as better rainfall and soil quality, higher levels of market integration and a higher degree of economic diversification (MEMD 2012). Table 4-3 shows the average yearly expenditure per capita in four regions by rural and urban.

[5] Gini coefficient is a measure to describe the distribution of income or consumption expenditure among individuals or households within an economy. Gini coefficient of 0 represents perfect equality, while an index of 1 implies perfect inequality.

Table 4-3. Average yearly expenditure per capita in Uganda by region and dwelling location (UBOS 2006b)

	Central	Eastern	Northern	Western
Urban	1231.9	850.2	520.4	980.4
Ruran	644.9	443.4	293.6	522.1

4.2 Final energy use

Uganda is one of the countries in the world with the least access to modern forms of energy. In 2011, 708 petajoule (PJ), or 92.7% of Uganda's primary energy was supplied by traditional biomass (firewood and crop residues) (MEMD 2011a), and among households, 73% used firewood and 21.5% used charcoal as the main source of cooking fuel (UBOS 2010c). Due to the undeveloped industry and commercial sectors, over 65% of the final energy use is in the residential sector. Energy security is also a major issue in Uganda. Currently Uganda imports all of its oil products by truck from Kenya, though there is a plan to extend the Kenyan Nairobi-to-Eldoret oil product pipeline to Kampala (EIA 2013b).

Table 4-4. Final energy use in Uganda in 2011 (MEMD 2011a)

[PJ]	Residential	Commercial	Industry	Transport	Agriculture	TOTAL
Firewood	274.0	55.9	46.7	0.0	0.0	376.6
Charcoal	18.4	9.0	0.0	0.0	0.0	27.4
Residues	22.5	0.0	0.0	0.0	0.0	22.5
Gasoline	0.0	0.0	0.0	12.0	0.0	12.0
AV Fuel	0.0	0.0	0.0	3.7	0.0	3.7
Kerosene	2.3	0.3	0.0	0.0	0.0	2.5
Diesel	0.0	0.0	5.1	15.8	2.3	23.2
Fuel oil	0.0	0.0	1.8	0.0	0.0	1.8
LPG	0.2	0.0	0.0	0.0	0.0	0.2
Electricity	1.4	0.8	4.0	0.0	0.0	6.2
TOTAL	318.8	65.9	57.8	31.5	2.3	476.2

Traditional biomass has historically been a cheap and accessible source of fuel, especially in rural areas, and it has been the most important energy carrier in Uganda. All of the crop residues and more than 70% of the firewood are consumed by the residential sector, directly through combustion or indirectly through charcoal production. According to the Ugandan 2009/10 National Panel Survey conducted by the UBOS, most rural households (86%) use firewood while most urban households (70%) use charcoal. In Kampala 75% of the population use charcoal as their main source of fuel for cooking. In absolute quantities, the household consumption of firewood and wood for charcoal was estimated at 29.2 million tonnes in 2011. With the commercial and industrial sectors accounting for an additional 12.2 million tonnes, the total consumption of wood for the country was 41.4 million tonnes (MEMD 2011a).

Despite many activities to promote improved cookstoves, Uganda has had very little success in commercialising these stoves or having them adopted compared to neighbouring countries such as Ethiopia and Kenya (Energy for Sustainable Development Ltd. 2000). The population using biomass, firewood and charcoal as the main sources for cooking remained at around 95% from 2005 to 2010, representing over 30 million people (UBOS 2010c). Toxic fumes from open fires are causing a range of health problems such as child pneumonia, lung cancer, obstructive pulmonary disease and heart disease. About 7.8 million women and children are exposed to open fires in Uganda, and the number of deaths attributed to indoor air pollution is nearly 20,000 per year (Clough 2012). The economy is growing at 7% per year, but the population is also growing at 3.5% per year, resulting in a continuous increase in biomass demand.

4.3 Natural resources and power grid

Although Uganda does not currently produce any hydrocarbons, there has been a growing interest in oil and gas explorations. An estimated amount of 1.7 billion USD has been collectively invested in explorations in the last 15 years (Musisi 2013). Since the discovery of commercially viable oil in western Uganda near Lake Albert in 2006, the outlook of the energy sector has been drastically altered. According to Tullow Oil plc., over 1.2 billion barrels of oil equivalent at P50[6] have been discovered in the Lake Albert Rift Basin (Tullow Oil plc 2008). Oil production is expected to bring high revenues for the government with some estimates running as high as 2 billion USD annually or more than 10% of the GDP in the coming decade (OECD 2012). Major oil companies such as Total and CNOOC[7] have also joined efforts to further develop the area, and Uganda is planning to start a large-scale oil production which is expected to reach a peak of 200,000 barrels by 2020 (EIA 2013a).

Along with oil exploration, natural gas discovery has also taken place. According to the *Oil & Gas Journal,* proven natural gas reserves are in the range of 500 billion cubic feet or 14 billion cubic meters as of 1 January, 2014. Currently the government plans to use the gas for electricity generation in an attempt to reduce the frequent blackouts in the country. There is also an interest in refining natural gas into compressed natural gas (CNG) for domestic use.

[6] "P50" refers to a 50% chance of finding a given volume.

[7] China National Offshore Oil Corporation

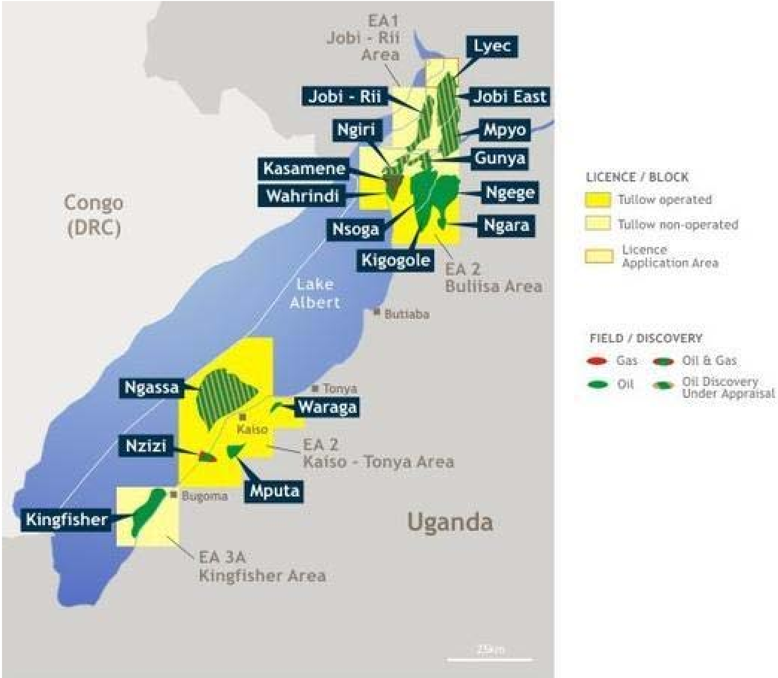

Figure 4-2. Map of oil fields around Lake Albert (Tullow Oil plc 2013)

Table 4-5. Ugandan oil and gas fields (EIA 2013a)

Field	Type	Discovery year	Operator
Gunya	Oil	2011	Total
Jobi East	Oil/Gas	2011	Total
Jobi-Rii	Oil/Gas	2008	Total
Karuka	Oil	2008	Tullow
Kasamene	Oil/Gas	2008	Tullow
Kigogole	Oil	2008	Tullow
Kingfisher	Oil	2006	CNOOC
Mputa	Oil	2006	Tullow
Mpyo	Oil	2010	Total
Ngara	Oil	2009	Tullow
Ngassa	Oil	2009	Tullow
Ngege	Oil/Gas	2008	Tullow
Ngiri	Oil/Gas	2008	Total
Nsoga	Oil	2009	Tullow
Nzizi	Oil/Gas	2006	Tullow
Taitai	Oil/Gas	2008	Tullow
Wahrindi	Oil	2009	Tullow
Waraga	Oil	2006	Tullow

The export pipeline route has not been decided yet. The government and the consortium (Total, Tullow, and CNOOC) are currently surveying three possible routes: via Kenya's Mombasa terminal, via Kenya's Lamu terminal, and via Tanzania's Dar es Salaam port.

Past global experience indicates that wealth from natural resources could lead to higher probability of: corruption; poverty, and instability and conflict in presence of weak institutions (Sachs et al. 1995, Ross 2001, Collier et al. 2005). An establishment of an institutional framework that ensures a fair and equitable distribution of resource wealth with an appropriate consideration given to all aspects of social economics will be extremely important to make the oil wealth a blessing for the country as a whole (World Bank 2012c).

Power grid of Uganda has some of the lowest access rates to electricity in the world, which stood at 12.1% in 2010 (UBOS 2010c). This means 4 million people had access to electricity compared to 30 million without access in the country. The situation is extremely severe in rural areas, where only 3.8% have access, and even in the regions surrounding Kampala the rate stood at only 67.4%. The low electrification rate in the rural areas is being handled by the Ministry of Energy and Mineral Development. The Ministry's publication "Rural Electrification Strategy and Plan Covering the Period 2001 to 2010" declared to address the issue, including considerations of off-grid solutions. The minimum aim for the Rural Electrification Strategy and Plan is to increase the connections to 10% by 2012, the equivalent of 400,000 new rural consumers.

Some NGOs, such as Heifer Project International, Adventist and Relief Agencies, have been promoting the use of biogas in Uganda (Walekhwa et al. 2009). Biogas technology can convert biological wastes, such as cow manure and elephant wastes, into energy, providing a sustainable source of power in some regions. The population and housing census of 2002 estimates there to be about 6 million cattle in Uganda. Based on this, the theoretical potential of biogas could be one billion m^3 per year or the equivalent of a 1000 megawatts (MW) power plant (Pandey et al. 2007).

The decreasing water level of Lake Victoria and a disruptive civil war have had major implications on Ugandan power supply shortages. The declining water levels of Lake Victoria caused hydropower plants to operate below capacity, and a severe drought in the mid-2000s caused major power supply shortages throughout Uganda.

The government has made efforts to deal with the situation, starting with a power sector reform in 1999. The Uganda Electricity Board (UEB) was unbundled, and an independent regulator, the Electricity Regulatory Authority (ERA), was established. However, more than a decade of reforms have still not solved many of the issues, as poor reliability and the high price still cripple many businesses (Mawejje et al. 2012). In 2010 the total distribution loss was still alarmingly high at roughly 30%, which ERA hopes to bring down to 13.25% by 2018 (Parsons Brinckerhoff Ltd 2011).

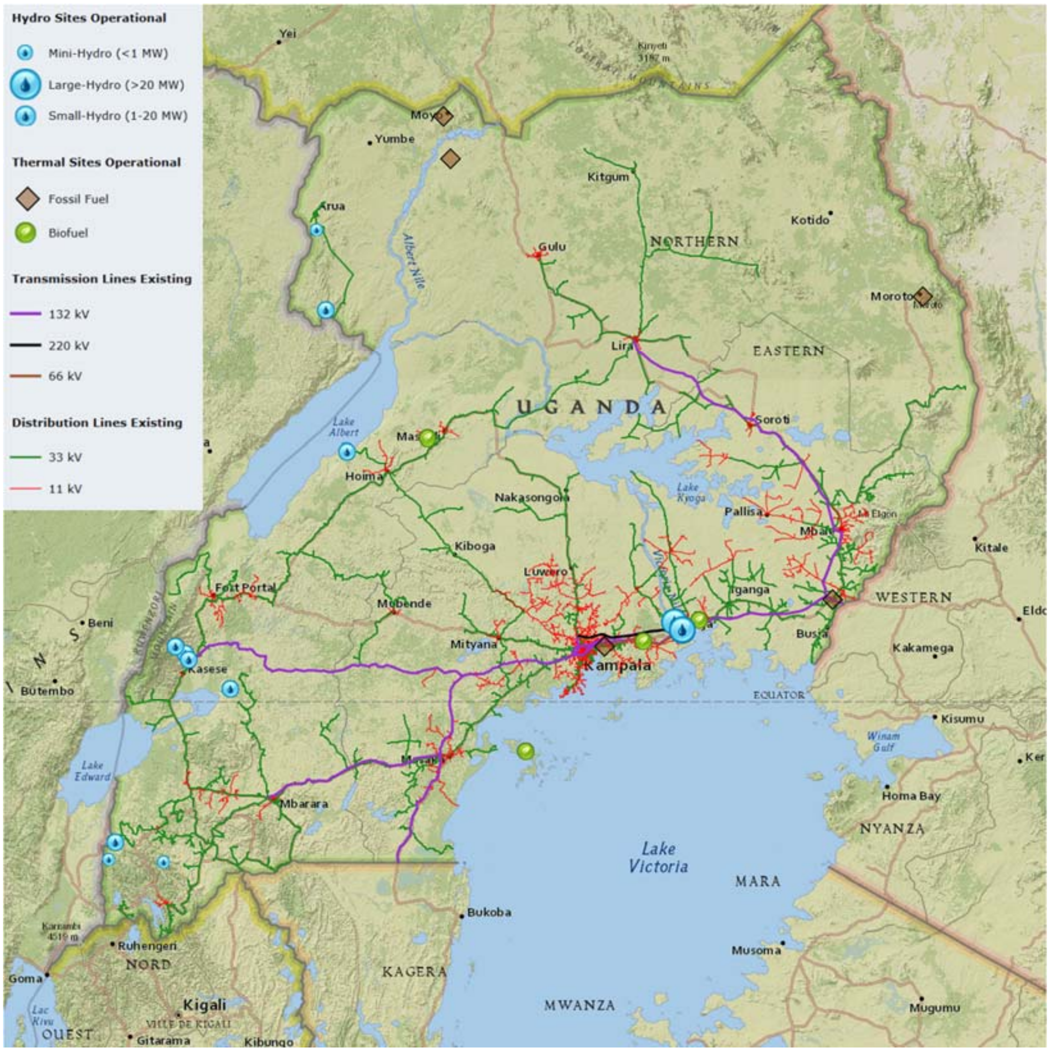

Figure 4-3. Electricity Grid in Uganda as of 2013
(Energy Sector GIS Working Group 2013)

With the completion of Bujagali hydropower in October 2012, the total installed electric power generation capacity was increased to 692 MW (Baanabe 2012). The three main hydropower plants, all located on the White Nile, make up more than 90% of the capacity (Bujagali 25 0MW, Kiira 200 MW, Nalubale 180 MW). The Government of Uganda is planning further large-scale hydroelectric plant expansions to fight the shortage of power, which includes the 600 MW Karuma plant scheduled to come online in 2018 (Kasita 2013). Other large hydropower projects on the way, with international assistance, are Isimba and Ayago. Preliminary geological data collection and transmission line feasibility study for Isimba, which has a potential of about 140 MW, were being carried out by the consultant, Fitchner, from Germany (MEMD 2011a). Ayago, which will be built downstream of Karuma power station, had its prefeasibility study completed by the Japanese government and is scheduled to be built by China Gezhouba Group.

4.4 Biomass use and environment

According to the energy balances published by the Ministry of Energy and Mineral Development (MEMD), the share of biomass in primary energy was 89.6% in 2011. Considering that biomass only supplies 50% of Africa's energy, the situation in Uganda is extremely severe even among the African countries. The per capita consumption of woodfuel is decreasing in Uganda along with the nation's economic development (Figure 4-4). Even then, the per capita consumption is still one of the highest in Africa, consuming more than the sub-Saharan average. The absolute amount has continued to increase since the 1960's (Table 4-6) reaching close to 40 million m^3 per year or almost twice the production compared to 1970.

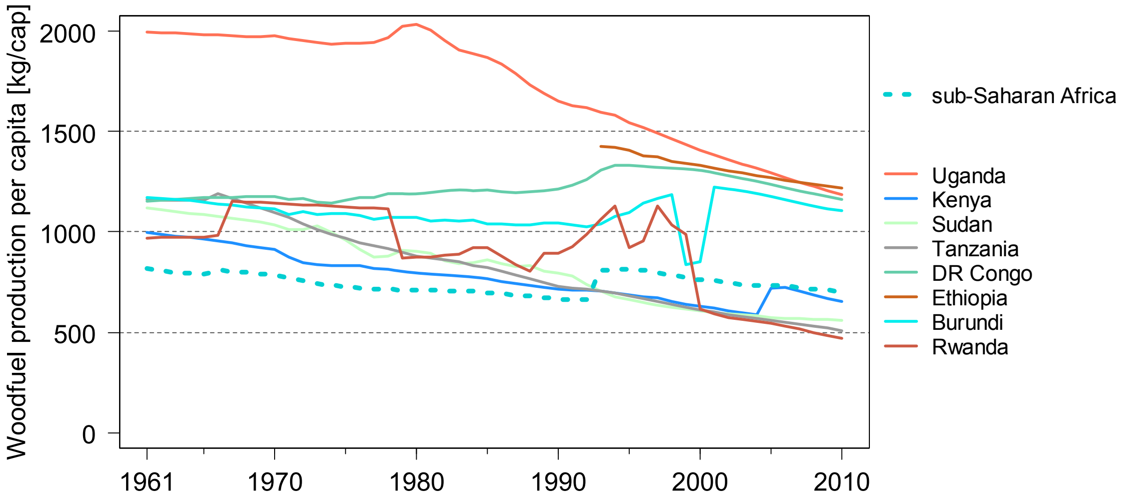

Figure 4-4. Woodfuel production per capita in Uganda and selected countries in sub-Saharan Africa from 1961-2010 (FAO 2013, World Bank 2013)

Table 4-6. Woodfuel production in selected sub-Saharan African countries (FAO 2013)

[million m^3]	1961	1970	1980	1990	2000	2010
Sudan	9.6	11.3	13.6	16.3	16.7	18.8
Tanzania	12.0	14.9	16.5	18.6	20.8	22.8
Kenya	8.3	10.3	12.9	16.8	19.7	26.4
Ghana	6.3	7.8	9.6	12.9	26.7	37.8
Uganda	14.0	18.7	25.8	29.3	34.1	39.6
Nigeria	36.2	38.9	42.2	50.9	59.3	63.2
DR Congo	18.2	23.9	32.2	44.2	64.9	76.6
Ethiopia	NA	NA	NA	NA	87.5	101.3
Sub-Saharan Africa	196.2	234.6	278.0	344.0	510.4	597.4

The high dependency on biomass is raising concerns about the sustainability of the resource, as the demand continues to increase while the supply, the forested areas, continues to decline. The natural forest cover consisting of tropical high forests, woodlands, and forest plantations had declined drastically between 1950 and 1990, from 13.2 to 4.9 million hectares, according to a biomass study in Uganda conducted in

1990. This represents a 63% loss in forest cover over the course of four decades (NEMA 2005). The trend of deforestation has continued after the study. In 2010, the forest cover was estimated to be 2.9 million hectares, representing an additional 40% loss of forest cover in just two decades (FAO 2011). From 2000-2010 the forest area in Uganda decreased at an annual rate of -2.6%, more than double the average rate of -1.0% in East Africa (FAO 2011). Most of it occurs on private or communally held forestland, which is nearly 70% of Uganda's forest cover. Public forestland—the permanent forest estate—accounts for 30% (World Bank 2012c). If the deforestation is to be slowed down, actions need to be taken to have a more sustainable biomass use on private land.

The continuously rising demand for biomass, coupled with unsustainable harvesting practices and poor forest management, has put Uganda on the brink of a biomass crisis (Ferguson 2012). With a rapid population growth rate of roughly 3.5% per year, the fifth-highest in the world in 2012 (World Bank 2013), the ongoing pressure on the forest resources will be aggravated. Unsustainable harvesting of trees for energy use is a major contributor to the degradation of Ugandan forests and woodlots. The National Forestry Authority of Uganda estimated that 59.4% of round timber produced was used for household wood fuel and an additional 20% was used for charcoal production in 2007 (UBOS 2010a). Since roughly 70% of the charcoal is consumed by the residential sector, this makes the residential sector responsible for 73.4% of the round timber consumption, as shown in Figure 4-5.

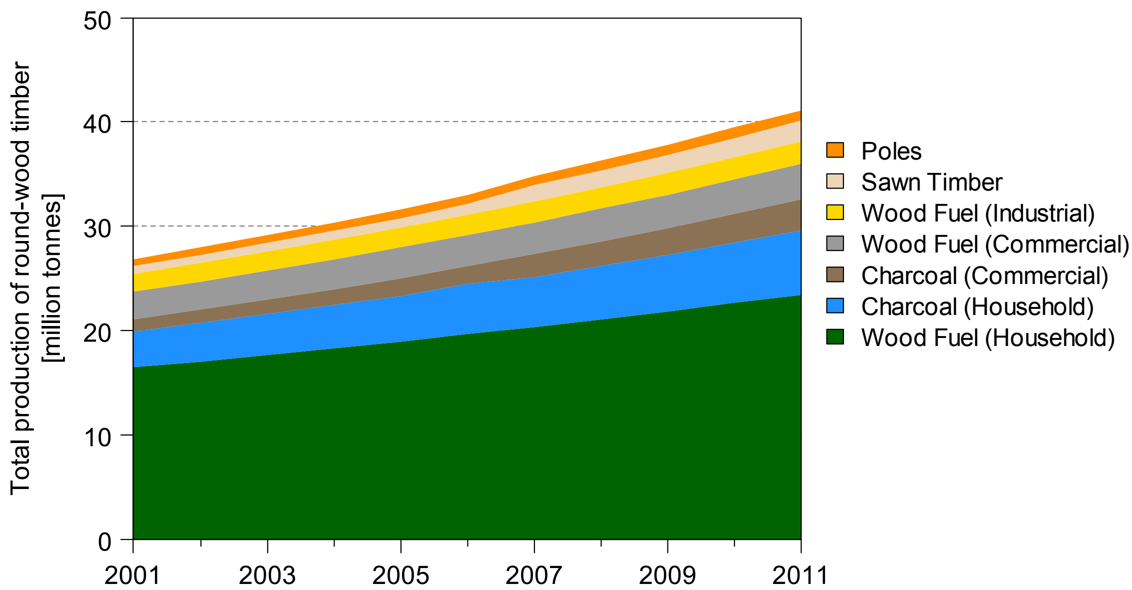

Figure 4-5. Total production of round-wood timber by purpose in Uganda, 2001-2011 (UBOS 2006a, UBOS 2010a, MEMD 2011a)

4.5 Cooking fuels in Uganda

The main energy services in the residential sector in Uganda are for cooking. Cooking demand comprises the highest share of residential demands. Cooking is a task carried out every day and is typically a task performed by women in Uganda. The cooking energy supply sources differ significantly between rural and urban areas. Both areas still use mainly solid fuels, but urban areas rely highly on charcoal while rural areas rely heavily on firewood as their source of energy, as shown in Figure 3-1. The situation is slightly better in Kampala, where about 12% of the people use the clean cooking fuel of LPG as the main energy source. However, the situation is still far from achieving universal access, as the overwhelming majority still use charcoal to meet their cooking demand.

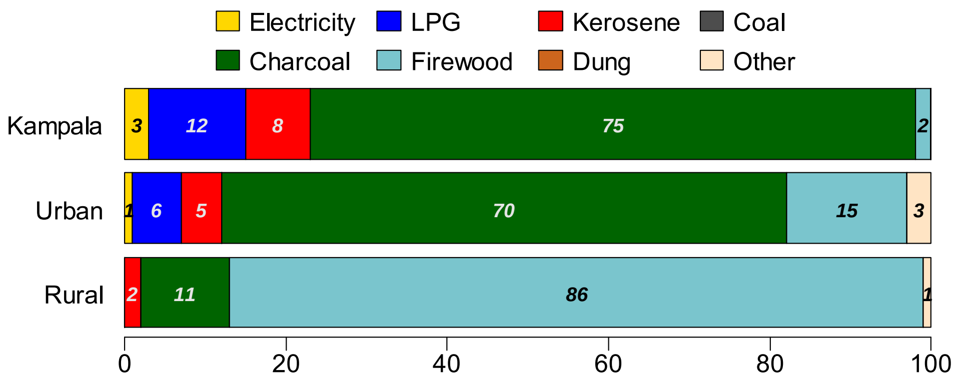

Figure 4-6. Shares of households relying on different types of cooking fuels in rural and urban areas in Uganda (Legros et al. 2009, UBOS 2010c)

The use of modern fuels for cooking, kerosene, LPG and electricity, is very limited and has been growing at a slow pace. Kerosene, although available in most places and used for lighting, is only used by a few groups for cooking. It is hardly used in rural areas and the use is less than 5% in urban areas. LPG use has also stayed at a low percentage. Even in Kampala, LPG users are around 12% (UBOS 2010c). One of the reasons for the low usage rate is infrastructural problems. Being a landlocked country with a limited pipeline access, Uganda suffers from frequent LPG shortages. In late 2008 and early 2009 disruptions in the supply chain from Kenya caused shortages of LPG. With some shops running out of supply, prices of charcoal also increased, harming not only LPG users but also charcoal users (Matthews 2014).

In Uganda, it is still not a common practice to use electricity for cooking, and many are sceptical about cooking without fire. Uganda has one of the lowest electrification rates as a nation at 12.1% according to the national household survey of 2009/2010 (UBOS 2010c). Although the overall electrification rate has increased from 10.5% in 2005/06, the electrification rate in rural areas actually decreased from 4.0% in 2005/06 to 3.8% in 2009/10, suggesting that population growth outpaced electrification rate. Even in

Kampala the rate stood at 67.4%, meaning roughly only two third of the city had electricity.

Biogas is another possible fuel source for cooking, but it is hardly used in Uganda. Although the national household survey lists biogas as a possible primary fuel used for cooking, no household answered biogas to be its main fuel in the 2005/06 survey. When the biogas system is not available, typically residue is simply burnt just like firewood. In Uganda the primary energy supply of residue was about 26.6 PJ or just about the same amount as diesel (24.4 PJ) in 2011. Schlag et al. (2008) report that Uganda also faces locational problems to supply a system, such as a lack of animals, nomadic grazing practice that depletes organic material and the inadequate water supply.

4.5.1 Cooking technology choice among different consumer groups

Financial situation is one of the key deciding factors in the choice of cooking technologies. Figure 4-7 shows the final energy use for cooking for 10 different expenditure groups [8]. The groups are expenditure quintiles of rural and urban, respectively. With an increasing purchasing power, the use of charcoal increases in both rural and urban areas. The increase is more significantly observed in urban areas, where charcoal supplies more than 80% of cooking energy. In rural areas, the use of collected firewood increases until R4, but starts to decrease starting at R5. Observing that other fuels such as charcoal and purchased firewood increase as well, there is a tipping point where consumers start to feel the opportunity cost of collecting biomass is more than cost of purchasing firewood or charcoal. In a similar manner, the use of LPG for cooking in U5, although at a small amount, shows that the value of convenience and cleanliness of LPG becomes high enough that the high cost of LPG becomes acceptable. The use of LPG is likely to increase with economic growth, as observed in other sub-Saharan countries.

[8] Expenditure is used as a proxy for income as there is a cultural sensitivity about disclosing income in Uganda. By assuming the savings rate is proportional to income, expenditure reflects the purchasing power of households.

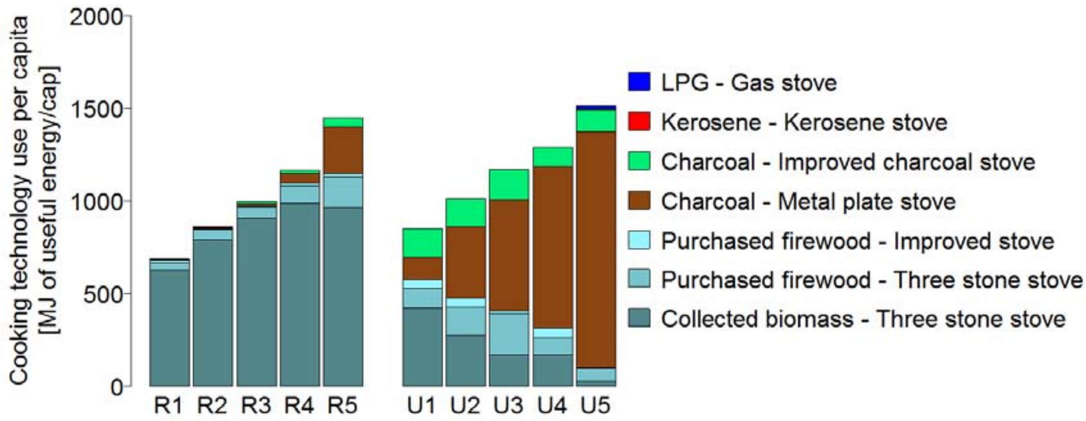

Figure 4-7. Useful energy for cooking by quintile in Uganda in 2005

The average yearly expenditures (used as a proxy for purchasing power or income) of households by regions and primary cooking stoves are shown in Table 4-7. Gas stove users have the highest household expenditure rate, followed by the traditional metal plate stove users. There is a tendency for the improved firewood stove users to have a higher household expenditure rate than the three stone stove users, showing the preference for improved stoves as purchasing power increases. However, the relationship is not the same for charcoal. The metal plate stove users, rather than the improved charcoal stove users, had a higher expenditure rate, showing that improved charcoal stoves do not become preferred as the purchasing power increases. This phenomenon is likely observed due to cultural preferences and the limited availability of improved charcoal stoves. Table 4-8 shows the primary stoves used by households in four regions. The most common cooking stoves used are the traditional three stone stoves in all regions. The share of traditional metal plate stoves is higher in the central region due to the preference of urban consumers to use charcoal. The primary stoves used by region differ most significantly in the Northern regions. Beyond income differences, the use of both improved firewood and charcoal stoves is much higher in the Northern regions than the rest, reaching 10% or more in both improved firewood and improved charcoal stoves. This is partially due to some international efforts to educate and improve the cooking situation in the North after the civil conflict. However, according to UBOS (2010b) the share of improved stoves in the Northern regions is on a decline, decreasing by 6.7% between 2004-2009.

Table 4-7. Average household expenditure per year by regions and primary cooking stoves

[2005USD per household, in ppp]

	Central	Eastern	Northern	Western
Traditional three stone stove	3,596	2,752	1,656	3,162
Improved firewood stove	4,137	3,056	1,588	4,416
Metal plate stove	6,322	5,351	4,474	4,517
Improved charcoal stove	4,949	2,798	3,698	5,961
Kerosene stove	3,959	2,479	1,891	2,735
Gas stove	16,515	-	-	17,103

Table 4-8. Primary stoves used by households in four regions

	Central		Eastern		Northern		Western		TOTAL	
Traditional three stone stove	1,272	65.6%	1,410	78.4%	1,096	70.4%	1,360	82.7%	5,138	74.1%
Improved firewood stove	42	2.2%	44	2.4%	235	15.1%	77	4.7%	398	5.7%
Metal plate stove	522	26.9%	318	17.7%	63	4.0%	175	10.6%	1,078	15.5%
Improved charcoal stove	79	4.1%	19	1.1%	161	10.3%	24	1.5%	283	4.1%
Kerosene stove	21	1.1%	7	0.4%	1	0.1%	7	0.4%	36	0.5%
Gas stove	4	0.2%	0	0.0%	0	0.0%	1	0.1%	5	0.1%
TOTAL	1,940	100%	1,798	100%	1,556	100%	1,644	100%	6,938	100%

Financial situation is one of the deciding factors, but available infrastructure, access to certain fuels, or cultural preference can also have an effect on fuels used. In order to test this hypothesis, energy use in rural and urban areas is divided into groups by common expenditure definitions. Figure 4-8 shows energy use by six expenditure groups, three groups each for rural and urban. R1 and U1 represent households with per capita expenditure of less than 1.25 USD per day, R2 and U2 are between 1.25-4.00 USD per day, and R3 and U3 represent households with over 4.00 USD per day in expenditure.

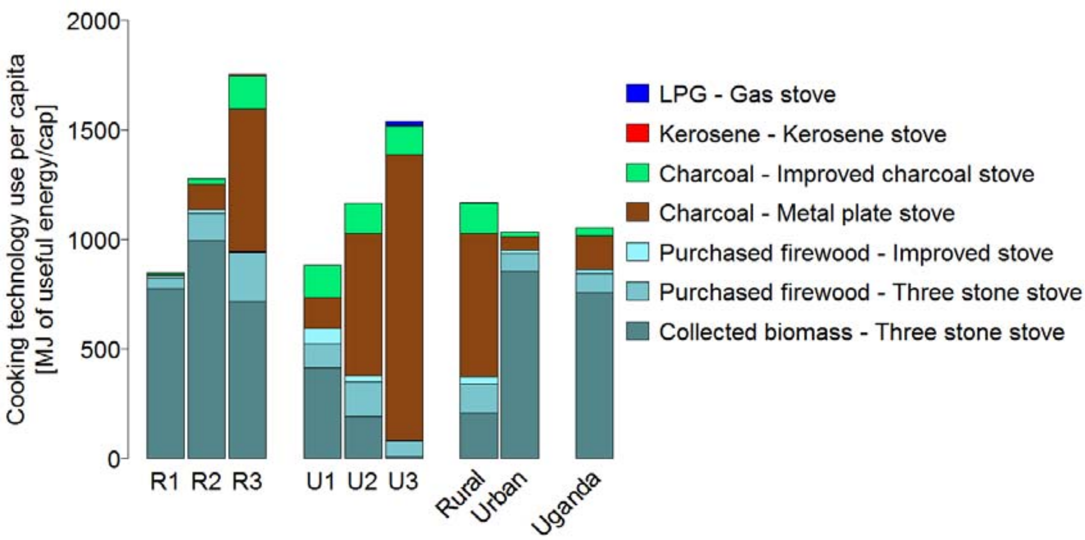

Figure 4-8. Final energy use for cooking by different household groups in Uganda

The result shows quite a difference in fuels used despite having the same expenditure levels. Collected firewood contributes much more in rural areas, as firewood is more readily available in rural areas and consequently its collection much easier. In the lowest expenditure group, 30% of firewood is purchased in urban areas but only 7.5% is purchased in rural areas. A transition to charcoal also occurs at a much quicker stage in urban areas because the opportunity cost to collect firewood is much higher in urban areas. Compared to U1 there is a switch to charcoal in U2, but R2 shows a continuous use of firewood and an increase in collected firewood. The price difference in charcoal between rural and urban can explain a part of the difference, but the strong preference to use charcoal in densely populated urban areas contribute greatly to the big difference despite having the same income levels. Due to the extremely low consumption it is not easy to observe, but the lack of infrastructure, such as roads and pipelines, should also affect penetration rates of modern fuels. LPG requires a distribution network, which could take years before rural areas can have a reliable supply of the fuel.

There is a fuel price discrepancy between rural and urban. Charcoal and kerosene are both available in rural and urban areas, but prices differ significantly between the two areas. Charcoal is more expensive in urban areas, by as much as 28% in eastern Uganda. The only region with a higher price in rural areas is the western region. Much of the produced charcoal is delivered to urban centres before being transported to Kampala. Due to the collection of charcoal in urban areas of the region, the price is lower in the urban centres of western Uganda. The kerosene price is higher in rural areas due to cost of transportation and average quantity purchased. The Oil products are first delivered to urban areas where they are consumed and stored. Because of the dense population of urban centres, it is more efficiently purchased there compared to rural areas. Although lighting creates demand for kerosene in rural areas, quantity per purchase or payment is lower in rural areas compared to urban areas. The lack bulk purchase discounts also contributes to the price in rural areas being higher than in urban areas.

Table 4-9. Charcoal and kerosene prices by regions

		Central	Eastern	Northern	Western
Charcoal	Urban	0.090	0.113	0.108	0.066
[USD/kg]	Rural	0.075	0.088	0.097	0.087
Kerosene	Urban	1.44	1.75	2.00	1.16
[USD/L]	Rural	1.65	1.82	2.19	1.35

4.5.2 Firewood collection

According to a survey study carried out in Bulamogi County, Uganda, the desirable attributes of firewood include hot flames, long-lasting embers, and easiness to split and ignite (Tabuti et al. 2003). Similar qualitative characteristics were also preferred in firewood in Kalisizo sub-county in Uganda and Malawi (Abbot et al. 1999, Agea et al.

2010). Popular species of trees and shrubs that were mentioned in studies carried out in Uganda include Acacia, Milicia Excesla, Sesbania Sesban and Eucalyptus, to name a few (Tabuti et al. 2003, Agea et al. 2010). Other than the burning characteristics, other criteria such as religion and culture beliefs could hinder the use of particular species. For example in Bulamogi, the use of *Hymenocardiaceae* is reserved for religious rites, and *Senna bicapsularis* is avoided for its unpleasant smell and the belief that it causes death of poultry (Tabuti et al. 2003). Firewood collection is normally carried out by women, sometimes as a group activity. It is not uncommon for a woman to travel more than 5 km and spend 4 hours for firewood collection. Most people prefer small diameter pieces of firewood as they are light, easy to carry and cut.

The availability of firewood in the environment also has an impact in the amount of time spent collecting firewood. Figure 4-9 shows the regional differences in rural areas among same the income groups. The population in the western region spend the most time collecting firewood among the four regions.

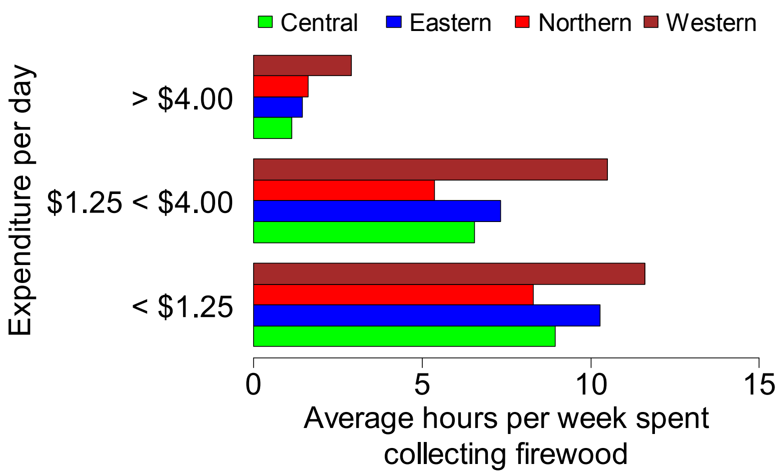

Figure 4-9. Average hours per week spent collecting firewood by regions in rural areas of Uganda

Different patterns in firewood consumption are also observed from the amount of time spent collecting firewood (Table 4-10). In R1 a household spends nearly 10 hours per week collecting firewood on average but U1 with the same income level spends only 5.6 hours per week. The increase in the collection rate shows a rising opportunity cost for firewood collection as income grows. The collection rate also supports the rising opportunity cost. In both rural and urban, the lowest income group collects around 5.5 kg per hour. In R2 the rate goes up to 7.4 kg and in U2 the rate is even higher at 9.7 kg per hour.

Table 4-10. Average hours spent collecting firewood and consumption of firewood by expenditure groups

Expenditure Group	Weekly Average per household		
	Hours spent on collecting firewood	kg consumption of collected firewood	kg consumption of purchased firewood
R1	9.74	53.6	4.0
R2	8.00	59.4	8.0
R3	1.46	27.1	8.6
U1	5.56	31.4	11.0
U2	1.24	12.0	10.8
U3	0.29	0.5	3.0

4.5.3 Charcoal economy and production

UBOS estimates that the nominal value of household charcoal consumption was about 230 million USD in 2010, a drastic increase from 2005, caused by the increase in the value of firewood and charcoal during the time period (UBOS 2013). It is common for rural areas to rely on charcoal for income. A study of charcoal in Malawi estimates the value of the charcoal industry in the four largest urban areas of Malawi to be over 40 million USD, which would be 0.5% of the country's GDP and comparable to Malawi's tea industry (Kambewa et al. 2007). In Kenya the charcoal industry generates over 400 million USD and supports 2 million people along the value chain (Njenga et al. 2013).

Charcoal trade represents one of the largest domestic industries, and it plays a crucial income generation role in rural areas of Uganda. The charcoal industry mainly involves four stages: production, transportation, retail and consumption. The chain starts with production, which takes place typically on rural land. After charcoal is cooled it is collected into a bag with an average weight of 50-60 kg. The bag is taken to the nearest collection point, where the transporter pays the producer and takes charcoal into city centres (Basu et al. 2013).

The most commonly used method to produce charcoal in Uganda is earth kilns, which has low conversion efficiencies in the range of 10-15% by weight (MEMD 2012). A charcoal production study by Khundi et al. (2011) in three districts of Uganda shows that charcoal production is carried out in all income levels and that participation in charcoal production correlated with a higher income and lower levels of poverty. Major charcoal producing regions include mid-western, central and northern districts of Uganda (Namaalwa et al. 2009). These districts are characterised by woodland vegetation, and they have been the main source of charcoal for years. Kampala consumes roughly about half of the charcoal produced in the country, and Namaalwa et al. (2009) estimate that districts of Luweero, Nakasongola, Masindi and southern Apac contribute to about half of the charcoal consumption in Kampala. The main tree species used for production are Combretum, Terminalia, Albizia, Acacia, Allophylus and Grewia spp (Shively et al. 2010).

Charcoal production for many is one of the few income generating activities available in the region. A study by Khundi et al. (2011) uses data from 284 households from the 2007-2008 agricultural season to evaluate the role of charcoal production in 12 villages of Uganda. Results show that charcoal producers have a significantly higher total and per adult income than non-producers. This is contrary to popular belief that charcoal production is mainly for the poor. In western and central regions of Uganda, it was practiced by all income levels for extra cash. The study concludes that in their sample group, involvement in charcoal production increases the annual income by approximately 122 USD per adult and reduces poverty by 14%.

The cooking fuel most popular in urban areas is charcoal due to its energy density, clean burn and the ease of storage and transportation. Unlike the consumption of firewood, which decreases with increasing income, charcoal consumption grows with the rise in wealth. Even in rural areas, high-income groups prefer to replace firewood with charcoal for cooking. The consumption of charcoal continues to grow, reaching close to one million tonnes in 2010 as seen in Figure 4-10. Charcoal is available in most areas and faces much less shortages than LPG. It is also the preferred cooking fuel for traditional foods such as steamed *matooke*, green bananas, making even the high-income groups to continue using charcoal (Lee 2013).

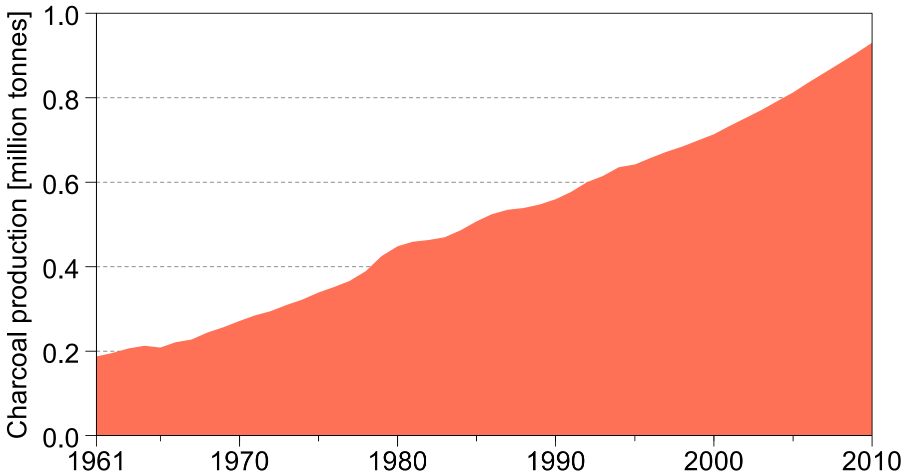

Figure 4-10. Charcoal production in Uganda from 1961-2010 (FAO 2013)

4.6 International efforts and outlook of improved cookstoves

Due to concerns over deforestation, improved cookstoves came into political agenda in the 1980s. The Ministry of Energy, joined with NGOs, formulated a wood conservation strategy by proposing a target of 2.45 million improved stoves to be installed in Uganda by the year 2000 (Marwick 1987). However, the government could not achieve the target because of technology limitations and a lack of resources (Global Village Energy Partnership et al. 2012a).

There are two prominent improved cook stove businesses in Uganda. The largest is UgaStove, who has been in the market since 1994, and the second is the International Lifeline Fund (Global Village Energy Partnership et al. 2012b). Both businesses have been facing difficulties in gaining people's acceptance of their products despite much help from NGOs. At the end of 2006 the use of 8224 improved charcoal stoves was reported in and around Kampala (Habermehl 2007), and according to the GIZ-PREEEP (2012) reporting, about 400,000 households had adopted the improved firewood stoves as of 2012. There have been many attempts to introduce improved cookstoves in Uganda, but success has generally been limited.

A study by Energy for Sustainable Development Limited has shown that Uganda shows a peculiar pattern to the acceptance of improved stoves (Energy for Sustainable Development Ltd. 2000). The study compares how improved stoves were adopted in three countries, Kenya, Ethiopia and Uganda. What they found was that Uganda's high-income households found the stoves to be something for the poor, and most of the acceptance happened in the low-income groups. For example, in a survey for 100 households in four income categories, none of the households in the highest income group owned a fuel efficient charcoal stove, but 95% of them owned unimproved or metal plate stoves. Most users would have had economic incentives to switch, but many resisted because of a cultural or an educational barrier to accepting the stoves. Since the adaptation only occurred in the low-income groups with low economic incentives, the success of the improved stoves has been limited. For the improved stoves to be a success in Uganda, there needs to be a more strategic implementation of the stoves, including educating the users about the benefits, as was the case in Kenya and Ethiopia.

Improved cookstoves installed in Uganda can be categorised into household cookstoves and institutional cookstoves depending on their size and purpose (CREEC 2011). The household ones are typically smaller and requires no major installation. Institutional cookstoves are typically fixed and are not easily moved. Both offer similar advantages in that they increase heating efficiencies, requiring less firewood use, and also reduces smoke in the kitchen, offering a healthier cooking environment. Common complaints expressed towards the use of improved stoves are difficulty in reloading additional firewood from a smaller opening (especially the top-lit updraft gasifier or TLUD or mwoto) and a high upfront cost.

The Global Alliance for Clean Cookstoves (GACC) plans to promote 100 million clean cookstoves by 2020, and they have chosen Uganda as one of the countries of focus. Past experience shows many challenges ahead. The adaptation of improved cookstoves has stagnated at around 8.4% from 2005-2009 (Global Village Energy Partnership et al. 2012a). The problems of the low acceptance rate among the high-income groups and the lack of education must be overcome in order for the programme to be successful.

Figure 4-11. Mwoto cookstove (left) (CREEC 2012) and UgaStove stoves (right) being locally made (Aljazeera 2013)

Chapter 5. Cooking Technology Choice Model

This chapter introduces a cooking technology choice model, which evaluates fuel and stove choices of heterogeneous consumers based on demand curves that reflect consumer preferences. Before going into the details of the model, it will first look at the historical development of energy models and classifies models according to their characteristics. Then, it will focus on the cooking models in particular, and how the new model fits within the modelling community.

5.1 Energy models and cooking models

5.1.1 Development of energy models

The use of energy plays a major role in stimulating economy worldwide, and it is a vital component in the formulation of regional, national and international policies (Hoffman et al. 1976). The importance of energy in policymaking became apparent in the early 1970s, and the research and development in the field of energy modelling started to grow rapidly. The improvement in energy infrastructure allows easier access to modern forms of energy, and many countries experienced economic growth in connection with a wider use of energy services. Today, energy models play an important role in providing quantitative analysis for national and international policy formulation.

Hoffman et al. (1976) advises that initial work in energy modelling involved development of energy balances using fuel consumption forecasts. For countries relying on imported fuels, it is an energy supply security issue to analyse and understand the effect of a supply interruption and the possibility of interfuel substitution. The high oil prices in the 1970s led to a number of energy modelling for strategic planning. A Model for Energy Supply System Alternatives and their General Environmental Impact (MESSAGE) is an example of such model developed by the International Institute for Applied Systems Analysis (IIASA). MESSAGE was developed to analyse long-term energy problems arising from a reliance on fossil fuel based resources. The model was designed to analyse and evaluate regional and global energy strategies for the next 15 to 50 years, incorporating macroeconomic parameters (Agnew et al. 1979) and energy demand model MEDEE-2 (Lapillonne et al. 1981, Schrattenholzer 1981) in addition to energy parameters. Another early pioneer model developed in the late 1970s was the MARKAL (MARket ALlocation) model by Brookhaven National Laboratory in the USA. The model was later adopted by the International Energy Agency (IEA) and led to the creation of the Energy Technology and Systems Analysis Program (ETSAP). Another international organisation, the International Atomic Energy Agency (IAEA), also developed a similar model called Wien Automatic System Planning (WASP) in 1978, which was designed to analyse long-term plans for the electricity sector using optimisation methods (IAEA 2001).

Another type of a model introduced in the early 1970s was an integrated assessment model (IAM). IAM combines multiple academic disciplines and includes scientific and socio-economic aspects within one model. Club of Rome was one of the first pioneers of such a model, and Meadows (1972) presented a system dynamics model, World3, which was designed to evaluate global environmental change. World3's objective was to understand and simulate long-term interactions of comprehensive physical components on the earth and their growths over time, for example interactions between economic growth and resource, food and population. One of the key messages that came out of the model analysis was that if the expansion of population and materials economy continued, the growth would exceed planet earth's capacity and cause it to collapse. World3 paved an important path for future IAMs, as it was the first of its kind, and also analysed global environmental issues before it became a hot global topic.

As the oil crises passed and the oil market became stable, the focus of energy models expanded beyond energy balances to include environmental problems (Yi-Ming Wei 2006, Bhattacharyya et al. 2010). The idea of using models to analyse possible pathways regarding the environment received a strong push during the last decades, as the computational power rapidly increased. With a spread of personal computers and the internet, data could be easily created in many locations and exchanged with much ease. This has led to creations of much heavier or larger models, which included much more detailed data on the economy, energy and environment.

The larger models were broader, in terms of spatial coverage, and longer, in terms of calculated periods. In the 1990s, the interaction between energy and climate change became a hot topic and pushed energy models to expand even further both in spatial coverage and calculated periods. Since climate related impacts occur across many sectors globally, the effort to expand country models to regional or global scales became necessary. During the 1990s, a number of new regional models came into existence, such as Asian-Pacific Integrated Model (AIM) (AIM Project Team 1997), Regional Air Pollution Information and Simulation (RAINS) (Amann et al. 2004) and POLES (II-EPE 2006). Since the main focus of the climate change research is the global temperature in the year 2100, energy models needed to be expanded to cover a time period of over a century. Faced with immense global challenges associated with reaching a climate target, it also became vital that a set of knowledge from broad disciplines be synthesised for a more broadly informed decision making on global climate issues (Weyant et al. 1996). This movement led energy models such as MESSAGE and Dynamic New Earth 21 (DNE21) (Akimoto et al. 2004) to further develop energy models into IAMs. The energy models started to put a strong focus on how the energy sector interacts with economy and environment. The growing importance and need for energy model analyses were highlighted in 2000, when the Intergovernmental Panel on Climate Change (IPCC) published the Special Report on Emission Scenarios (SRES) (Nakicenovic et al. 2000). The report used six global energy models to analyse emission pathway scenarios, which were used by policymakers all over the world to make decisions on climate change policies and international agreements on emissions reductions.

The main use of energy models today is to explore and understand a development path for the global energy system, which strikes a good balance between environmental and economic sustainability. The use of energy is a key factor in sustainability problems such as depletion of fossil fuels, air pollution and climate change. The energy models are extremely useful to evaluate the pros and cons of different development paths of energy systems to maintain sustainability in environment and economy, and the models play a key role in policymaking including international agreements such as emissions targets.

5.1.2 Energy models and developing countries

In the past, global energy use was dominated by OECD countries, and the majority of the global energy models were developed in industrialised countries. Therefore, the models assumed full access to modern forms of energy and services and did not contain the typical situation of budget limits to purchasing these fuels in developing countries. Energy models have made a great leap since the 1970s, but they still have a major problem that the models tend to focus on the issues that primarily pertain to industrialised countries. For example, the analysis by SRES contributed greatly to exploring future pathways for greenhouse gas emissions, but all of the modelling teams in SRES were from industrialised countries (AIM-Japan, IMAGE-the Netherlands, MARIA-Japan, MESSAGE-Austria, MiniCAM-USA). However, if a model developed in industrialised countries are simply applied to developing countries, the model implicitly assumes that the energy market of developing countries, including residential, behaves in a similar manner as in the industrialised countries. Pandey (2002) has criticised this point stating that the models need to include characteristics specific to the culture, such as social and economic barriers along with technological status, and models based on industrialised situations cannot be used for policy analysis for developing countries. In order to make such analysis, Shukla (1995) points out the importance of including in the analysis the informal sector and the restrictive trade regulations and barriers that often exist in government monopolies.

However, the tide is turning, as energy use among the world's poorer countries has been increasing at a rapid rate in recent years. The share of the total primary energy demand by non-OECD countries reached 58% in 2011, and their share is projected to increase further in the coming decades (IEA 2013). The situation regarding the energy related CO_2 emissions is similar. Emissions are expected to grow in developing countries, while the emissions from OECD countries are expected to decrease in the coming decades (IEA 2013). The impact of energy choices made by developing countries is becoming increasingly important. They will play a major role in combating climate change, and developing energy models that can reflect social and economic barriers of developing countries is a crucial next step in the modelling community.

5.1.3 Energy model classifications

This section provides an overview and an insight of the differences and similarities between energy models by categorising energy models in existence. The difficulty in classifying is that there are many ways of characterising models. For example, a model can be classified according to its purpose (forecasting, backcasting, demand/supply analysis, etc.) or its structure (assumption, endogenous and exogenous variables) (van Beeck 1999). Another difficulty is that most models fit into more than one distinct category. As explained earlier in the chapter, the models may keep expanding to continue handling multiple emerging issues or may have a complex structure that cannot be neatly categorised. Over time, various classification schemes have been proposed, but there are still no definite ways to classify energy models.

The analytical approach, bottom-up and top-down models, is one common, crude way to classify energy models. The main distinctions between the two modelling approaches are treatment of technology adoption, decision-making behaviour and representation of markets. Bottom-up models, sometimes called the engineering approach, refer normally to a technology detailed model, which chooses the best combinations of technologies to satisfy the given demand. Models typically focus on the energy sector exclusively and do not account for economic feedbacks. The current and future costs of technologies are exogenously given, and microeconomic decision making processes or macroeconomic parameters of labour or change in demand are not reflected in the model. Bottom-up models are extremely useful in illustrating possible technological pathways on supply and demand sides. Examples of bottom-up modes are LEAP (Heaps 2008), MEDEE (Lapillonne et al. 1981), MARKAL (Loulou et al. 2004) and MESSAGE (Messner et al. 1995). On the other hand, top-down models focus on the macroeconomic structure, and the details are given to describe supply and demand relationships along with behavioural parameters. The future behaviour characteristics are constructed based on historical development patterns and relationships, so a change over time is often smoother compared to bottom-up models. The aggregate of technologies is represented as one parameter in the models, and the details of technologies are often not provided. The top-down models are valuable in understanding the consequences that policies can have on economic variables such as demand, employment and public finances. Examples of top-down models are ETA-MACRO (Manne 1977), DICE (Nordhaus 1993) and RICE (Nordhaus 2010). In recent years, a new approach of hybrid models has developed. Hybrid models attempt to combine the strength of both models and represent detailed technology choices which also reflect macroeconomic feedbacks (Hourcade et al. 2006).

Another classic way to categorise models is by their method of computation. van Beeck (1999) identifies eight different methodologies for energy models: 1) econometric, 2) macroeconomic, 3) economic equilibrium, 4) optimisation, 5) simulation, 6) spreadsheet, 7) backcasting, and 8) multi-criteria. Although the distinction is not always clear, econometric, macroeconomic and economic equilibrium are often referred to as top-down models, and optimisation, simulation and spreadsheet are referred to as bottom-up models.

Econometrics connect economic theories with statistical methods to study economic data and problems (W.C. Hood et al. 1953). Econometric models employ this technique to analyse energy-economy interactions based on aggregated data that have been measured in the past. The model often extrapolates past market behaviours into the future to analyse development pathways. Early energy demand models typically used econometrics methodology, but today the econometric method is being used as a part of macroeconomic models (van Beeck 1999). The macroeconomic models are a simplified representation of the entire economy of a society and on a set of relationships between different sectors. Examples of econometric and macroeconomic are ETA-MACRO (Manne 1977) and POLES (II-EPE 2006). The econometric and macroeconomic models are great in capturing economy-wide movements, but it often lacks the detailed representation of the energy sector. Specific end-use technologies are often aggregated as one technology within a sector, and some macroeconomic models do not always have detailed representations of the energy sector, as energy is only a part of the economy.

Optimisation models have an objective function, which is to minimise or maximise a certain variable. Models often optimise energy costs under the provided assumptions and constraints in order to form investment strategies. For example, optimisation models are often employed to make long-term investment decisions such as when and what kind of power plants to build in order to keep the cost down. In recent years, their employment in the electricity sector has also increased under the need to factor in emissions constraints. Examples of optimisation models are MESSAGE (Messner et al. 1995) and MARKAL (Loulou et al. 2004).

Simulation models provide a set of rules that needs to be obeyed, and sees how a system behaves under a given condition. The models do not necessarily choose or show the least cost system, like optimisation models, but rather they provide the most likely outcome given the rules provided. These rules tend to be defined based on real world experiences, so the models would often reflect currently observed systems. Simulation models are especially helpful when experiments in the real world are quite expensive or difficult. Examples of simulation models are MEDEE (Lapillonne et al. 1981), TIMER (de Vries et al. 2001) and POLES (II-EPE 2006).

Table 5-1. Examples of energy models and their categories and types

	Bottom-up / Top-down	Model category and types	References
LEAP (Long range Energy Alternatives Planning	Bottom-up	Econometrics/ Simulation	(Heaps 2008)
MEDEE (Model Demand Energy Europe)	Bottom-up	Simulation	(Lapillonne et al. 1981)
MARKAL (the Market Allocation of Technologies Model)	Bottom-up	Optimisation	(Loulou et al. 2004)
MESSAGE (the Model for Energy Supply Systems Alternative)	Bottom-up	Optimisation	(Messner et al. 1995)
WASP (Wien Automatic System Planning)	Bottom-up	Optimisation / Electricity system model	(IAEA 2001)
TIMER (The Targets IMage Energy Regional)	Bottom-up	Simulation	(de Vries et al. 2001)
ETA-MACRO (Energy Technology Assessment-Macro Model)	Top-down	Optimisation / General equilibrium	(Manne 1977)
DICE (The Dynamic Integrated Climate-Economy model)	Top-down	Optimisation / Integrated assessment modelling	(Nordhaus 1993)
RICE (Regional Integrated Climate-Economy model)	Top-down	Optimisation / Integrated assessment modelling	(Nordhaus 2010)
World3	Top-down	System dynamics / Integrated assessment modelling	(Meadows 1972)
POLES (Prospective Outlook on Long-term Energy Systems)	Bottom-up / Top-down	Econometric / partial-equilibrium	(II-EPE 2006)

5.1.4 Cooking models

Only a few energy models account for cooking energy dynamics in developing countries. The majority of energy models are developed for industrialised countries, where the transition to clean cooking technologies has already occurred and energy access is universal. Many models are based on the data and history of industrialised countries and thus automatically assume the energy systems of developing countries to behave similarly (Shukla 1995, Pandey 2002).

Modelling end-use technology choices is critical for understanding the cooking fuel transition. The traditional biomass consumption using three stone stoves has significant impacts on the lives of the poor. Cooking energy models can be categorised into two major types using methods of calculation. The first type is an econometric method, which uses historical fuel consumption, fuel prices and economic relationships to project transitions in fuel consumption. The second type is an optimisation method, which makes fuel choices a part of a cost optimisation model, providing various constraints typically involving budgets and fuel growth rates.

The first type, the econometric method, has an advantage that it allocates a fuel mix based on past choices made by the consumers, which inherently includes social costs that consumers placed on choosing a fuel. The rate of fuel transition does depend on parameters chosen, but it typically delivers a rate of change that has been observed in the past. However, the method can also have a disadvantage in that it has difficulty deriving a relationship for new technologies. Developing countries typically have rapidly changing social structures and many factors, such as new technologies and policies, can cause them to break away from historical trends. The second type, the optimisation method, has an advantage that new technologies, which did not exist in the past, can be added to the model. The fuel mix choices in the future years are selected based on costs, so the least cost option is chosen regardless of past trends. The model has a flexibility to include technological advancements and new technology options in the analysis, and see how the new technologies could change trends from the past. However, the main disadvantage of the optimisation method is that it does not include the social costs related to fuel use. The consumers make decisions based not only on prices but also on utility from the money spent. This is especially true for cooking, which carries much cultural value. In order to reflect consumer preferences in an optimisation model, the value gap between fuel prices and consumer utility must be integrated into the model.

IEA's World Energy Model (WEM) (IEA 2012c, IEA 2014b) and the household energy model developed by van Ruijven (van Ruijven et al. 2010, van Ruijven et al. 2011) fall in the first type, the econometric method. Their models determine future fuel consumptions using the relative prices of alternative fuels along with the other parameters such as per capita income, urbanisation level and demographic growth. Due to the way historical energy statistics are usually covered, both methods are suitable in allocating fuel consumptions but not in allocating the types of cooking technologies associated with fuel use. The consideration for cooking technologies is not of particular importance for fuels such as gas and electricity, for which a choice of technology does not greatly change the services provided. However, for biomass such as firewood and charcoal, energy services obtained can vary in great degrees, depending on the choice of cooking technology. The model by van Ruijven does not cover cooking technologies but makes a great effort in using detailed household survey data to disaggregate consumption trends into different household groups, depending on income and dwelling locations. IEA's model takes a more crude approach due to a lack of data and assumes all households relying on traditional biomass to use traditional stoves (IEA 2012c). Using the model, IEA calculates the cost of replacing all traditional stoves in urban areas with gas stoves and providing improved biomass cooking stoves in rural areas. This is reported as the additional cost needed to achieve universal energy access.

Analysis by MARKAL and MESSAGE falls into the second type, the optimisation method. Both models use linear optimisation, which projects the future cooking fuel consumption based on prices. To overcome the issues of including the social price in fuel choices, Howells et al. (2005) chose to include the externality cost of using different types of fuel. Ekholm et al. (2010) and Mainali et al. (2012) included inconvenience costs, which represent the inconveniences associated with obtaining and using certain types of fuel. Both models incorporate behavioural aspects in the model by applying minimum constraints to the equation to reflect consumer preferences that do not correspond with the observed costs. The model developed by Howells et al. (2005) is one of the few models that has a detailed representation of the end-use energy demand for cooking by giving multiple technology options for each fuel. However, the model only considers one type of consumers and fails to reflect how different income groups react differently to price changes.

5.2 Conceptual model and overview

5.2.1 Consumer preferences

Energy models are a useful tool to analyse the transition to clean cooking technologies and to estimate the cost in achieving universal access to modern fuels. Most energy models ignore consumer preferences for cooking technologies, but a handful of energy models does explicitly account for cooking energy dynamics or household characteristics in developing countries. At a country level Howells et al. (2005) examined fuel transitions in South Africa by extending the MARKAL model to include energy choices in rural areas. Similarly, Ekholm et al. (2010) and Mainali et al. (2012) introduced cooking fuel options in MESSAGE to analyse energy transitions in India and China respectively. Van Ruijven et al. (2011) introduced an energy use projection model for India, which disaggregated historical energy use into various household groups to capture household characteristics in the model. On a global scale, IEA has developed the World Energy Model (WEM), which they use to estimate additional investments needed to achieve universal access to clean cooking technologies. Their results have been published yearly since 2010 in the World Energy Outlook since 2010 (IEA 2010b, IEA 2011, IEA 2012b, IEA 2013). The Global

Energy Assessment is another global scale analysis on the transition to modern fuels for cooking, in which Riahi et al. (2012) estimated the investment required to achieve universal access to modern energy services by 2030 using two integrated energy assessment models (IMAGE and MESSAGE).

Although these models are excellent in revealing the magnitude of additional investments needed to achieve universal access to clean cooking technologies and to provide a projection on the number of people who will be without access to modern fuels, they focus on the total or average fuel consumption and fail to include consumer preferences and end-use cooking technologies in their analyses. This is largely due to the limited availability of energy statistics. Most national and international energy statistics report fuel consumption by sector only and do not report the end-use technology associated with that fuel consumption.

Using disaggregated data to analyse the cooking situations among different household groups is critical not to underestimate the hardships faced in the low-income households. Due to the higher fuel consumption of wealthy income groups, average fuel consumption data can be deceiving, giving a higher weight to the wealthy households. In a similar manner, fuel price changes have a stronger effect on low-income households due to their limited disposable income, but data averaging the population as a whole may disguise these important issues.

5.2.2 Model concept

The main objective of the cooking technology choice model is to determine the technology share that would maximise the satisfaction level of all households. Shortcomings of previous cooking model analyses are a lack of focus on the end-use technologies and the heterogeneity in consumer preferences in choosing those end-use technologies. The types of fuel used and the prices of fuels were often closely analysed, but cooking technologies required to use these fuels have been treated lightly in the analyses. Many factors affecting cooking technology choice, such as education, dwelling location and household size, have been evaluated (Hosier et al. 1987, Heltberg 2005, Pundo et al. 2006). However, the relative strength of how fixed investments (stove purchases) and variable costs (fuel purchases) are influencing cooking technology choices remains poorly understood. A model evaluation that can weigh both of these prices and see how cooking technology transition could occur can be a great assistance in policy forming processes to improve the effectiveness of programmes. Therefore, the mechanism for technology selection in the cooking technology choice model is constructed by deriving relative utility and preferences from the consumption patterns observed.

In classical economics, consumer choice is often explained using the term utility. The term utility describes the overall satisfaction or enjoyment that consumers gain from consuming a good or service, and it serves as a main indicator in consumer choices. If consumers act rationally, they choose combinations of goods and services that maximise their total utility under their budget constraints.

The concept is sensible, but the difficulty lies in quantifying the amount or value of utility that a consumer places on different choices. Consumers make choices on cooking technologies by considering many factors such as fuel prices, stoves prices, ease of handling, fuel availability and stove durability (Karekezi et al. 2008). Each consumer uses his or her own value judgement in making a final choice, which is subjective and is significantly affected by their perceptions of product attributes (Adesina et al. 1995). Some may value fuel availability as the most important criterion, whereas others may value stove prices as the most deciding factor. These choices cannot always be compared or measured in common units, and one person's utility for two products is not necessarily the same as another's. Moreover, consumers also derive utility not only based on one service from the goods, but on the overall attributes of the goods (Lancaster 1966). The difficulty encountered in quantifying utility for cooking technology choice is no different, as ease of lighting the fuels, amount of pollution, safety, and cost all contribute in forming the utility of each individual.

An economic theory of consumer's behaviour, which assists in avoiding this conceptual problem, is a notion of "revealed preference." Samuelson (1938) argued that by comparing the costs of different combinations of goods at different relative price situations, preference for a given batch over another can be revealed. If the consumer's demand is determined by his or her preferences under a budget constraint, analysing empirical observations of consumer choices can provide information on the utility functions that a particular consumer places on a good or service (Samuelson 1938, Samuelson 1948, Little 1949, Varian 1987). Arguments often made against the revealed preference theory is that the choices made do not always truly reflect consumers' preferences and that consumers act with "bounded rationality" (Simon 1984, Simon 1991). For example, Beshears et al. (2008) have suggested factors such as passive choice, a tendency for decision makers to adopt the default choice given, and third-party marketing, a possibility that the decision was influenced by persuasions, can cause the consumers to make decisions that do not truly reflection their choices. In the case of cooking choice in developing countries, poor infrastructure and reliability are factors that also confound revealed preferences. Deriving preferences based on empirical observations does have shortcomings of containing distortion in revealed preferences, but this can be reduced by taking a large sample of data and limiting the analysis to a field which consumers face often and have a less chance of being influenced, such as cooking fuel and technology choices in developing countries.

The cooking technology choice model takes the method of deriving relative utility and preferences from the consumption patterns observed. The Uganda National Household

The cooking technology choice model takes the method of deriving the relative utility and preferences from the consumption patterns observed. The Uganda National Household Survey 2005/06 provides critical data that can be used to estimate the consumer's utility from multiple cooking fuel-stove combinations. Along with the amount of fuel that the consumers purchased, the survey also gives unit prices that the consumers paid for the fuel and the primary stove-type used for cooking by each household. Therefore, estimated utility data is gathered into groups according to several attributes. By grouping, a trend in the consumption pattern and the relative utility level of particular groups can be established. Using this group utility information, the model looks to provide an insight into the effectiveness of access policies among the consumers under different conditions and environments.

5.2.3 Model overview

The cooking technology choice model developed in this dissertation is designed to fill the gap in current cooking models by reflecting both consumer heterogeneity and end-use technology in one model. It considers both multiple cooking end-use technologies and heterogeneous consumer preferences by dividing consumers into household groups. The model focuses on cooking energy use in Uganda and bases its data on the household survey performed by the Ugandan government in 2005-2006.

The purpose of the cooking technology choice model is to answer the following questions:

- Cooking technology transition: What price signals are needed to shift consumers from traditional cooking technology to modern clean cooking technology?
- Consumer heterogeneity: How are consumer groups with different preferences affected by price changes in fuels and cooking technologies?
- Policy implications: How would energy access policies change the cooking technology mix of households under different conditions?

The cooking technology choice model with a focus on heterogeneity in consumer preferences for different cooking technologies is soft linked to a global energy model with a detailed representation of energy supply technologies. The results from the two models are in a feedback to reflect the influence that fossil fuel prices, calculated by the global energy model, has on the mix of cooking technologies, calculated by the cooking technology choice model, and vice versa. The detailed description of soft-linking is provided in the next section.

There are two approaches to improve cooking conditions of biomass users. One is fuel switch to more modern, clean fuels, such as LPG and electricity. The other is a switch to improved biomass cookstoves. Improved biomass cookstoves can reduce firewood consumption, improving health conditions and also easing the burden of firewood collection. Nevertheless, this should be considered a middle step, or a linking technology, before making a further improvement to modern fuels. Therefore, in the analysis of this model, a switch to modern fuels is represented by a switch to gas stoves. The gas stove is used as a proxy for clean cooking fuels, as other possible clean cooking technologies such as electricity plates and natural gas cooking are still not widely used in Uganda, and there is no data on consumer preference.

Some caveats should be borne in mind when interpreting the results from the cooking technology choice model. First, the model analysis is restricted to cooking technology choice. Only the direct influences from fuel prices and cooking technologies are analysed, and indirect effects from other factors such as new roads or education are not reflected. A fully representative household choice model would require price elasticity of all consumer goods and substitutes. Second, the future fossil fuel prices are derived from a linked energy model, but deriving proper fuel prices for firewood and charcoal would require implementations of a spatial model and a land-use model. The price of firewood varies from region to region, and scarcity issues drastically change the price. Furthermore, estimating the price of firewood is complicated due to the heavy involvement of non-commercial transactions, which are not reflected in the household surveys. Therefore, the effects of price changes in firewood and charcoal are analysed using a sensitivity analysis in this dissertation.

The infrastructural problem is also noted. The lack of pipelines and roads limit the availability of fuels and stoves in many rural areas. With fewer options available, the rural population needs to resort to the last option of using biomass available in their surrounding areas. However, including infrastructural issues into a model requires spatial data on infrastructure and demand, which is beyond the scope of this dissertation. A plan to introduce such large investments into modelling gas delivering facilities or logistics is set aside for further studies in the future. Instead of looking into the infrastructural plans, the study will focus on the implications for the consumers when fuels do become available, in order to provide information to the possible plans to extend the market area of LPG.

The cooking technology choice model looks to provide a new insight into the transition to clean cooking technologies by providing an analysis of how price changes in fuels affect cooking technology choices among different household groups. The analysis can assist in setting price targets to accelerate the transition to modern fuels, in addition to informing the level of support needed by different household groups. A group specific analysis can reduce the unnecessary support given to the wealthy or those who are not in need and decrease free riders and a subsidy leakage.

5.3 Model formulation

5.3.1 Household groups

The cooking technology preference model divides the households into subsets according to dwelling location and annual expenditure level to reflect both affordability and availability issues. The affordability and availability of fuels and stoves are key influencing factors in consumer cooking preferences. The World Energy Assessment (Goldemberg et al. 2000) illustrates this trend with the concept of the "energy ladder" (Smith et al. 1993, Reddy et al. 1994), which shows changes in the types of fuel used with an increase in income (Barnes et al. 1992). Critics view the energy ladder as too simplistic because it assumes that a household moves from one fuel to the next, when in reality, multiple fuels are often used by each household (Martins 2005). However, the concept is helpful in illustrating the consumers' inclination to move to a higher quality fuel with an increasing income. Along with affordability, the availability of fuels is another key issue in consumer preferences. If the fuels are not available, consumers cannot purchase them even with enough income, and if the fuels are scarce, consumers typically need to pay above the market price to secure the fuel or switch to a less preferable fuel. This availability issue is partially reflected in studies that compare fuel uses not only across income but also between rural and urban areas (Heltberg 2004, Pachauri et al. 2004, Prasad 2008).

The model distinguishes between rural and urban households belonging to 3 different expenditure levels for a total of 6 groups. The rural-urban divide is important to reflect their differences in infrastructure and resource availability, and the divide according to expenditure represents differences in the ability to pay. For analysis of policy relevancy, it is important to distinguish people below certain poverty thresholds, so that one can choose to track certain groups based on the absolute income level, and the rest are dynamic to account for the overall income and population growth. The static groups represent the low-expenditure groups, who face severe access problems. The two static expenditure groups have expenditure per capita calculated at purchasing power parity (PPP) at below 1.25 USD/day and 1.25-4.00 USD/day. The definition of the groups stays the same throughout the calculation periods, so the energy use of different periods are comparable. The dynamic groups represent households with expenditure of over 4.00 USD/day. With increasing wealth the dynamic groups grow larger, and the expenditure per capita also increases accordingly. The groups are not comparable across time periods, but the results of the dynamic groups represent the energy use pattern among the high-incomes households. Combining the results of both static and dynamic groups allows for an analysis for the whole country. The cut off of 4.00 USD/day is comparable to the poverty line often used in the developing regions of Latin American and the Caribbean (World Bank 2012a). The Table 5-2 shows expenditure group definitions and information.

Table 5-2: Expenditure group definitions and basic information

$ = 2005USD in ppp

Expenditure Group	Static or Dynamic	Definition	Mean expenditure per day	Average HH size	HHs in the survey
R1	static	exp < $1.25	$0.78	6.47	3,072
R2	static	$1.25 < exp < $4.00	$1.99	5.58	2,146
R3	dynamic	$4.00 < exp	$6.35	3.55	227
U1	static	exp < $1.25	$0.85	7.07	362
U2	static	$1.25 < exp < $4.00	$2.43	5.84	825
U3	dynamic	$4.00 < exp	$7.18	3.98	306

5.3.2 Cooking technology assignment mechanism

The main outputs of the cooking technology choice model are cooking technology mixes of different household groups. Five forms of fuels along with six types of cooking stoves are considered in the model. Taking compatibility issues into account, seven combinations of fuel and stove are available in the model for the household groups to meet their cooking energy demand (Table 5-3).

Table 5-3. Cooking fuel and stove combinations considered in the model

Technology	fuel	stove
1	collected firewood	three stone stove
2	purchased firewood	three stone stove
3	purchased firewood	improved biomass stove
4	charcoal	metal plate stove
5	charcoal	improved charcoal stove
6	kerosene	kerosene stove
7	LPG	gas stove

The main idea behind the technology choice in the model is to allocate demand according to consumer preference and fuel prices for each household group. An ideal method to accomplish this is to develop demand curves for each cooking technology based on the household survey. However, curves for technologies using biomass or firewood could not be created due to the low price of fuels and stoves. For example, cooking using collected firewood and three stone stoves bear no cost, and thus there is no way to draw a curve for such technologies. Although not completely free, cooking with purchased firewood also results in very low cost. If a curve were drawn for such technologies, it would be a flat line with low elasticity. However, it is unlikely that a small change in price of firewood or stove would drastically change the consumption. Firewood is one of the last resorts in terms of cooking choices, so consumers will not shift to another source so quickly. Therefore, the model takes two steps to decide the share of each cooking technology.

In the first step, the model decides the share of cooking demand in a household group for those technologies for which demand curves could be derived (Technologies 4-7 in Table 5-3). The model assumes the consumers' aspiration to use more convenient fuels, a concept also known as the energy ladder (explained in Section 2.5), so the share of cooking technologies is assigned such that priority is given to more convenient or modern stoves. A cooking technologies choice is typically made by each household, but the model develops a demand curve for each household group. Therefore, the derived fuel use is to be treated the average use for the household group, and not of a particular household. A detailed explanation of the methods to derive demand curves to estimate missing curves is provided in Section 5.4.5.

1. According to the LPG and gas stove prices, the demand for gas stoves is calculated based on the demand curve and assigned accordingly. If the calculated demand for gas stoves exceeds the cooking demand, all of the demand is assigned to LPG, and the assignment is completed.
2. If gas stoves do not satisfy the cooking demand, the demand for kerosene stoves is then calculated using the demand curve to fill the remaining demand. If the calculated demand for kerosene stoves exceeds the remaining cooking demand, all of the remaining demand is assigned to kerosene, and the assignment is completed.
3. If kerosene stoves do not satisfy the remaining cooking demand, the demand for improved charcoal stoves is calculated. If the calculated demand for improved charcoal stoves exceeds the remaining cooking demand, all of the remaining demand is assigned to improved charcoal stoves, and the assignment is completed.
4. If improved charcoal stoves are not enough to satisfy the remaining cooking demand, the demand for metal plate stoves is calculated. If the calculated demand for metal plate stoves exceeds the remaining cooking demand, all of the remaining demand is assigned to metal plate stoves, and the assignment is completed. If there is still remaining demand to be satisfied, the second step is taken to fill the gap.

The second step allocates the remaining demand for cooking with technologies for which demand curves could not be derived (Technologies 1-3 in Table 5-3). The relationship used to assign the share of biomass and firewood is described in Section 5.4.6.

1. The demand for three stone stoves and improved firewood stoves is calculated based on the share observed in the 2005 household survey. The demand for improved firewood stoves is not further divided, so the amount of use is assigned.

2. The demand for three stone stoves is further divided into different fuels, collected firewood and purchased firewood. The share is calculated based on the 2005 data.

5.3.3 Cooking cost calculation

To determine the demand for each cooking technology, the cooking price *(CP)* is calculated in terms of "USD per GJ of useful energy" using Eq. (1) for each household group. The equation provides an average total cost of a cooking technology by dividing the sum of the annualised stove cost *(AS)* and annual fuel cost *(V)* by the total cooking demand in a year *(UD)*. All costs are in constant 2005 USD.

$$CP_{pe}^{f} = \left\{AS^{s} + \left(V_{pe}^{f} \times \frac{UD_{pe}}{Eff^{fs}}\right)\right\} \Big/ UD_{pe} \tag{1}$$

Fuel prices are different among household groups. High-income groups are frequently able to pay lower prices because they have the ability to purchase in bulk. The annualised stove cost *(AS)* also differs among household groups. The stove capital cost *(SC)* and lifetime *(LT)* are the same for all household groups, but the implicit discount rates *(DR)* vary among groups.

$$AS^{s} = \left(SC^{s} \times DR_{pe}\right) \Big/ \left\{1 - \left(1 + DR_{pe}\right)^{-LT^{s}}\right\} \tag{2}$$

Table 5-4: Model annotation

Sets:	
f	Fuel types (1: Collected firewood, 2: Firewood, 3: Charcoal, 4: Kerosene, 5: LPG)
s	stove types (1: three stone, 2: improved biomass, 3: metal plate, 4: improved charcoal, 5: kerosene stove, 6: gas stove)
p	Location of dwelling (rural, urban)
e	Expenditure groups (E1, E2, E3)
Input parameters:	
AS	Annualised stove prices ($/yr)
CP	Total cooking costs per unit of useful energy ($/GJ)
DR	Implicit discount rate (%)
Eff	Cooking stove efficiency for a given fuel (%)
EX	Household expenditure per year ($)
LT	Lifetime of cooking stoves (years)
SC	Capital cost of cooking stoves ($)
UD	Useful energy demand observed from household survey (GJ/yr)
V	Fuel cost ($/GJ)

The implicit discount rate is a calculation of net present values by discounting future costs. Due to stronger budget constraints faced by low-income households, the discounting rate of future costs typically correlates negatively with annual expenditure of households, as observed in a study by Reddy et al. (1994) for Indian households. A number of studies have made attempts to estimate implicit discount rates of consumers but has shown diverging results (Dubin 1992, Frederick et al. 2002). However, confining results to studies of consumer discount rates compiled by Train (1985), omitting investment studies of larger equipment such as automobiles, reduces variations to a range between 0% and 100% as shown in Figure 5-1. A regression line was calculated taking a total of seven energy related investment study results, and the relationship was used to calculate implicit discount rates for each expenditure group using Eq. (3). Since the studies took place in different years, all the reported cost values were converted to 2005 USD using the consumer price index.

$$DR_{pe} = -0.162 \times \ln(EX_{pe}) + 1.956 \qquad (3)$$

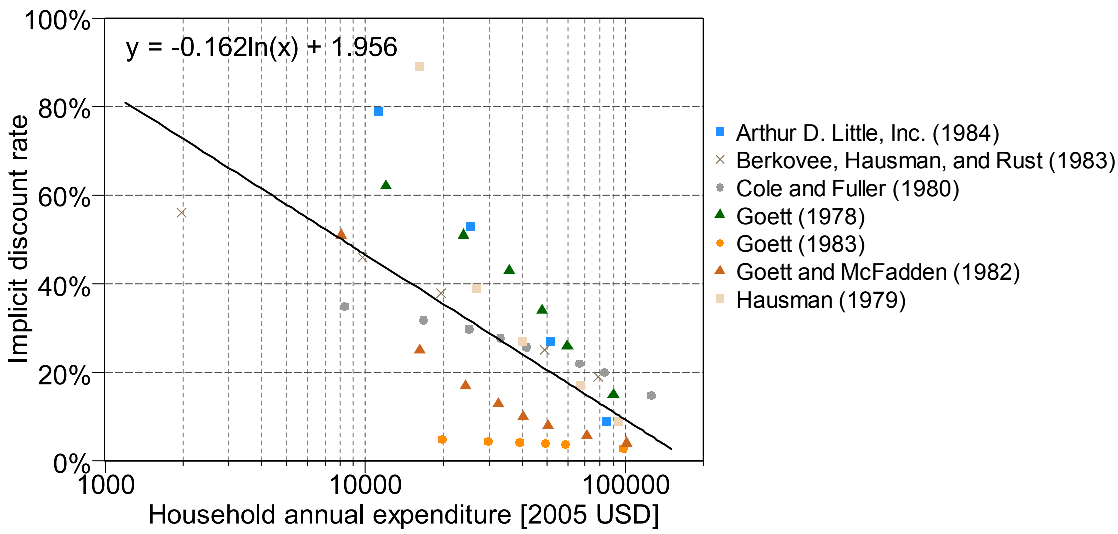

Figure 5-1: Implicit discount rates for energy appliances form various studies (Train 1985)

5.3.4 Soft link with a global energy model

A special attention is given to keeping consistent scenarios in the development of global fossil fuel consumption and fossil fuel prices. Fossil fuel is a global commodity, and the price is determined in the international market. External events on the market or geopolitical instability can have an impact on the price, but overall, it is determined by the balance between the global supply and demand for the fuel.

The cooking technology choice model evaluates the share of cooking technologies by various consumer groups based on their observed preference from a household survey, but it does not have the capability to determine fossil fuel prices. A global energy model with an explicit representation of the upstream and downstream fossil fuel flow can provide future fossil fuel prices that are consistent with global energy demands. Therefore, a set of models and formalised procedures, each describing one part of the energy system, is soft linked or arranged in a loop as shown in the overview of the model proceedings in Figure 5-2. Iterative application of this model loop leads to consistency in cooking technologies chosen according to fossil fuel prices based on global fossil fuel consumption. For each scenario calculation, two types of data are exchanged between the models until a convergence in fuel prices and demand share is achieved. First, the cooking technology mix based on fuel prices is passed onto the energy model. Second, the information on fuel prices based on fuel consumption is passed back onto the cooking technology choice model.

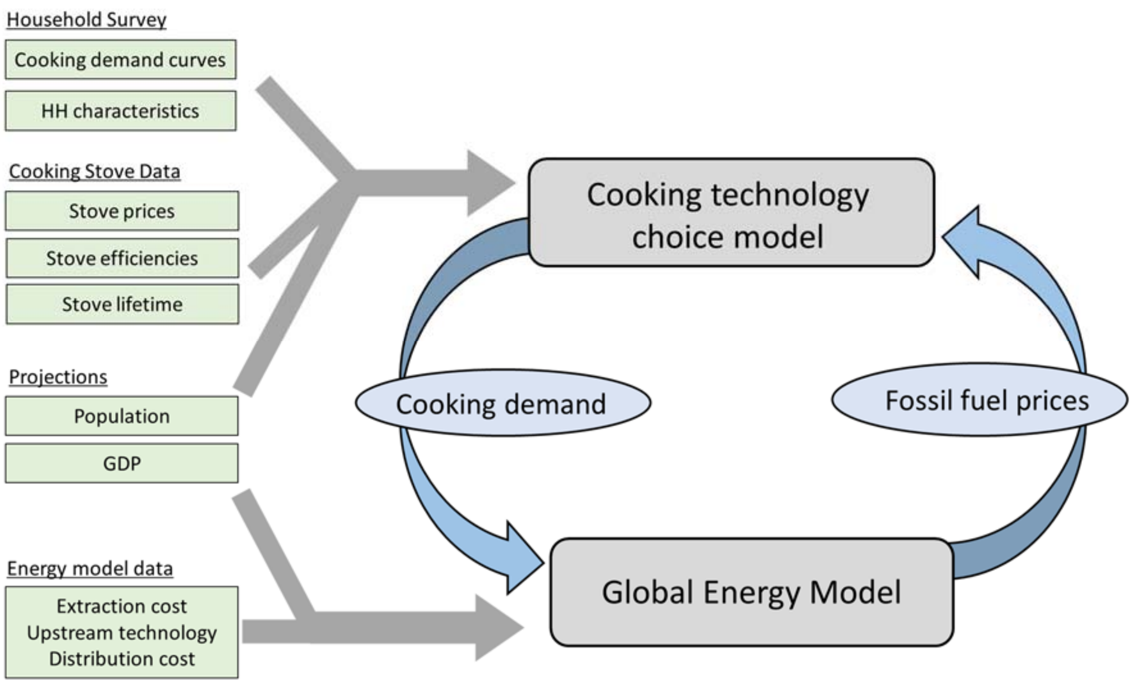

Figure 5-2. Overview of the cooking technology choice model and a soft link to a global energy model

The cooking technology choice model is designed in a flexible manner in which fuel consumption can be output in various formats. It can establish an easy link with multiple energy models, given that they explicitly model residential cooking demands and are able to feedback fuel price information. There are a handful of well-established global energy models that can derive fossil fuels internally. In this dissertation, a link to MESSAGE (Model of Energy Supply Systems Alternatives and their General Environmental Impacts) developed by the International Institute for Applied Systems Analysis (IIASA) is chosen.

There are two main reasons why MESSAGE is chosen as a linking global model. The first reason is the detailed upstream representation of fossil fuel extraction technologies. In MESSAGE each fossil fuel resource is attributed by grades, which has different extraction costs, allowing the model to derived fossil fuel prices endogenously. Furthermore, within each grades existing resource volume, maximum possible rate of growth, maximum possible resource depletion rate and upper limit on the annual extraction are set (Schrattenholzer et al. 2004). The second reason is the model's previous use in analysing the cooking energy transition in India and China (Ekholm et al. 2010, Mainali et al. 2012). Although the two studies use different methods to analyse the transition, the use of MESSAGE to link cooking energy demands and energy use has been previously established. The details of MESSAGE are explained in the following section.

5.3.5 MESSAGE

MESSAGE is a family of time-dependent linear optimisation models with an objective function to minimise the total energy system cost by optimally allocating fuels to meet a given demand (Messner et al. 1995). The model is used to analyse energy policies through the use of scenario planning, and it has been used in many reports including IPCC reports. The model evaluates many possible energy flows and finds the least cost solution under given constraints. It has a detailed representation of energy technologies, upstream and downstream, and allows for an explicit treatment of inter-fuel substitution, which takes place over time in the energy supply and conversion sector.

MESSAGE model is typically employed to analyse long-term implications of energy systems, with the time horizon from 1990 to 2100. Between 1990 and 2010, the data is calibrated to historical data, and the model determines the energy pattern for the future years between 2020-2100 in ten-year periods. MESSAGE is a global model that divides the world into 11 aggregated regions (see Appendix A.6).

Within the model, energy flow is imitated using energy carriers and linking energy conversion technologies. There are five levels of energy carriers, which start from resources (crude oil, hard coal) and get converted to primary energy, secondary energy, final energy then finally to useful energy, or demand. Between the energy carriers, the model considers energy conversion technologies. For example, between primary energy and secondary energy, the model considers conversion technologies such as refinery and power plants. By providing constraints on energy flows and conversion rates and capacity, engineering feasibility is ensured. Figure 5-3 provides a flow diagram of energy in MESSAGE model.

Most MESSAGE inputs can be attributed to the three categories: primary energy resources, conversion technologies and useful energy demands (Messner et al. 1995). For primary energy costs, quantities and constraints are provided as inputs. For conversion technologies, costs, market penetration rate and available time frame are provided. Useful energy demands are determined typically using Scenario Generator, a simulation model to formulate scenarios to calculate energy demand for the given economic development paths. It calculates demand under given assumptions of GDP growth and energy intensity improvements (Gritsevskyi 1996).

There are seven types of useful demands in MESSAGE model. Residential and commercial demands are divided into two types: thermal and electricity demand. Industry sector is divided into three types: thermal, electricity and feedstock demands. In addition to these five demands, transportation demand and non-commercial demands are modelled. The non-commercial demand corresponds to traditional biomass demands in the developing countries.

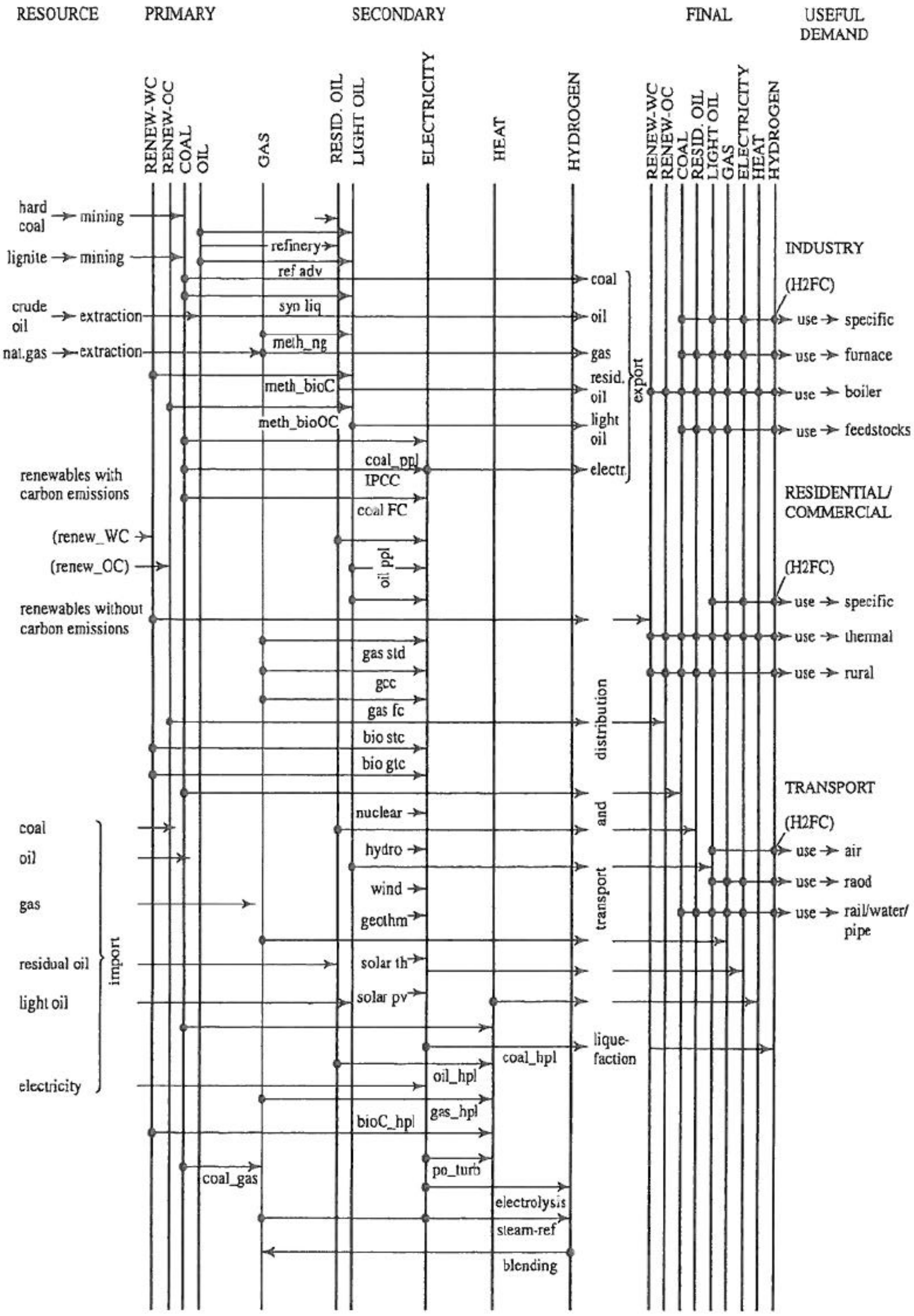

Figure 5-3. Schematic illustration of the reference energy system

(Strubegger et al. 2004)

Fossil fuel is a global commodity, the price of which is determined in the international market. External events on the market or geopolitical instability may have an influence, but the main price determinant of fossil fuel is the balance between its global supply and demand. The cooking technology choice model only covers the fossil fuel consumption of residential cooking sector, but a global energy model with an explicit representation of the upstream and downstream fossil fuel flow can provide future fossil fuel prices that are consistent with global energy demands.

5.4 Input data

In order to gain an understanding of the cooking technology choice processes of households in Uganda, the model draws on data from a household survey conducted by the Uganda Bureau of Statistics, the Uganda National Household Survey 2005/06. Through consumption behaviours observed in the model, the model estimates the relative values that consumers considered, conscious or subconscious.

The Uganda Bureau of Statistics (UBOS) has carried out a household survey every three to five years since the late 1980s. The collected data has been the main source of statistical information for monitoring poverty levels, consumption trends and welfare status. The Uganda National Household Survey (UNHS) 2005/06 was undertaken from May 2005 to April 2006 and covered close to 7500 households countrywide. The survey is designed to look at five different areas: socio-economic, agriculture, community, market and qualitative issues. The survey covered all the regions and districts in Uganda and used a two stage sampling design to draw the samples. At the first stage, Enumeration Areas (EAs) were drawn with Probability Proportional to Size (PPS), and at the second stage, households, which are the Ultimate Sampling Units, were drawn using Simple Random Sampling (SRS).

In a large household survey, input errors can occur during data collection. Households with incomplete sets of data or mismatched data were excluded from this analysis. An example of mismatched data is a household reporting firewood use for cooking yet not consuming any firewood, or not reporting any fuel use. In order to avoid including these errors, data cleaning was performed for extreme values or outliers. The most common error in the raw data is the introduction of an additional "0" to the input. Values that diverge more than 5 times the standard deviation are likely to occur only once in over 1.5 million cases. In a household survey that covers 7500 households, the chances that the survey will contain such a value is less than 0.5%. Therefore, when a value was more than 5 times the standard deviation from the mean, the observation was taken to be an input mistake and was divided by 10. Out of the 7426 households in the original file, 6938 households were used in the final analysis. The reasons for exclusion are as follows.

Table 5-5: Reporting issues in the household survey data

7426	Total households in the suvery
-11	no data on household size
-50	no data on cooking technology, cooking fuel or lighting fuel
-91	no data on food expenditure
-13	no data on fuel expendtiture
-125	reported non-analysed cooking technlogy
-149	reported three stone stove or improved firewood as cooking technology but no firewood consumption
-29	reported metal plate or improved charcoal as cooking technology but no charcoal consumption
-2	reported gas stove as cooking technology but no LPG consumption
-18	reported kerosene stoves, but kerosene seems to be used only for lighting
6938	HH data used in the final reporting

5.4.1 Expenditure data

Household consumption of various items is provided in value and quantity for each household in the survey. They are divided into four different categories:

- Food, beverages and tobacco (7 day recall period)
- Non-durable goods and frequently purchased services (30 day recall period)
- Semi-durable goods and durable goods and services (365 day recall period)
- Non-consumption expenditure (365 day recall period)

The consumption data is further divided into four different types of consumption: consumption out of purchase at home, consumption purchase away from home, consumption of home produce, and goods received in kind (or received as a gift or for free). For most of the products, only consumption purchases are accounted for as expenditure. The exceptions are food and fuels, for which consumption of home produce and goods received in kind are also counted. Food and fuels are vital for survival, so if not produced or received, they would have had to purchase them outside. In order to estimate the yearly expenditure of households, consumer patterns for the given period are converted to 365 days, assuming that consumption patterns remain constant over the whole year. There is no dedicated category for LPG, and its use is included under “other fuels”. To avoid including fuels other than LPG, fuel expenditure reported under “other fuels” is treated as LPG use only for households that answered gas as their main fuel used for cooking. In some cases expenditures were reported per household member, but they were aggregated at the household level, as all cooking analysis is done at the household level.

Two types of households with uncommon expenditure patterns that could affect results were dropped from the dataset. The first group is households that did not report expenditure or goods received in kind for both categories of food, beverage and tobacco and non-durable goods (91 households). This implies that they had a large stock of goods or they were not consuming goods at home, which can distort the expenditure parameter. The second group is households that did not report expenditure in fuels. Since households that do not cook are outside the scope of this cooking analysis, they were also dropped (13 households).

5.4.2 Fuel prices

The fuel price of firewood, charcoal and kerosene are derived from the average unit prices that households paid for the fuels. In addition to expenditure data, the survey reports units purchased, which allows for calculating the average price under a common unit (i.e. kg or Litre).

The quantity provided is given in many different units such as bundle, sack, basket, bottle, and jerrican, to name a few. Many are accompanied by estimated weight or volume, but some are simply provided under ambiguous terms that cannot be converted to standard units. Most of the data that were provided with ambiguous terms were deleted from the dataset, but commonly used terms of “bundle” for firewood and “akendo” for kerosene were estimated to derive fuel prices that are more representative of the population. A “bundle” of firewood is assumed to be 32.5 kg based on a survey by USAID, which found the average bundle weight to be 25 kg in Kitgum and Lira and 43 kg in Gulu (USAID 2007).

An “akendo” or a small cup with a handle is estimated for each region, using average fuel price variances from a known quantity such as a litre or a 350 mL bottle. A socioeconomic survey sheet for Uganda’s “Reaching end-user project” provides three choices for sizes of akendo: 10, 20 and 50 mL. Taking the middle size of 20 mL as the base quantity in the central region, the size of the other regions were determined to make sure the prices estimated will provide a similar price per quantity variance across regions, as we have observed in the other units. The calculation resulted in 20 mL for central and northern regions, 15 mL for the eastern region and 30 mL for the western region. The common unit of measurement used for firewood and charcoal is kilogram, and litres are used for kerosene. The average fuel prices are calculated by taking the average of the unit prices weighting by a household multiplier.

Fuel prices vary depending on many factors. Firewood and charcoal are collected and produced in the rural areas, bringing the unit price down in rural areas. Kerosene, which has a good infrastructure for distribution due to its use for lighting, did not show a difference in prices between rural and urban areas. The amount of purchase also affects the price, as bulk purchases often offer lower prices per unit. To test this hypothesis, regression tests with the unit fuel price as the dependent variable and four independent variables were performed. The four independent variables are:

- 1) Total household expenditure
- 2) Household size
- 3) Dwelling location (rural or urban)
- 4) Region

The variable region is a categorical variable, and the central region was used as the indicator variable. The price savings that result from purchasing in bulk are not linear but rather logarithmic with most of the discounts occurring at lower quantities. Therefore, the natural log of total household expenditure and household size were used in the regression analysis.

The price of firewood showed statistical significance in the northern region. Neither expenditure level, nor household size nor dwelling location seems to affect the firewood price. Therefore, the price of firewood is uniform among central, eastern and western regions, but set higher for the northern region.

$$firewood\ price = 0.011 + 0.002 * X_{\mathrm{N}} \quad (4)$$

Where,

X_N=1 if the household in the northern region, otherwise 0

The charcoal price was statistically significant in household size, dwelling location, and eastern and northern regions. The larger households consumes a higher quantity of charcoal making the cost per energy content cheaper, and charcoal price is higher in urban areas and eastern regions where the resource is scarcer.

$$charcoal\ price = -0.012 \ln(\mathrm{X}_{exp}) - 0.008 * \mathrm{X}_{UR} + 0.014 * X_{\mathrm{E}} + 0.188 \quad (5)$$

Where,

X_{exp} is the household expenditure per capita in 2005 USD in PPP

X_{UR}=1 if the household in rural area, otherwise 0

X_E=1 if the household in the eastern region, otherwise 0

The kerosene price showed a statistically significant relationship with the total expenditure of the households, and for northern and western regions. This indicates that high-expenditure households buy kerosene in bulk to receive a discount. The prices are not different between rural and urban. This effect can be observed from the purchased unit reported. The ratio of purchases by “akendo” decreases and by “bottle” increases with a rise in household expenditure. However, the northern and western regions saw difference prices than the central.

$$kerosene\ price = -0.261 \ln(\mathrm{X}_{exp}) + 0.286 * \mathrm{X}_{N} - 0.358 * X_{\mathrm{W}} + 3.470 \quad (6)$$

Where,

X_{exp} is the household expenditure per capita in 2005 USD in PPP

X_N=1 if the household in the northern region, otherwise 0

X_W=1 if the household in the western region, otherwise 0

The price of LPG could not be derived from the survey, as the unit prices were not reported. The LPG price has been similar to Kenya's price due to the connection in the supply infrastructure. Therefore, the fuel price of LPG in Kenya in 2005 of 13 USD for a 6 kg cylinder is used for Uganda in this analysis (Karekezi et al. 2008). The results of the average fuel prices are shown in Table 5-6. Although not used in the model, the electricity price is also provided for a reference. The price is taken from the 2006 annual report by the Ministry of Energy and Mineral Development, which lists a residential electricity price of 216.9 USh/kWh or 12 cents/kWh in 2005 USD (MEMD 2006).

Table 5-6: Average fuel prices in urban and rural, based on the household survey (UBOS 2006b)

	Pruchased quantity	unit	Unit cost [2005USD/unit]		Unit cost [2005USD/GJ]	
			Rural	Urban	Rural	Urban
Firewood	bundle, 32.5kg	[kg]	0.01		0.77	
Charcoal	Plastic basin, 5.25kg	[kg]	0.14	0.17	4.65	5.52
	Sack, 100kg	[kg]	0.04	0.06	1.46	1.91
Kerosene	Akendo*	[L]	3.16		90.49	
	1 litre	[L]	0.91		26.14	
LPG	1 kilogram	[kg]	2.17		47.90	
Electricity	1 kilowatt hour	[kWh]	0.12		33.83	

* small cup with a handle (15-30 mL)

This fuel price analysis using the survey shows the influences of social factors, such as the location of dwelling, household sizes and annual expenditure rates, in the final fuel prices. Although this detailed data is useful to understand the current price structure in Uganda, energy models report fuel prices that do not reflect expenditure levels or locational disadvantages. Even in technology rich bottom up models, one fuel price or shadow price is typically used to represent average fuel prices. If the fuel prices were directly used, these social factors involved in deciding fuel prices would be lost.

In order to reflect the different fuel prices faced by different household groups, a concept of adjustment factors is applied. The adjustment factors convert an average fuel price into household group specific fuel prices. To calculate adjustment factors, average unit prices paid by each household group is compared against a reference price. A reference price is a national average unit price of each fuel that was purchased at standard units chosen for each fuel. The standard unit for each fuel is: firewood – bundle, charcoal – 100 kg, kerosene – Litre, LPG – kg. The adjustment factors are the ratio of group specific price to this reference price. Table 5-7 shows the adjustment factors for each fuel and group. When average fuel prices are output from an energy model, the prices are multiplied by these factors to assure price differences observed in the survey is reflected in the cooking technology choice model.

Table 5-7: Fuel price adjustment factors

[standard unit]	Firewood [bundle]	Charcoal [100kg]	Kerosene [L]	LPG [kg]
R1	0.83	1.07	2.01	1.00
R2	0.83	0.96	1.72	1.00
R3	1.04	1.17	1.51	1.00
U1	0.97	1.46	2.17	1.00
U2	0.83	1.30	1.66	1.00
U3	1.24	1.27	1.39	1.00

5.4.3 Cooking technologies

The survey includes nine different types of stoves, but only six stoves are used in this analysis. The three types of stoves that are omitted are "electricity plate", "saw dust stove" and "others". The saw dust stoves were omitted because only one household reported using it, and the stoves classified as "others" were deleted due to the lack of information about these stoves. The electricity plate was deleted due to the difficulty in separating energy used for cooking from the total consumption (11 households). Electricity is a versatile energy medium and can be used to satisfy many types of services, unlike kerosene, which is mostly used for lighting or cooking.

Table 5-8: Distribution of cooking technologies represented in the Uganda household survey 2005/06

	R1	R2	R3	U1	U2	U3	Rural	Urban	TOTAL
Three stone	2,821	1,780	113	183	216	25	4,714	424	5,138
Improved firewood	202	122	3	46	23	2	327	71	398
Metal plate	25	195	81	68	482	227	301	777	1078
Improved charcoal	24	48	21	65	94	31	93	190	283
Paraffin stoves	0	1	9	0	10	16	10	26	36
Gas stoves	0	0	0	0	0	5	0	5	5
TOTAL	3,072	2,146	227	362	825	306	5,445	1,493	6,938

The stove prices and efficiencies used to convert final energy to useful energy are taken from the literature review. Many different types of stoves can exist for one type of fuel (Reddy 2003, Ohimain 2012). The majority of the stove prices in this model are taken from GVEP International (2012c). GVEP International is a non-profit organisation that works in developing countries to increase energy access to modern energy forms, focusing strongly on cooking issues. They performed a market assessment on cookstoves in Uganda, and the stove prices from that study are converted to 2005 USD and used in this analysis. GVEP International did not assess kerosene stoves, so the price of the kerosene stove is taken from a study in Ghana by Afrane (2012). The lifetime of the stoves are mostly taken from Afrane and Reddy. Lifetime was not available for improved firewood and metal plate stoves, so they were assumed to be the same as improved charcoal stoves and three stone stoves, respectively. Summarised data on the cooking technologies are shown in Table 5-9.

Table 5-9: Characteristics of cooking technologies

	Unit cost [2005USD]	Efficiency [%]	Lifetime [years]
Traditional 3 stone stove	0.00	12%	3
Metal plate stove	3.61	20%	3
Improved charcoal stove	9.03	30%	5
Improved firewood stove	13.54	22%	5
Kerosene stove	18.68	35%	5
Gas stove*	79.44	60%	10

* Gas stove cost includes cost of purchasing 13kg cylinder

5.4.4 Cooking energy demand

The consumption of biomass/firewood, charcoal and LPG is mostly used for cooking purposes in Uganda. Therefore, their fuel consumption can be directly used as an estimate of cooking demand. However, the use of kerosene needs to be separated by use, as the fuel can serve both lighting and cooking demands. The consumption of kerosene for lighting typically correlates with household expenditure and the number of household members. Additional disposable income allows for an increased use of kerosene per capita, but additional household members reduce the use per capita due to shared lighting. In order to determine the relationship between kerosene consumption versus expenditure and household size, a regression was performed using Eq. (7).

$$\ln(kerosene\ use) = \beta_1 \ln(total\ expenditure) + \beta_2 (HH\ memebers) + \beta_3 \quad (7)$$

The main purpose of this analysis is to determine how much kerosene is consumed for lighting. Therefore, households that use kerosene as the main cooking fuel are omitted from the analysis, as their consumption numbers already include some for cooking distorting the average. The result of the regression analysis (Table 5-10) showed that the natural log of expenditure and household members is statistically significant against kerosene consumption. This supports the original hypothesis that consumption increases with expenditure but is negatively correlated with household size.

Table 5-10: Regression results for kerosene use per capita versus log of expenditure and household members

		Coefficents	Std. Err.	p-value	[95% Conf. Interval]	
log(total expenditure)	β_1	0.7700	0.0185	0.0000	0.7337	0.8064
HH members	β_2	-0.0322	0.0038	0.0000	-0.0397	-0.0246
constant	β_3	0.2987	0.1002	0.0030	0.1023	0.4950

This relationship is applied to households that use kerosene for cooking and lighting, in order to separate the amount of use reported into the two different purposes. First, the use of kerosene per household is estimated using the regression results. If the estimated use is less than the reported use by the households, the difference is considered to be used for cooking. However, if the resulting cooking kerosene use is less than 500 mL per month per capita or approximately 200 MJ/capita-yr, the household is dropped from the analysis, as the amount is not enough to provide cooking services as a main fuel, and the difference is likely due to statistical error.

Table 5-11: Cooking final energy demand by groups and stoves in 2005

[MJ of final energy per capita]

fuel - stove	R1	R2	R3	U1	U2	U3
collected firewood - three stone stove	6545.2	8634.0	6272.8	4154.4	1822.7	0.0
firewood - three stone stove	373.1	932.6	1967.9	660.9	1236.0	0.0
firewood - improved firewood stove	37.1	76.4	22.4	223.2	129.4	0.0
charcoal - metal plate stove	19.9	411.7	2927.3	415.4	3078.7	6846.3
charcoal - improved charcoal stove	23.7	97.5	656.0	566.5	494.4	540.7
kerosene - kerosene stove	0.0	0.0	0.0	0.0	0.0	0.0
LPG - gas stove	0.7	2.2	8.2	0.0	7.5	15.9
TOTAL	6999.6	10154.3	11854.5	6020.5	6768.7	7402.9

5.4.5 Demand curves

The demand curves for each fuel in household groups are derived from the demand observed and the price that consumers paid for the cooking technology. To obtain a trend for each household group, a regression analysis for a power curve is performed weighted by a household multiplier. Assuming that price elasticity stays constant within the group, the power curve is chosen over other regressions. The final demand curve equation takes a form of Eq. (8) with the two coefficients *(a, b)* being group and fuel specific.

$$u_{pe}^{f} = a_{pe}^{f} \times \left(UP_{pe}^{f}\right)^{b_{pe}^{f}} \qquad (8)$$

To perform a power curve regression, non-users of each fuel had to be dropped. With all non-users dropped, the derived relationship represents a demand curve for only those households in the group using that particular cooking technology. In order to derive a curve that represents the demand for the group as a whole, the observed demand of each household is multiplied by the percentage of users in the group.

An example of the observed relationship is shown in Figure 5-4. This observed relationship is used as the demand curve for this particular technology in this household group. This process is repeated for all technologies in all household groups. Figure 5-5 shows demand curves observed for metal plate stoves in different expenditure groups.

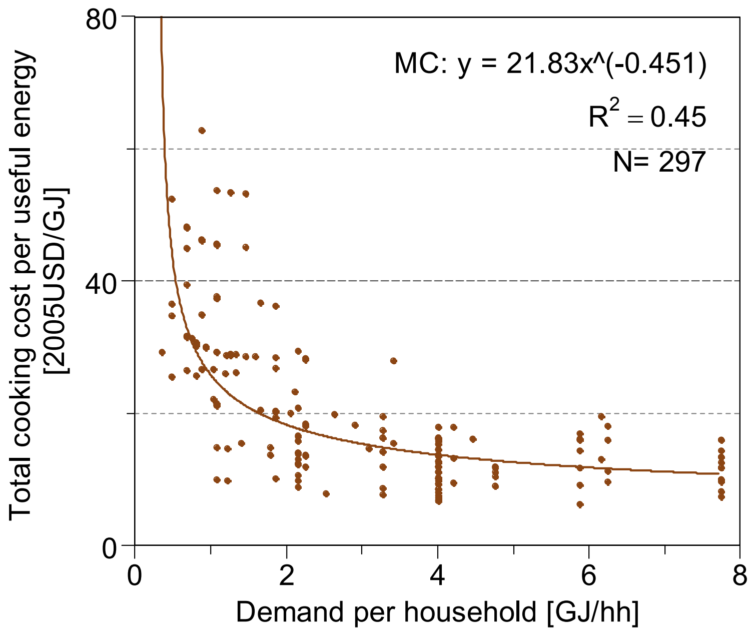

Figure 5-4: Observed total cooking cost versus household cooking useful energy demand for charcoal cooking with a metal plate stoves in household group U2.

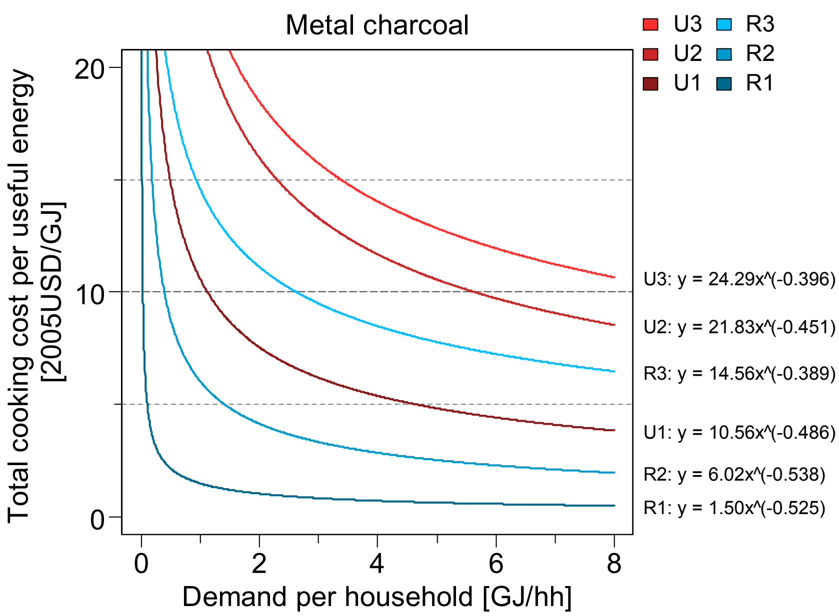

Figure 5-5: Demand curves for charcoal cooking with a metal plate stoves (All household groups)

A problem in deriving the demand curve occurs when only a few households use the technology. This was the case for kerosene and gas stoves. A curve for the gas stove could be drawn only in U3 as other groups did not use the technology. Similarly, for kerosene stoves, only R3 and U3 produced graphs. In order to estimate the curves for other groups, the following adjustments are made to construct demand curves.

In order to derive a curve, two coefficients/values are needed. One is the price elasticity determining the shape of the curve (*b* in Eq. (8)), and another is a point on a curve to determine the location of the curve (*a* in Eq. (8)). The demand curves from charcoal stoves show that price elasticity does not differ significantly between expenditure groups. Therefore, price elasticity for kerosene and gas stoves are assumed to be the same within the rural and urban sectors, meaning the data from R3 and U3 can be used for the low-expenditure groups. In the case of gas stoves, data from U3 is applied to all groups. The adjustment for determining the location of the curve is performed with the assumption that consumers in other groups are willing to pay the same percentage of their expenditure for cooking technology as U3 or R3. To do so, the coefficient *a* from the dynamic group is multiplied by the ratio of annual household cooking expenditure of the dynamic groups to the cooking expenditure in the static expenditure groups. Making these adjustments results in demand curves shown in Figure 5-6.

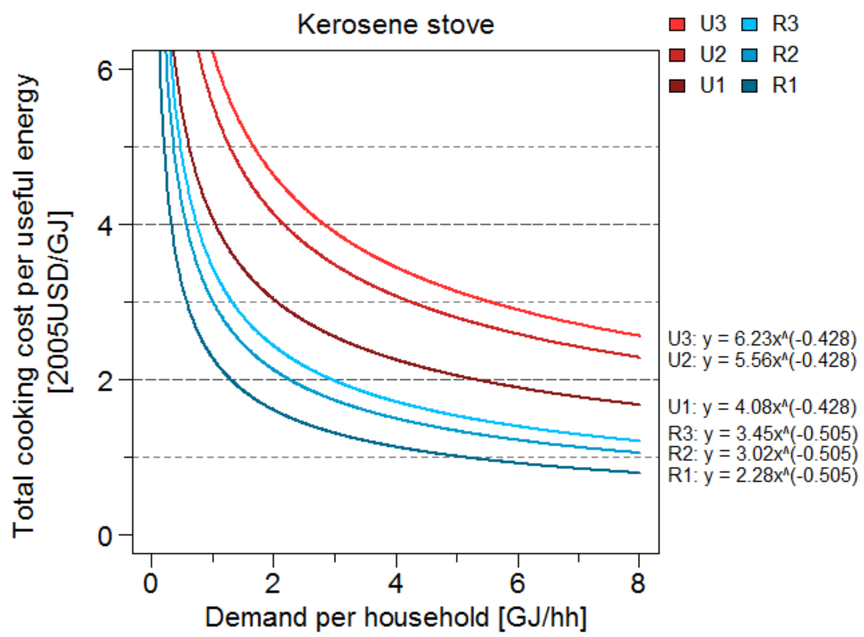

Figure 5-6: Demand curves for kerosene stoves (All household groups) in 2005

5.4.6 Share of firewood and improved stoves

Cooking with three stone stoves can take two forms of fuel, collected firewood or purchased firewood. The survey shows that the time spent on collecting firewood decreases with increasing annual expenditure and the consumption of collected firewood decreases accordingly. Table 5-12 shows the time spent on collecting firewood and an average consumption of collected firewood and purchased firewood per household groups. This observed ratio is applied to determine the share between collected firewood and purchased firewood.

Table 5-12. Weekly average on hours spent to collect firewood and consumption for cooking

Expenditure Group	Weekly Average		
	Hours spent on collecting firewood	kg consumption of collected firewood	kg consumption of purchased firewood
R1	1.39	53.6	3.6
R2	1.14	59.4	7.4
R3	0.21	27.1	8.6
U1	0.79	31.4	8.2
U2	0.18	12.0	9.7
U3	0.04	0.5	2.8

It would be logical to think that with increasing fuel prices, more households would adapt by using improved cooking stoves. It would also be cost effective for consumers with high consumption to switch to improved stoves. However, a study has shown Uganda to have a peculiar rejection of improved cooking stoves (Energy for Sustainable Development Ltd. 2000). The high-income households views the improved stoves as not suitable for their class, and the acceptance is higher among the low-income groups as seen in Table 5-13 despite lower consumption rates. Since the social scope or social change such as education is not within the scope of the model, the adaptation of improved firewood stoves will be assumed to be constant from 2005.

Table 5-13. Ratio of improved stoves by expenditure groups in 2005

	Improved stove ratio	
	firewood	charcoal
R1	0.9%	57.6%
R2	1.8%	21.8%
R3	0.3%	21.5%
U1	10.0%	58.1%
U2	5.3%	17.6%
U3	4.3%	8.2%

5.5 Parameters in future years

The household survey can only provide static data for 2005/06, so a method is needed to estimate the parameters required in the future years. Due to the definition of the household groups, the average expenditure of R1, R2, U1 and U2 stays the same throughout the time horizon of the model. Therefore, parameters such as household size and cooking technologies can also remain static. However, R3 and U3 are dynamic expenditure groups that represent all the households with an expenditure over 4 USD per day in PPP. The expenditure level is determined by the economic and population growth, and the consumer preferences need to change according to the growth rates.

The future parameters are calculated based on regression analysis of each parameter observed in the survey across multiple expenditure groups. In order to get a better regression, the rural and urban groupings are divided into eight quantiles each rather than the three expenditure groups employed in the model. Since the relationship is being derived for future high-expenditure groups, only household groups with an expenditure level higher than 2.00 USD per day per capita are used in calculating the regression lines. The exception to this is the allocation method of future expenditure groups, which is explained in the next section.

5.5.1 Expenditure groups

The model uses two projections to draw out scenarios, population and GDP taken from the Global Energy Assessment (GEA 2012). The projection in the Global Energy Assessment is one of the few projections which provides both GDP and population projections disaggregated for rural and urban areas for each country. The projection for Uganda is shown in Figure 5-7.

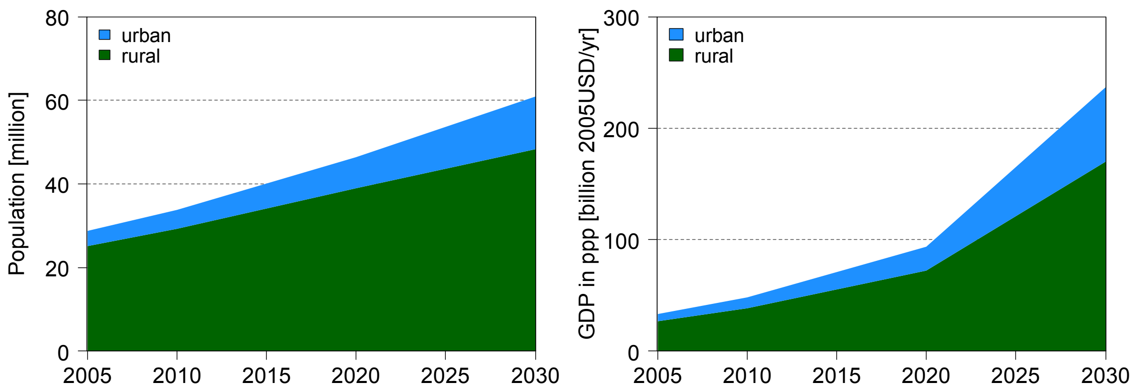

Figure 5-7: Population and GDP projections for Uganda by GEA

The rural-urban divide of population and GDP is helpful, but the data needs to be further divided into different expenditure groups to reflect heterogeneity. In order to further disaggregate the data, a relationship between expenditure and population is used based on the 2005 household survey data. The reported Gini index in the WDI for Uganda has stayed relatively stable at around 45 since 1989 (1989 – 44.4, 2006 – 44.3). Therefore, this relationship between expenditure and population in 2005 is assumed to stay constant in the model.

To calculate the number of people in each expenditure group in the future periods, the rural and urban data from the survey are divided into 25 clusters each according to the per capita expenditure. By summing expenditures in each cluster and dividing by the total expenditure, the share of total expenditure in each cluster is calculated. This share is kept constant, but the per capita expenditure in each cluster increases due to increasing expenditure. The expenditure is assumed to increase at the same rate as the GDP.

The resulting per capita expenditure is used to allocate each cluster into expenditure groups. The allocating criteria are the same as in Table 5-2. For example, when the expenditure per capita in the rural cluster is below 1.25 USD per day, the population of the cluster is assigned as R1. When all the allocated clusters are calculated, the expenditure group trends result as shown in Figure 5-8.

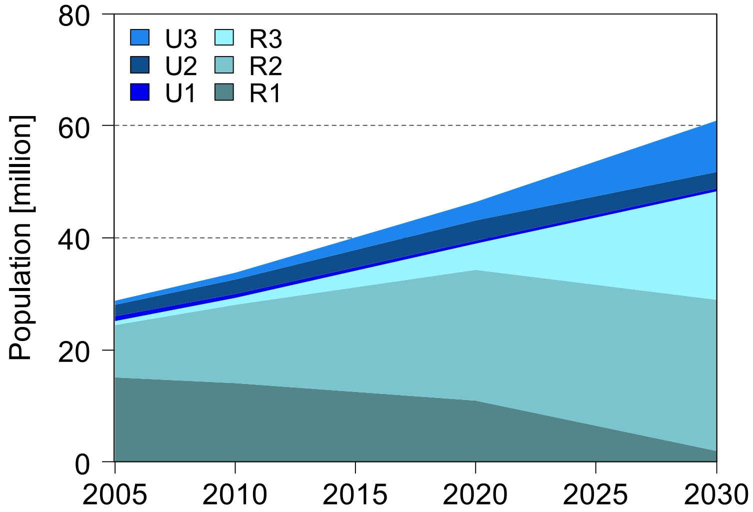

Figure 5-8: Household group projection in Uganda from 2005-2030

5.5.2 Cooking demands

Due to the different lifestyles of rural and urban households, the amount of energy used for a given annual expenditure level is different between rural and urban expenditure groups. One explanation of this difference is that the types of food and opportunities to eat out are different in the rural and urban sectors.

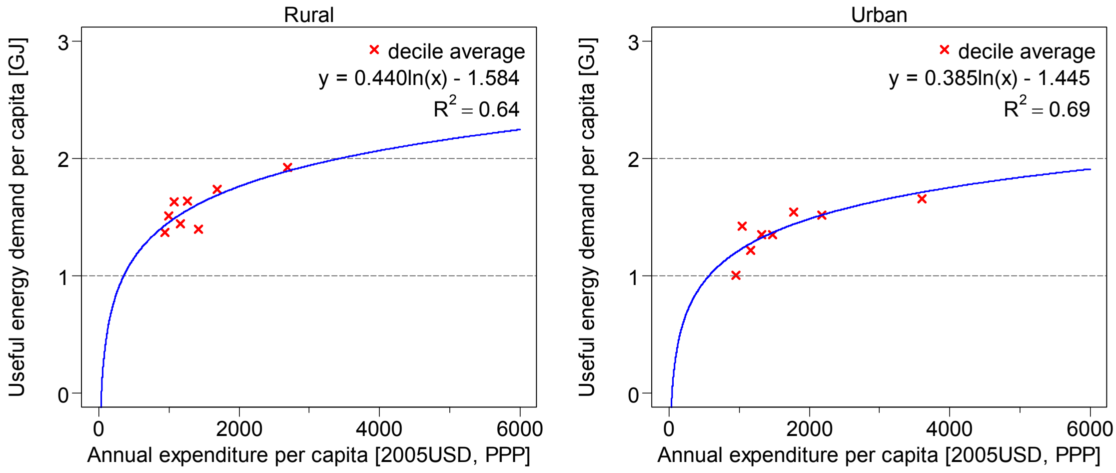

Figure 5-9: Cooking demand and expenditure per household

5.5.3 Household size

Another important factor in household cooking decisions is the household size. The household size tend to decrease with increasing annual expenditure. This decrease in household size that accompanies increasing expenditure is similar in both rural and urban areas. The household size plays an important role in the cost of cooking technologies. The decrease in the number of people per residence means the cooking technology is used less, which in turn makes the annualised cost per useful energy higher.

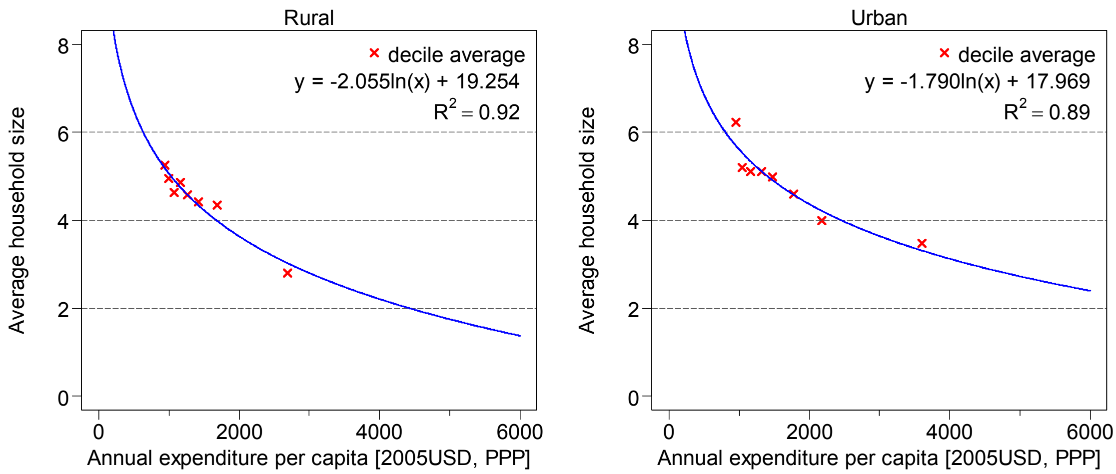

Figure 5-10: Household size and expenditure per capita

5.5.4 Cooking share

The cooking share of the total budget is also an important parameter to estimate future expenditure on cooking by the consumers. The expenditure on cooking does not increase proportionally with the total expenditure. Typically, the expenditure on basic needs decreases as a percentage of the total expenditure, as is illustrated by the Engel's law (Engel 1895, Houthakker 1957). The cooking expenditure as a percentage of the total expenditure can be seen in Figure 5-11. The derived relationship of cooking share to budget is useful in calculating how demand curves will shift in the dynamic groups as they get wealthier. In the model, demand curves are shifted upwards according to the increase in the cooking expenditure.

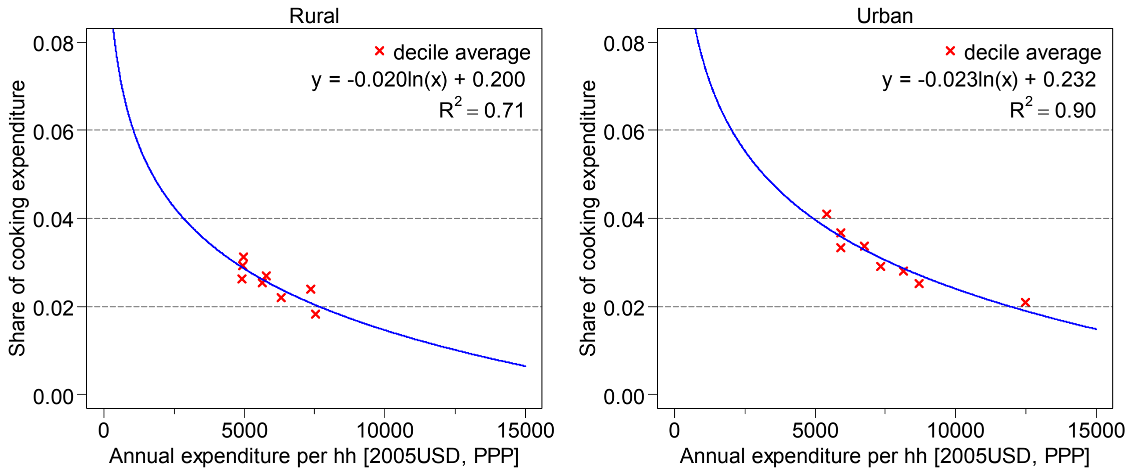

Figure 5-11: Cooking share and annual expenditure per capita

The total expenditures on cooking per capita in 2005 and in future years are shown in Table 5-14. In general, the cooking expenditure increases as time progresses. An exception occurs in 2020 in rural areas. In 2020 the expenditure slightly decreases due to a large increase in the population in R3 (2010 – 14 million, 2020 – 23 million). The numbers shown in the table are the average for all households in the group.

Table 5-14. Annual expenditure on cooking in the high-expenditure groups

[$/cap]	2005	2010	2020	2030
R3	43.11	44.67	44.10	51.95
U3	57.86	58.21	62.73	75.72

5.5.5 Collected firewood ratio

Cooking demands met with three stone stoves are not calculated based on the demand curves, but rather they are allocated when other technologies do not supply all of the cooking demands as described in Section 5.3.2. When they are to be allocated, the ratio of collected firewood to purchased firewood is an important factor in deciding the kinds of fuels consumed. An increased expenditure decreases the use of three stone stoves and also the share of collected firewood. The rate at which the ratio decreases is estimated using the relationship shown in Figure 5-12. A more rapid fall in the ratio of collected firewood is observed in urban areas.

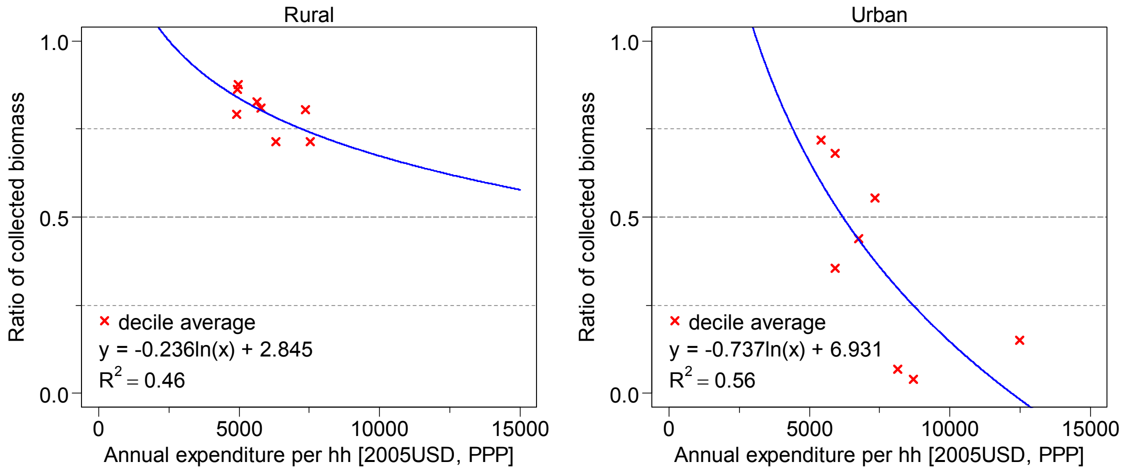

Figure 5-12: Share of collected firewood and annual expenditure per capita in Uganda

Chapter 6. Results and policy implications of access to clean cooking technologies

This chapter evaluates policy option to make the transition to clean cooking technologies using the cooking technology choice model introduced in Chapter 5. The analysis in this chapter is carried out in the following ways. First, the model results for 2005, the base year, are compared to the household survey data to make sure the model is calibrated. Second, the calculation results of the baseline case (NNP: no new policies) without any access policies are presented. After analysing the baseline case, pathways to clean cooking technologies are evaluate focusing on the three issues: Financial support, Climate change policies and Charcoal price sensitivity. The chapter concludes with an analysis and discussions of the evaluation.

6.1 Scenario analysis to affordable access to clean cooking technologies

The goal is fixed. The United Nations has called for a major UN initiative to achieve universal access to modern energy services by 2030. Modern energy services include access to electricity and access to clean cooking technologies. The initiative aims to provide electricity to 1.4 billion people with no connection and to switch 2.6 billion people to clean cooking technologies. There are no fundamental barriers in achieving the goal. Clean cooking technologies are available, and the interest in renewable energy is increasing, benefitting off grid solutions. Financial barriers do exist, but estimates of the total capital investment required is only around 3% of the total global energy investment (IEA 2011). Nevertheless, governments have not taken action for implementing policies and investing in capacity development in order to achieve the goal of universal access.

With over 95% of the people using solid fuel and more than 90% without access to electricity in Uganda, it will take a combination of policies to achieve universal access to modern forms of energy services. With so few people having access to clean cooking technologies, a massive scale up from the current rate of investment is required despite financial obstacles. The number of people living below the poverty line has decreased in recent years, but it still represents about 20% of the population. In addition, more than 70% of the population live in rural areas, so there needs to be investments in roads and pipelines in order to deliver modern fuels to them. Getting the local artisans involved in the manufacturing of improved stoves is another key to having a successful market in a country.

Although all of these issues are critical and significant, the cooking technology choice model concentrates on technical and economic issues. The analysis in this chapter will take note of social issues of infrastructure and education, but its main emphasis is on removing financial and technical barriers.

The evaluation of pathways to clean cooking technologies focuses on three policies.

1. Financial support: How much would a fuel price support to purchase LPG or a credit access to reduce the initial investment to purchase clean stoves assist consumers with different social status to switch to clean cooking technologies?
2. Climate change policies: How much would a climate change policy to limit worldwide GHG emissions increase the price of LPG and kerosene, and how much would that negatively affect the transition to clean cooking technologies?
3. Charcoal price sensitivity: Charcoal is still the most popular next step fuel after firewood especially in urban areas. How would a change in the charcoal price alter the outlook of the cooking technology mix in Uganda?

The first policy attempts to facilitate transition by providing financial incentives to consumers. If modern technologies become available at similar prices as traditional technologies, people should switch to higher quality services. Scenarios look to evaluate how much support is required to make such a shift. The second policy looks closely at the effects of climate change policies on low-income households. The transition to clean cooking technologies require an increasing use of fossil fuels, but climate change policies attempt to reduce the consumption of fossil fuels. Slight increase in modern fuel prices can drastically set back the transition of low-income households, despite being one of the lowest GHG emitters. The analysis considers one scenario, in which all countries share a burden to reduce GHG emissions, in order to evaluate the possible negative effects of the global effort to mitigate climate change. The third policy deals with uncertainty in the price of charcoal. Charcoal is a very influential fuel in transition, and its price drastically changes the cooking technology mix. A higher charcoal price can shift people back to using firewood under tight budget constraints, and a lower price can cause them to hesitate making a transition to modern forms of energy services. The scenarios aim to provide a cooking technology mix outlook under different price paths.

In all calculations, the same main underlying assumptions of GDP, population, stove prices and stove characteristics are used. The GDP and population projections are taken from the Global Energy Assessment (GEA), which provides population projections for countries disaggregated into rural and urban. The projected total population of Uganda in 2030 is to reach 60.8 million, of which 79%, or 48.3 million, will be living in rural areas. The economy is projected to grow seven times the current size with the national GDP reaching over 235 billion USD in PPP. The per capita GDP of rural areas reaches the urban area level of 2005 in 2020 (1800 USD per capita) and continues to increase to over 3500 USD per capita in 2030. In urban areas the GDP reaches 5300 USD per capita in 2030, which is comparable to urban areas of Zimbabwe in 2005. The stove prices are taken from GVEP International and a study by Afrane (2012) as explained in Chapter 5.

This study uses gas stoves with LPG as a proxy for clean cooking technology. LPG is non-solid fuel, and emissions of particles from its combustion is comparable to the levels observed in industrialised countries. Many developing countries face shortages of modern fuels. Blackouts happen daily, and a shortage of LPG is a cyclic problem. However, there is no universally-agreed-upon definition of access to modern fuels. The UN Secretary General's Advisory Group on Energy and Climate (AGECC) defines access to modern energy as the "basic minimum threshold of modern energy services for both consumption and productive uses" (AGECC 2010). An easy concept to grasp, but the problem lies in how to define the minimum threshold. IEA has proposed 100 kWh of electricity and 100 kilogram of oil equivalent (kgoe) of modern fuels per person per year, but it is only one of the many suggestions. For example Die Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and *Poor people's energy outlook* by Practical Action (2010) recommends to have indicators that are connected to specific services rather than consumption (i.e. lighting is defined in lumens, and heating is defined by indoor air temperature). AGECC also states that "access to modern energy services must be reliable and affordable, sustainable and, where feasible, from low-GHG-emitting energy sources."

The analysis aims to assist in providing information on prices at which the transition to clean cooking technologies could occur. This information then can be used to evaluate investments into different infrastructure. The analysis does not intend to specify that LPG is the only choice of fuel for clean cooking. Other possible modern fuels, biogas, natural gas or electricity, can also serve the same purpose. However, due to the available data and considering the current situation in Uganda, LPG is used as the representative for clean cooking technologies.

6.2 Comparison of model results and household survey

Before running the scenarios, the cooking technology mix data of 2005 from the household survey is compared to the model result of 2005. If the demand curves properly represent the six household groups (the definition of household groups is explained in Section 5.3.1), the derived curves should closely represent the fuel choices of the group. Figure 6-1 shows the comparison results. The overall trend of cooking technology mix matches the household survey results. A majority of energy supply in rural areas comes from collected firewood, and high-expenditure groups are supplied mostly by charcoal stoves. There is a trend of slightly underestimating the demand for metal plate stoves and overestimating the use of improved charcoal stoves, but the difference between the results are less than 5% in most cases. The largest difference is observed in metal plate stoves in low-income households in urban areas (U1), where the model underestimates the charcoal demand, resulting in overestimating the demand for collected firewood. However, the difference is about 0.08 GJ/cap or only 10% of the total demand, showing that the derived demand curves represent the consumption patterns observed in the household survey with a reasonable accuracy.

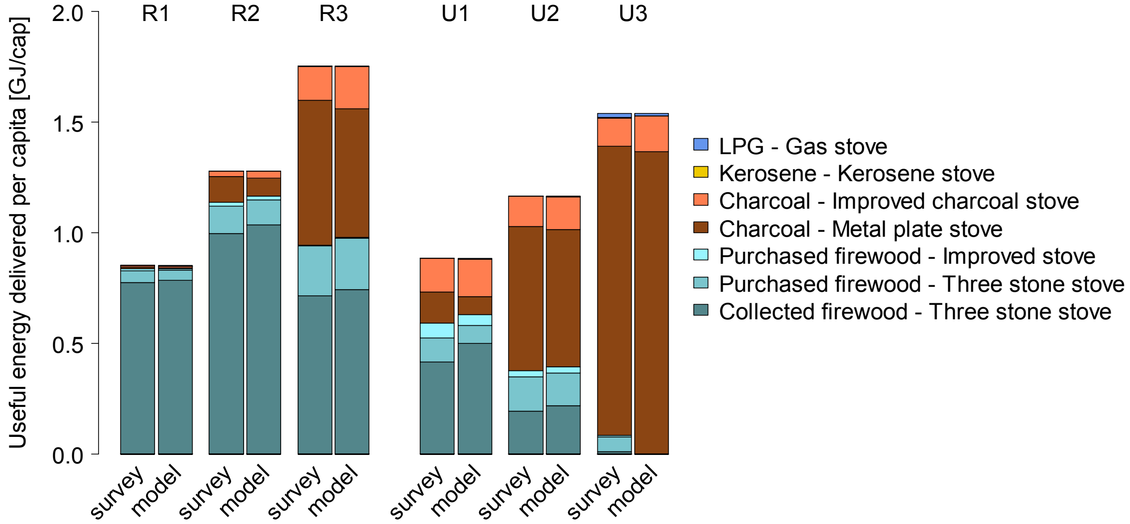

Figure 6-1. Comparison of cooking technology mixes in 2005 between the Ugandan survey data and the model results

6.3 No new policies (NNP) scenario

6.3.1 Population and GDP

The "No New Policies" (NNP) scenario is designed to serve as a baseline, to which other policy scenarios are compared to evaluate their effectiveness. The NNP scenario assumes that no energy access policies are implemented before 2030, and the rate of increase in price of charcoal of 2% per year (detailed explanation of the 2% increase is in Section 6.6).

The basic input data of population and GDP per capita used in the model is shown in Table 6-1. With the expected economic growth in Uganda, the population in both rural and urban moves slowly into high-expenditure groups as the years pass by. The GDP per capita estimates stay the same in static groups (R1, R2, U1 and U2) but grows in dynamic groups (R3, U3). One exception is in R3 in 2020, in which the average income slightly decreases compared to the previous period. This occurs because a high share of population moves from R2 into R3 in 2020. The new R3 population has an expenditure level closer to the lower bound of the cut-off level, or daily expenditure of 4.0 USD/day, which lowers the average expenditure of the whole group. However, since the number of people in the high-income group increases, the overall wealth of the rural population does increase. By the year 2030, the majority of the urban population belongs in the highest income group (U3).

Table 6-1. Population and GDP data in NNP scenario

	Population [million]				GDP per capita [2005 USD in ppp]			
	2005	2010	2020	2030	2005	2010	2020	2030
R1	15.07	14.07	10.90	1.93	456	456	456	456
R2	9.38	14.07	23.36	27.03	1460	1460	1460	1460
R3	0.65	1.17	4.67	19.31	2083	2211	2164	2597
U1	0.83	0.72	0.59	0.50	456	456	456	456
U2	2.10	2.52	3.84	3.01	1460	1460	1460	1460
U3	0.66	1.26	2.95	9.03	2371	2400	2795	3787

6.3.2 Number of people with access to clean cooking technologies

Disposable income increases with economic growth. Although only a part of the increase will be spent for cooking technologies, consumers become more willing to spend on higher quality energy services, such as cooking with gas stoves. This increasing interest is reflected in the cooking technology choice model by a shift in demand curves. All the conditions staying the same, shifted demand curves lead to a higher demand for clean cooking technologies. As a result, the ratio of the people using modern fuels increases. However, the increase is moderate, changing from 0.1% in 2005 to 0.5% in 2030. This rate is far from effectively reducing the total number relying on solid fuels. Population growth outpaces the rate of population gaining access, and from 2005 to 2030, the number of people without access to clean cooking technologies grows from 27 million to 60 million people (Figure 6-2).

One of the reasons for the moderate increase is the increasing price of LPG. Under the NNP scenario the fossil fuel prices increase as the global demand for fossil fuel grows (2005: 1.05 USD/kg; 2020: 1.07 USD/kg; 2030: 1.08 USD/kg). The higher price slows down the shift to clean cooking technologies, subduing the interest arising from economic growth.

Even among the highest urban expenditure group, the share of population using clean cooking technologies stays low at 1.5%. The increase in people without access under NNP scenario is consistent with other studies. IEA estimates an increase in the number of people relying on traditional biomass, agreeing with the World Bank and GEA (IEA 2012b, Pachauri et al. 2012, World Bank 2012b, Pachauri et al. 2013).

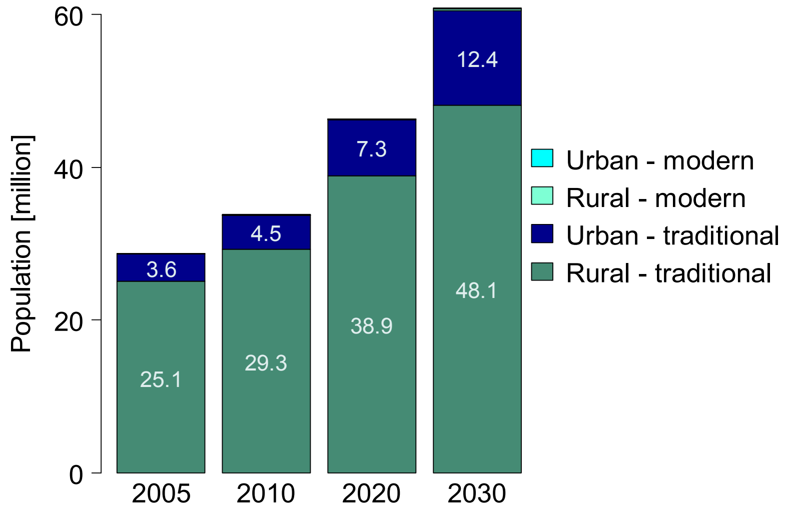

Figure 6-2. Number of people with and without access to modern fuels in NNP scenario

6.3.3 Cooking technology mix

Due to the expected rapid growth of the economy between 2020 and 2030, the share of charcoal in the country more than quadruples in a decade to nearly 30%. In the decade of 2020-30, the economic growth overshadows the rate of increase in price of charcoal of 2% per year, spurring the transition to more convenient fuels regardless of the price increase. The rural GDP per capita grows by 20% in a decade, and more than 30% in the urban area. Therefore, the share of charcoal declines until 2020, but it becomes the main urban fuel again in 2030. On the other hand, the access to clean cooking technologies remains a major problem in rural area, as more than half of the population uses collected firewood as their main fuel even in 2030.

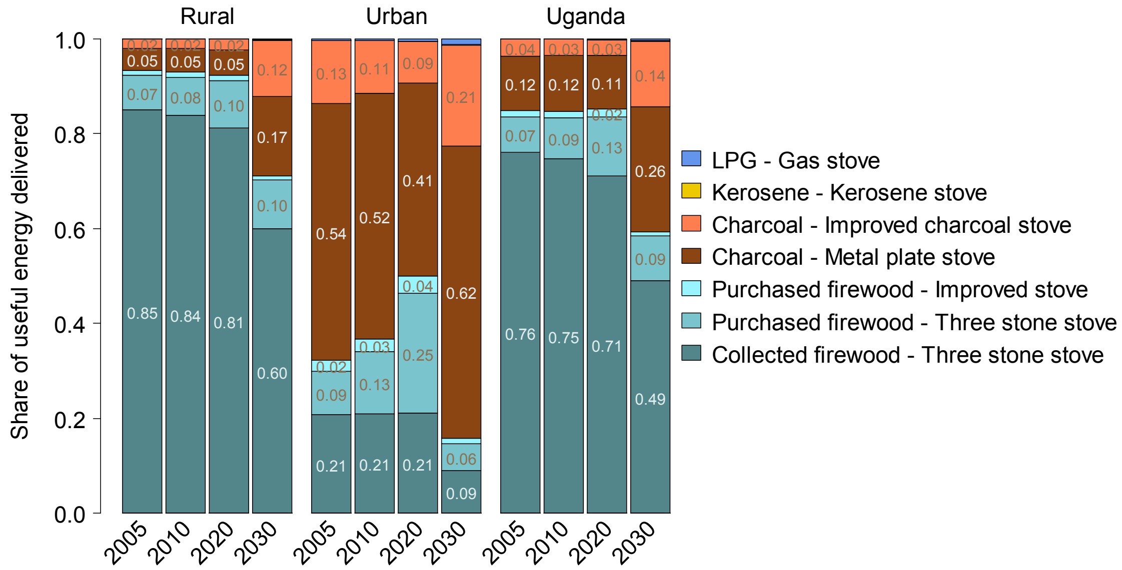

Figure 6-3. Shares of useful energy delivered by different cooking technologies under NNP scenario by household groups: rural, urban and Uganda

The shares of cooking technologies in 2030 compared across household groups show a shift from collected firewood to other fuels as income increases. The consumption of firewood decreases in rural and urban areas with an increase in income, and the use is completely faded out in high-income households in urban areas (U3). All of the cooking energies in U3 are delivered by coal, kerosene and LPG. The LPG also starts to penetrate the R3 market. However, the LPG share is only 0.5% in R3 and 1.5% in U3, which is far from reaching the target of universal access to clean cooking technologies.

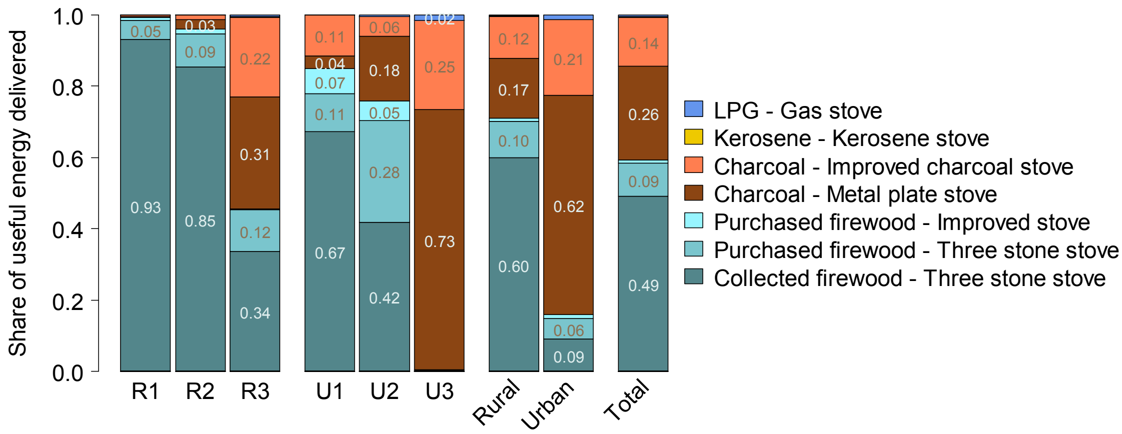

Figure 6-4. Shares of useful energy delivered in 2030 under NNP scenario by household groups: rural, urban and Uganda

6.3.4 Firewood consumption

The direct consumption of firewood for cooking increases from roughly 15 million tonnes in 2005 to nearly 30 million tonnes or 0.45 exajoule (EJ) in 2030. However, the rate of consumption does slow down after 2020, as consumers make a transition to charcoal. This shift to charcoal, which consumes firewood during the conversion process, contributes substantially to an increase in firewood consumption. Since Uganda employs mostly inefficient earth kilns to produce charcoal (10-15%), a conversion rate of 10 kg of firewood producing one kg of charcoal is assumed. With this conversion rate, the amount of firewood lost during the conversion reaches about 40 million tonnes (about 0.65 EJ) by 2030. Since the total yearly consumption of firewood is 84 million tonnes (equivalent to roughly 1.2 EJ) in 2030, this means more than half of the firewood energy is lost during the conversion process. If a more efficient production process of casamance kiln, which could double the efficiency, is used instead, the consumption of firewood lost during the conversion process could be halved. Halving the loss in 2030 would save 20 tonnes of firewood, which is approximately the total firewood consumption in 2005.

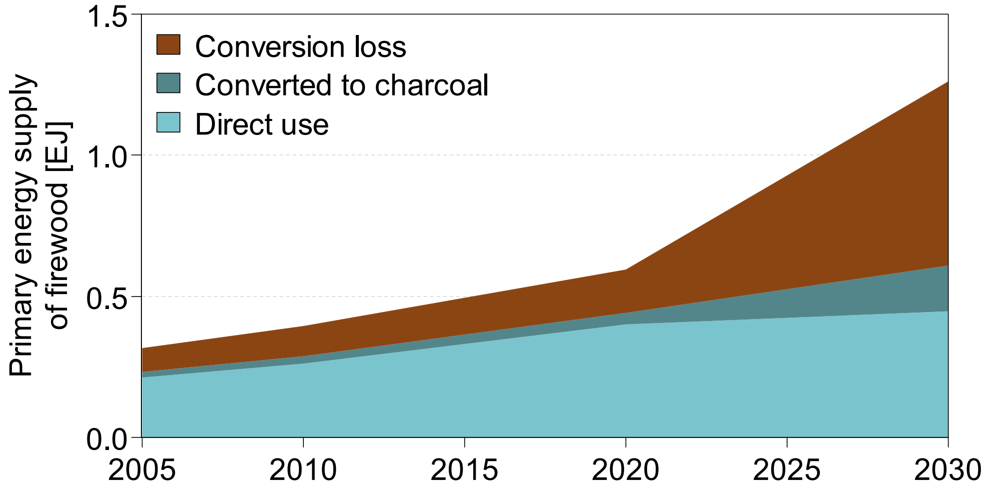

Figure 6-5. Firewood consumption in NNP scenario including the firewood use for charcoal conversion

6.4 Fuel price support and credit access for stoves

Removing or alleviating the financial constraints is a common method of facilitating the transition to clean cooking technologies. In this section, two financial policies are analysed. The first policy is a support on fuel purchases, alleviating the running cost of using modern fuels for cooking. The second policy is credit access, which decreases the upfront capital costs to lower the barrier of purchasing clean cooking technologies. To analyse the outcomes and the effectiveness of these two financial policies, the following 22 cases are analysed (Table 6-2).

Table 6-2. List of scenarios to analyse the impact of financial policies on access to clean cooking technologies

		cases	LPG price support	Credit Access
Fuel support scenario	1	ps10	10%	none
	2	ps25	25%	none
	3	ps40	40%	none
	4	ps50	50%	none
	5	ps60	60%	none
	6	ps75	75%	none
	7	ps80	80%	none
	8	ps85	85%	none
	9	ps95	95%	none
Credit access scenario	10	ca30	none	@30%
	11	ca15	none	@15%
	12	ca10	none	@10%
Combination scenario	13	ps25_ca30	25%	@30%
	14	ps25_ca15	25%	@15%
	15	ps50_ca30	50%	@30%
	16	ps50_ca15	50%	@15%
	17	ps75_ca30	75%	@30%
	18	ps75_ca15	75%	@15%
	19	ps85_ca30	85%	@30%
	20	ps85_ca15	85%	@15%
	21	ps95_ca30	95%	@30%
	22	ps95_ca15	95%	@15%

The fuel support scenario evaluates cases in which the price of LPG is reduced through a governmental support. The model does not specify any particular type of a support, but possible support types could be in a form of subsidy or allocation through public distribution. The scenario assumes that the average price paid by consumers falls at a given percentage point indicated in the scenario names. The percentage is calculated based on the 2005 price of 2.17 USD/kg. As an example, the "ps50" case provides a support of 1.09 USD/kg, equivalent to 50% of the 2005 LPG price. The support on fuel purchase is implemented from the calculation period of 2020, and the support level is kept constant until 2030.

The credit access scenarios consider a financial support to purchase cooking stoves. The cooking technology choice model uses variable implicit discount rates ranging from 50% to 77% depending on the household expenditure level. Higher implicit discount rates indicate that the consumers give future money a lot less value, which makes them hesitant to purchase things that require a long payback period or a high upfront investment. The credit access allows the upfront payment to be paid back over a certain period at a low interest rate, reducing the risk that consumers feel in purchasing efficient yet expensive stoves. Microfinance, grants or lending stoves would be examples of such policies. For a sensitivity analyses, different rates at which the consumers receive the support are evaluated. The percentage is similar to interest rates, so the lower the percentage, the more helpful it is for the consumers.

Finally, there is also the last scenario of combination cases, in which fuel support and credit access policies are both applied to the consumers. By providing assistance for both fuel purchase and stove purchase, the scenario attempts to facilitate the uptake of clean cooking technologies. Ten combination cases are analysed to evaluate a good combination range for an effective policy.

6.4.1 Fuel support scenario

The model results show, as expected, that the LPG price support allows the consumers to shift to modern fuels at a faster rate (see Figure 5-6). With 85% price support (ps85) or 1.84 USD/kg, over 20 million people switch to modern stoves as their main cooking technology. With 95% price support (ps95), the clean cooking technology users reach 45 million, or 75% of the population. The main beneficiaries in the fuel support scenario are the urban population, with over 98% gaining access to clean cooking technologies in ps85. Overall, however, the results reveal that even with 60% price support (ps60), over 95% of the total population remain using traditional fuels.

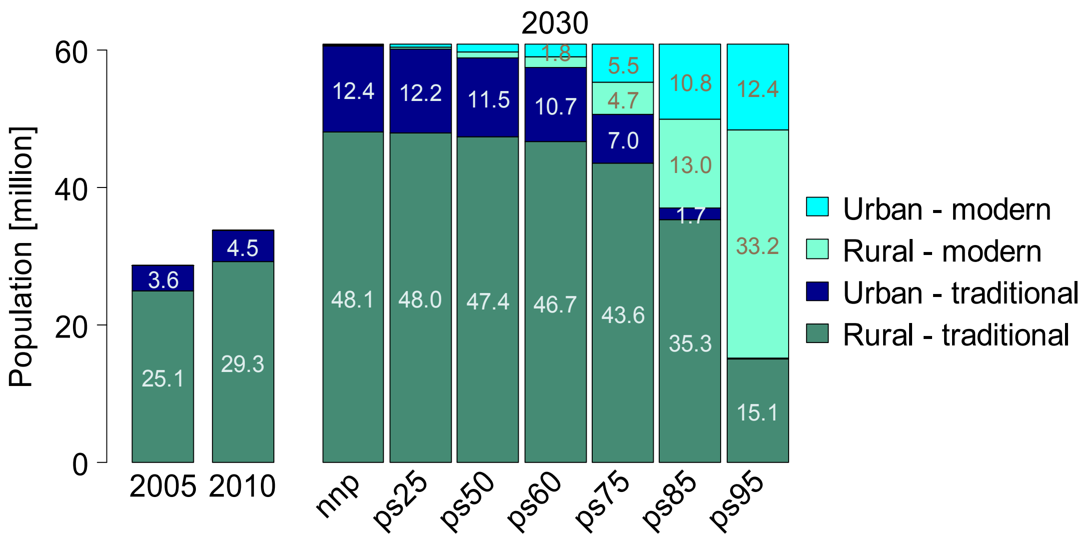

Figure 6-6. Number of people with access to modern fuels in 2030 under fuel support scenario

The LPG prices are the same among all households, so the difference in the uptake of the technology depends on the utility that consumers place on cooking with LPG. With more disposable income, the highest expenditure group is the first to make the switch to gas stoves. The transition is slow, but already in the ps10 case, consumers start to make the switch. Figure 6-7 shows the changes in the shares of population using modern fuels among different groups with increasing fuel support. In the ps85 case, 100% of the population in U3 switches to gas stoves. However, the situation among the low-income groups (R1 and U1) is different. The acceptance rate of gas stoves is less than half, even in ps95. Since a 95% price support means LPG is being sold at 7 cents/kg, the result signifies that even if the fuel were to be free, the high upfront cost of gas stoves would hinder most of the consumers in low-income groups. With a limited disposable income, most low expenditure groups prefer to spend their money on other important things such as food and education rather than on higher quality cooking technologies.

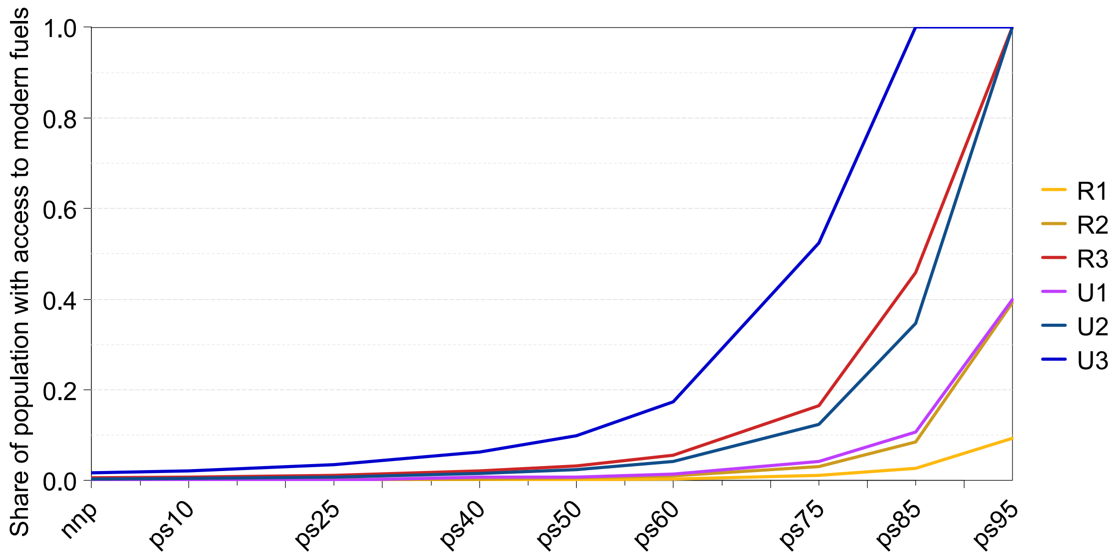

Figure 6-7. Number of people with access to modern fuels in 2030 under fuel support scenario by household groups

These observations suggest that if only the LPG price support policy is implemented to propagate energy access, there are almost no improvements in the cooking technology mix in the low-expenditure groups. Along with LPG, the price of charcoal is increasing at 2% per year in these scenarios. The consumers who do not choose LPG at low prices are also the population who do not see the value in spending additional money on charcoal purchases. Therefore, the cooking technology mix in the ps95 case becomes top and bottom heavy, meaning only the modern technology of LPG or the most traditional technology of firewood is chosen, crowding out the use of charcoal, as seen in Figure 6-8.

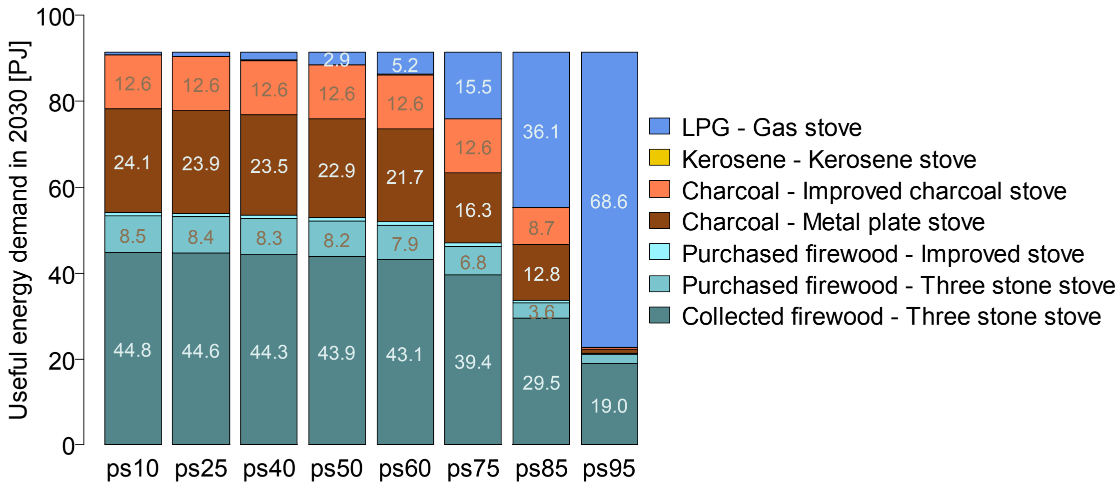

Figure 6-8. Change in useful energy demands under fuel support scenario

6.4.2 Credit access scenario

The credit access scenario provides different levels of incentives for each household group. The policy allows the consumers to get a financing option to purchase stoves at a given lower rate. The implicit discount rates of household groups differ. This means, in relative terms, that unlike in the fuel support scenario, the consumers with higher implicit discount rates, or those in the low-expenditure groups, would receive more assistance than those in the high-expenditure groups.

For the cases in which credit access is offered as the single energy access policy, access rates change or shift very little. The access level in 2030 stays at less than 1%, even when a credit rate of 10%, a rate comparable to industrialised countries, is offered. The most recommended policies are the ones that enable assistance to widely reach the low-income households. However, the impact of a single policy is very limited. Unless support for energy access is granted from multiple angles simultaneously, the resulting changes will be minimal.

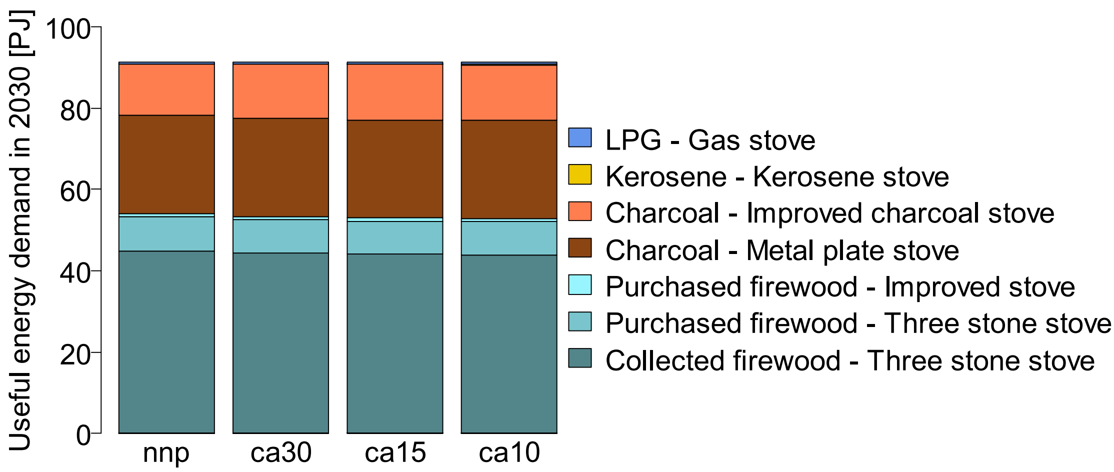

Figure 6-9. Changes in useful energy demands under credit access scenario

6.4.3 Combination scenario

With a limited success of fuel price support or credit access on its own, the logical next option would be to combine the two policies. By providing support for both parts of the cooking cost, fuel price and stove cost, access to higher cooking technologies should be facilitated.

Figure 6-10 shows the results of the cooking technology mix in the high-income households in rural areas (R3), when 75% price support (ps75) is combined with a credit access policy at different rates. With only fuel price support, 16% of the consumers take up gas stoves, and 22% rely on improved charcoal stoves as their main cooking technology. When credit access of 30% is added to the same fuel price support, the number of LPG users goes up to 22% (+6%), and improved charcoal stove users go up to 23% (+1%). Because the main benefit of credit access is a reduction in the cost of upfront investment or a delay in the payment, this policy is more effective for technologies with big upfront costs, such as gas stoves and other clean cooking technologies. When credit access rate further drops to 15%, LPG users increase to 27% (+11%).

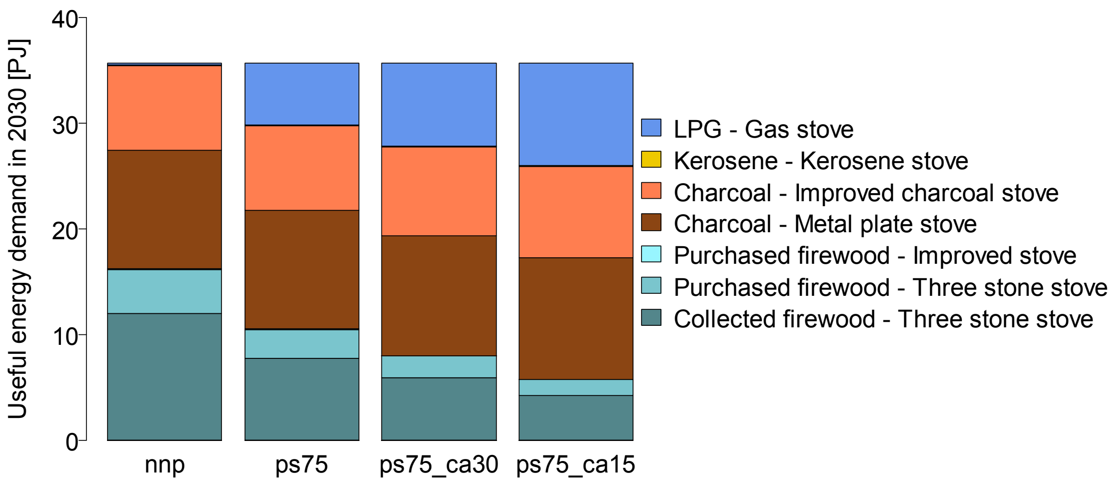

Figure 6-10. Changes in useful energy demands in rural high-income households in 2030 under a combination scenario with fuel price support of 75%

Combining fuel price and credit access policies also has synergy effects. Since the relationship between the cooking technology price and demand is not linear, the penetration rates of gas stoves and other upfront cost heavy stoves increase more rapidly as the transition point in cooking technologies is approached. As seen in Figure 6-11, the effectiveness of credit access policies is limited in the high-income households in urban area (U3) when the LPG price support is 25% or 50%. However, when the support is raised to 75% there is a rapid increase in the switch rate, showing that the price is approaching the transition point. Therefore, when a credit access of 15% is applied on top of the 75% price support (ps75_ca15), the effect of credit access is multiplied, and LPG users increase by roughly 50%. The turning point for Uganda as a country occurs between 75% and 95% price support, as shown in Figure 6-12. The 95% fuel support on its own leaves over 20% of the population using traditional fuels, but combined with a credit access of 15%, practically the entire population switches to cooking with LPG.

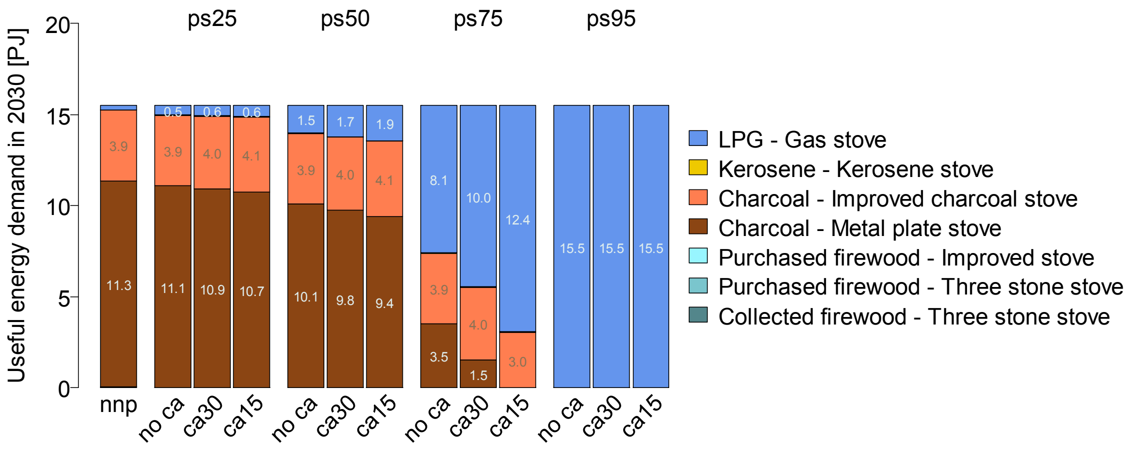

Figure 6-11. Changes in useful energy demands under combinations of fuel price support and credit access scenarios in high-income households in urban areas

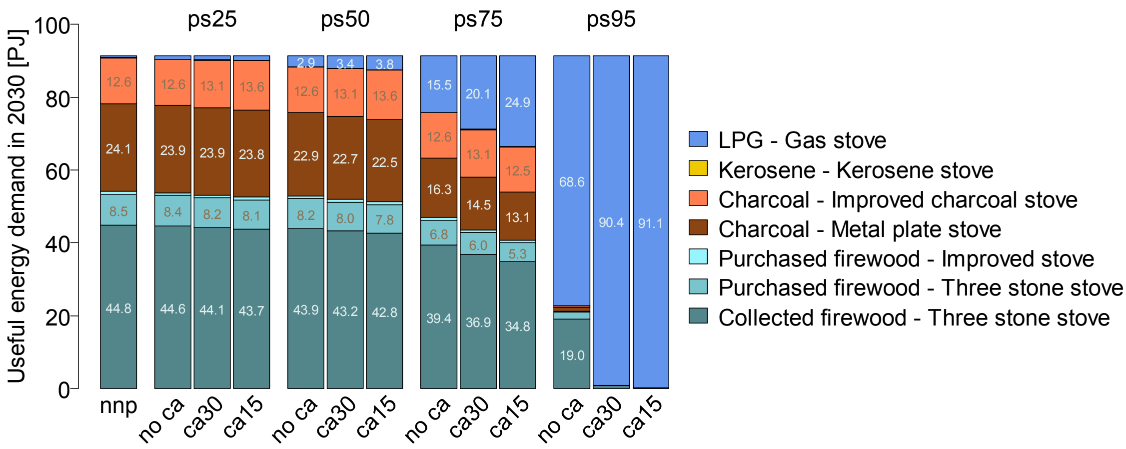

Figure 6-12. Changes in useful energy demands in Uganda in 2030 under the combination scenario

6.4.4 Policy costs

Currently, no support is provided for the purchase of kerosene or LPG in Uganda. Given the possibility of a high fuel price support to drastically increase the number of clean cooking technology users, ideally, as much financial support as the budget would allow should be allocated. However, fuel price support policies place a heavy burden on the government budget, and cooking energy transition is only one of the many needs in Uganda. Action plans must be carefully considered to decide the most effective level of support for the country.

Fuel price support can take many forms such as tax reduction or fuel stamps, but in most cases the cost needs to be covered by the government. The support needs to be sustained for the users to continue using LPG, so the support cost accumulates over the years. If a LPG price support policy is assumed to be implemented in the year 2016, the model results show that the cumulative cost of implementing a fuel price support of 95% (ps95) could total 5.25 billion USD over 15 years, or an average of 350 million USD per year. The projected GDP in Uganda according to GEA is 27 billion USD in 2020 and 73 billion USD in 2030 (both in MER), so the annual cost of 350 million USD would be 1.3% of the national GDP in 2020 and 0.5% in 2030. 95% price support does accomplish close to full access in urban areas (99%), but it still leaves 30% of the rural population, or 15 million people, without access to clean cooking technologies. A high burden policy, which fails to provide the necessary support for the low-income households in rural areas, is unlikely to be accepted by the public.

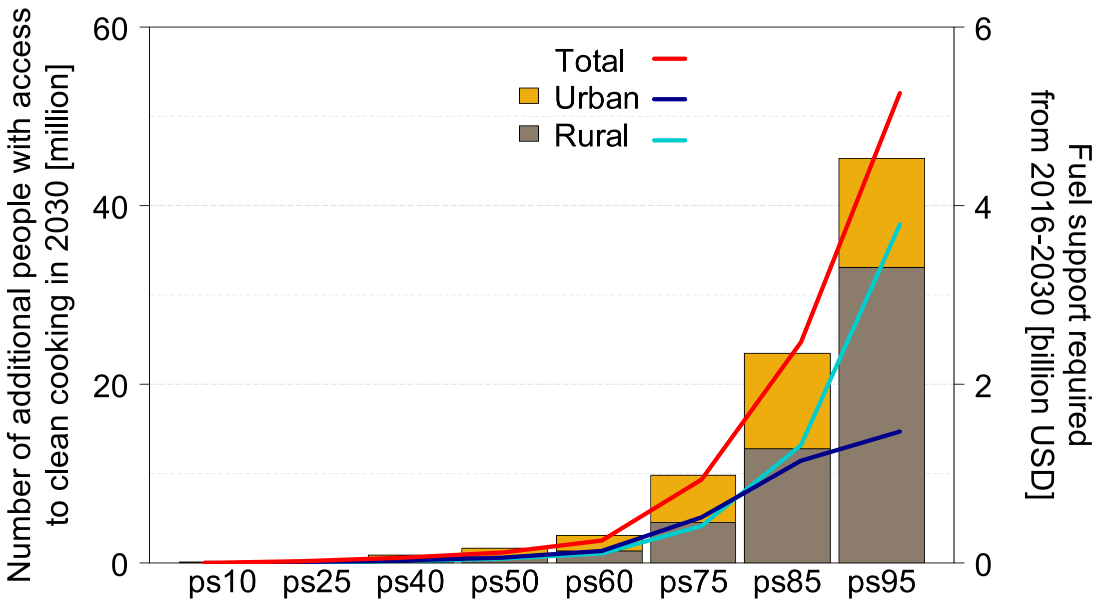

Figure 6-13. Number of people with access to modern fuels in 2030 and the cumulative cost of fuel price support policy

Providing credit access at 30% or 15% can be considered to not bear any cost to the government, as the interest rate of Bank of Uganda in 2013 was around 15%. Although the cost will be recovered when the payments are received, the challenge in providing such a service is the need to mobilise considerable funding. The required funding to support credit access policy is the cost of stoves multiplied by the number of households that gains access to new stoves. Using the stove cost and analysis results from Chapter 5, the estimated funding needed to support credit access policy could reach more than one billion USD, if most households were to take advantage of the policy (Figure 6-14).

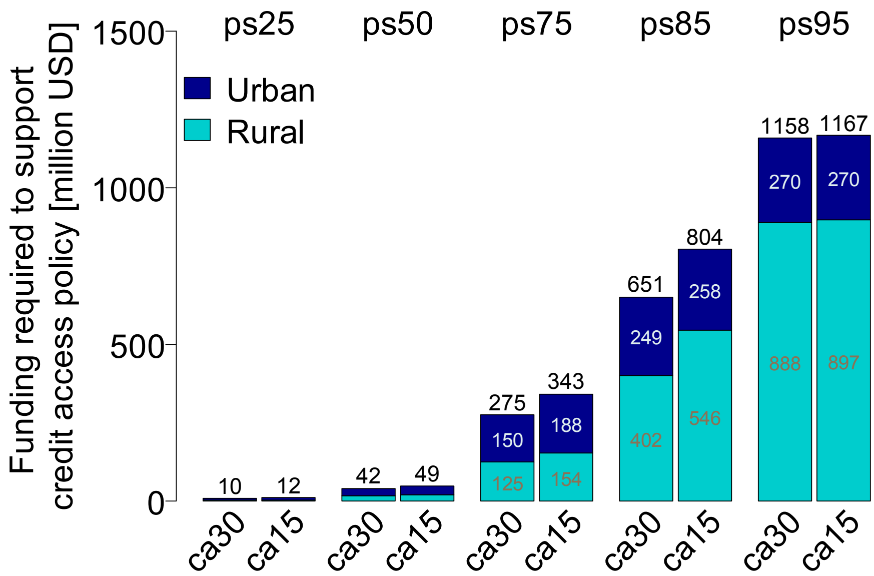

Figure 6-14. Funding needed to support purchase of stoves through credit access policy

In order to secure 50% access rate to clean cooking technologies in 2030, a 75% price support and credit access at 30% (ps75_ca30) are required in urban areas, whereas an 85% price support and credit access at 15% (ps85_ca15) are needed in rural areas. The cost analysis of these policies over 15 years show that they would require 3448 million USD to provide fuel price support (urban: 643 million, rural: 2805 million) and 696 million USD to manage credit access (urban: 150 million, rural: 546 million). Because implementation can take place over a period of time, the required amount of money does not have to be prepared all at once, but ultimately, over 4 billion USD will be required in order to support such programmes.

6.5 Impact of climate change policy on energy access

The analysis in this section focuses on the impact of a climate change policy on clean cooking technology transitions in Uganda. Under a global target that limits GHG emissions, fossil fuel prices increase. Because a shift to clean cooking fuels requires an increase in the consumption of fossil fuels, the increase in fossil fuel prices slows down the transition to clean cooking technologies.

The reduction of GHG emissions is a good cause that should be pushed forward, not only for industrialised countries but also for developing countries. However, if the reduction causes populations in developing countries to revert back to using traditional fuels, the policy will have a strong negative side effect, including the loss of many lives. The importance of transition to clean cooking technologies should not be overshadowed by the aspiration to stabilise the global climate, and any climate change policy needs to consider the potential of delaying a step toward universal access to modern fuels.

The Kyoto Protocol was the first attempt to bring all the parties together to agree on an emissions reduction path, but it only brought a limited success, as the biggest emitter at the time, the United States of America, did not ratify the protocol. The emissions in developing countries grew rapidly during the period covered by the Protocol, 2008-2012. Learning from the past mistakes, another international negotiation has been concluded (The Paris Agreement) during the 21st Conference of the Parties (COP21) of the UNFCCC in Paris. The agreement, which includes emissions reduction from all countries, was adopted by consensus on 12 December 2015. A long-term target of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels" has been established, but an emissions pathway to achieve the target has not been agreed upon, and international negotiations and reviews will continue as needed.

There are many possible reduction strategies to satisfy the agreement. Equity has been one of the key terms in the discussion of climate change and climate change policies, and the phrase "common but differentiated responsibility" has been the centre of many international negotiations and discussions. However, a consensus on a "fair" attribution of responsibility is far from being reached, and there are limited discussions on how these agreements may affect transition to clean cooking technologies among developing countries.

Only time will tell how much burden each country will carry to achieve the climate change target. In this analysis, noting that additional efforts to limit the temperature increase to 1.5°C is a possibility, only one basic climate change scenario is used: that of achieving the concentration of CO_2 in the atmosphere to 450 ppm in 2100 to keep the temperature increase to 2°C or below. The climate change target is implemented in the global energy model, which then reflects the effect of the climate change policy through the increase in fossil fuel prices.

6.5.1 Impact on fuel prices

A target to reduce GHG emissions penalises the use of fossil fuels, affecting petroleum-based fuels including LPG and kerosene. In the analysis using MESSAGE to achieve 450 ppm in 2100, the LPG price goes up 3.33 USD/GJ (0.15 USD/kg) in 2020, and 4.87 USD/GJ (0.22 USD/kg) in 2030. The LPG prices in each time period for climate change policy scenarios are shown in Figure 6-15.

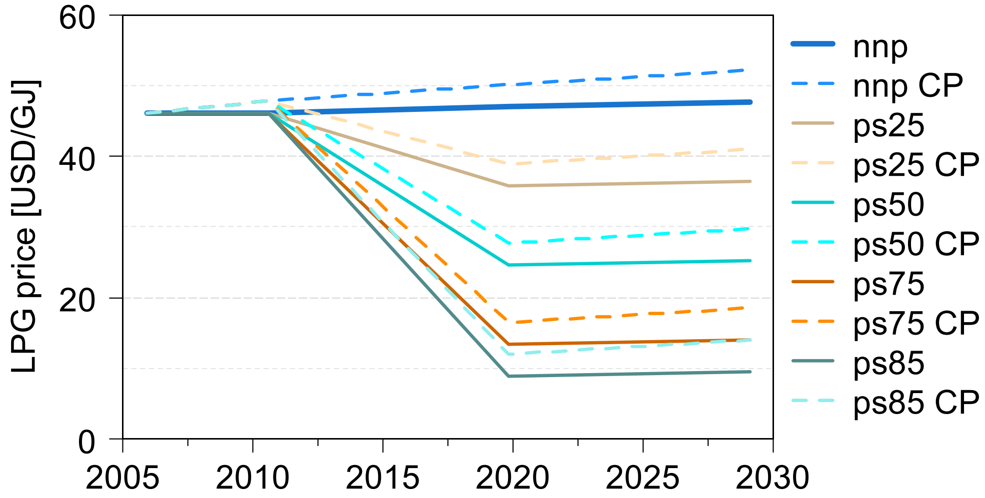

Figure 6-15. Changes in LPG price under climate change mitigation policy of 450 ppm and fuel price support scenario

Increased LPG and kerosene prices cause a reverse shift back to traditional fuels such as charcoal and firewood. In climate change policy case, the LPG price increases by 4.87 USD/GJ in 2030, an amount that is roughly equivalent to 10% of the LPG price in 2005. Therefore, the result of an 85% price support (ps85) with an emissions reduction target is comparable to a 75% price support (ps75) without an emissions reduction target. If Uganda is to reach the millennium target of universal access to clean cooking fuels by 2030, rise in cost of fossil fuels will be a major obstacle. A simple reduction target could require the government to offer an additional 10% support for LPG cost, compared to the absence of such a target.

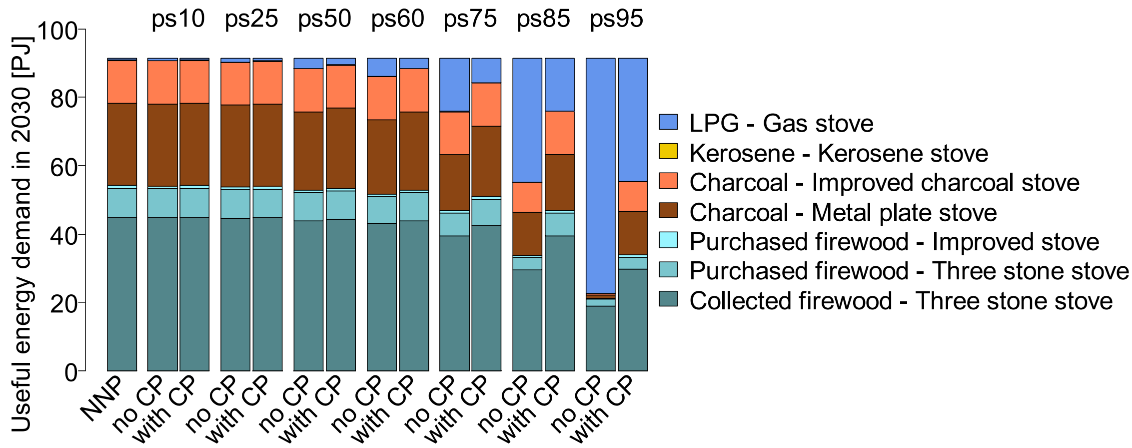

Figure 6-16. Changes in useful energy demands in 2030 under the climate mitigation policy of 450 ppm and fuel support scenario

6.5.2 Effects on the household groups

When changes in the access rates are compared across household groups, the most affected groups are the highest expenditure groups. When changes in the access rates are compared across household groups, the most affected groups are the highest expenditure groups. Economic growth makes many in this category willing to pay for gas stoves, but their affluence is just at the threshold level of where they are willing to make the shift. This means that an increase in LPG price caused by climate change policies could give just enough pressure to push them back to using traditional stoves. A similar challenge would have hit low-income households as well, if they had switched to gas stoves. However, the level of gas stove users is barely over 10% in R1, even with a 95% fuel support (ps95). Therefore, the impact of climate change policies does not cause a huge reverse shift in these household groups.

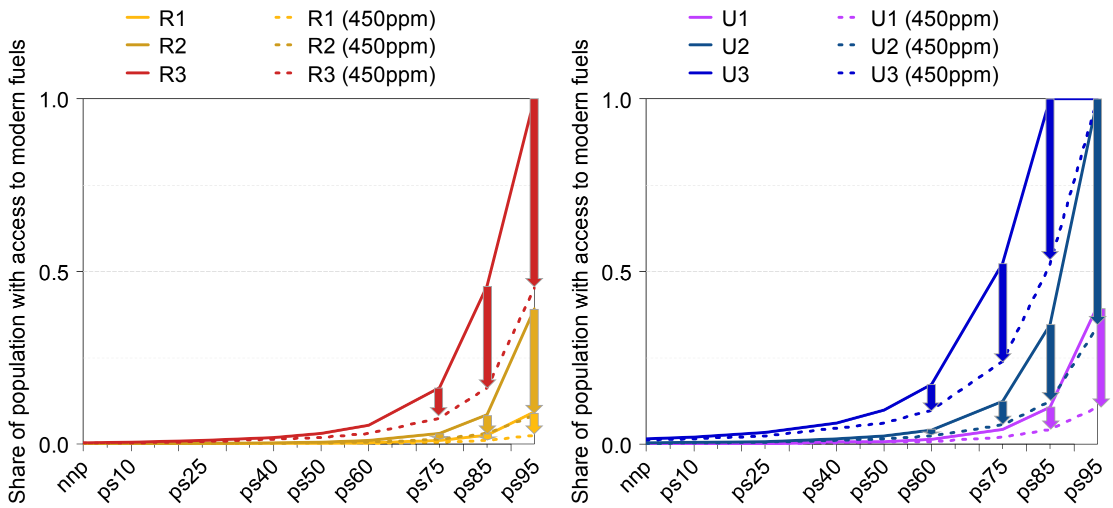

Figure 6-17. Changes in the number of people with access to modern fuels with emissions reduction target in 2030 under different fuel price support scenarios

6.6 Charcoal price sensitivity

One of the key parameters that changes the technology mixture is the price of charcoal. The price of charcoal is provided based on the past price trend, unlike prices of fossil fuel, for which an iteration calculation is made between the cooking technology model and MESSAGE to assure a consistency between fossil fuel prices and fossil fuel consumption. Biomass products used for cooking do not have a global market that determines their prices, and energy use makes up only a small part of their total use. The future price of charcoal depends on many factors. A new road improving transportation access may lower the price, or a shortage of LPG may increase the price. A detailed regional biomass analysis looking not only at the cooking sector but at all the sectors would be required to determine the future prices of biomass products. Furthermore, even with a full representation of the biomass consuming sectors, the locations of biomass also need to be considered to reflect proper regional prices.

Although the importance of including non-energy factors is noted, it is beyond the scope of this dissertation to represent the biomass sector in full details or to create a spatial model to reflect the geographical availabilities of biomass. Therefore, a sensitivity analysis using various price paths is used to assess the effects of changes in the price of charcoal. Figure 6-18 shows the recent trend of average charcoal prices in Uganda in Kampala's middle and low-income households (UBOS 2006a, UBOS 2012). Price had stayed fairly constant over the first half of the decade (average increase of 1% per year from 2001-2005) but from 2006 began to increase at a relatively rapid pace (average of 3% per year from 2006-2010). This increase in the average market price can be attributed to firewood becoming scarce around dwelling areas and frequent shortages of LPG. A report published in 2009 by the Ministry of Water and Environment suggests that, if the current trend continues, Uganda would need to import firewood in 2020 (MWLE 2009). The lack of firewood for energy would create a vicious cycle in which the poor must sacrifice other basic needs for fuel purchase.

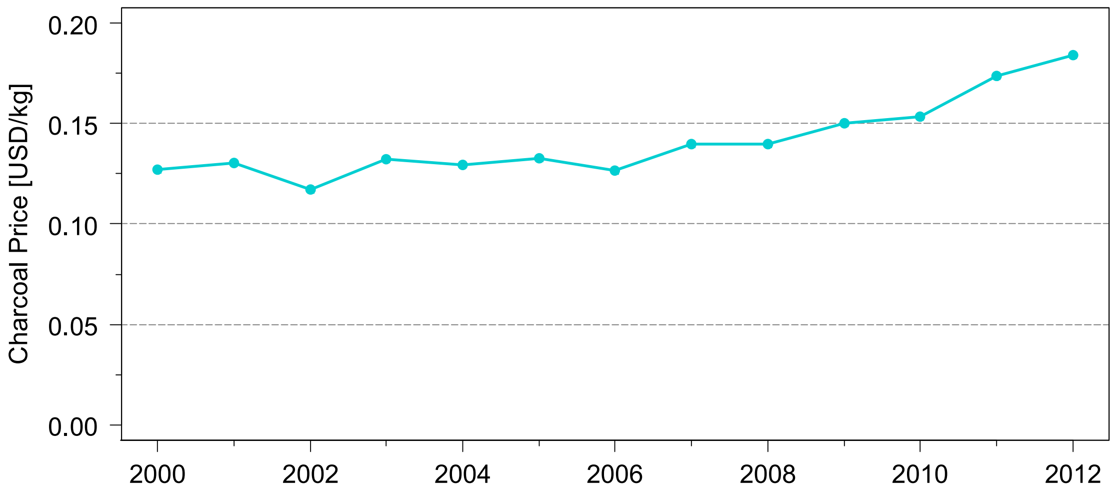

Figure 6-18. CPI adjusted charcoal prices in Uganda from 2000-2012

In this analysis, a price sensitivity method is used to assess the effects of various trends in prices of charcoal. The average rate of increase in price of charcoal of 2% per year between 2006 and 2010 is used as a base, which is the rate used in the NNP scenario. The charcoal scenario considered are listed in Table 6-3.

Table 6-3. Cases considered in the charcoal scenario

	Cases	Rate of increase in price of cahcharcoal	Charcoal price in 2030 [USD/kg]		
			U1	U2	U3
1	ch_1.0	1.0% per year	0.11	0.10	0.10
2	ch_1.5	1.5% per year	0.13	0.11	0.11
3	NNP	2.0% per year	0.14	0.13	0.13
4	ch_2.5	2.5% per year	0.16	0.15	0.14
5	ch_3.0	3.0% per year	0.18	0.17	0.16

6.6.1 Change in energy use

In rural areas, the useful energy composition shows a rapid shift back to firewood as the rate of increase in price goes up. One result to note is that due to the higher efficiency of improved charcoal stoves, a shift back to firewood is slower for their users than for the metal plate stove users. When using stoves with a higher efficiency, the fuel price plays a smaller role in the decision making process. Due to the different rates of shifting back to firewood, the amount of metal plate stove users and improved charcoal stove users become about the same at 3% rate of increase in price, as seen in Figure 6-19.

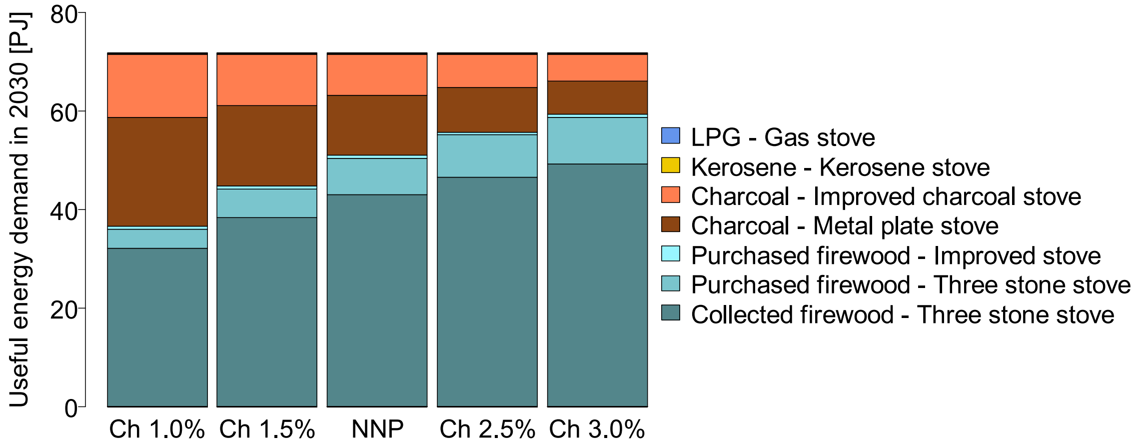

Figure 6-19. Useful energy demands in rural areas in 2030 under different charcoal price scenarios

The analysis of useful energy composition in urban areas shows slightly different patterns. In contrast to the observations above, in urban areas the metal plate stove users decrease when the rate of increase in price gets below 2%, as well as when the rate gets above 2%. On the other hand, similar to rural areas, an increase in the adoption of improved charcoal stove is observed as the rate of increase gets lower (Figure 6-20).

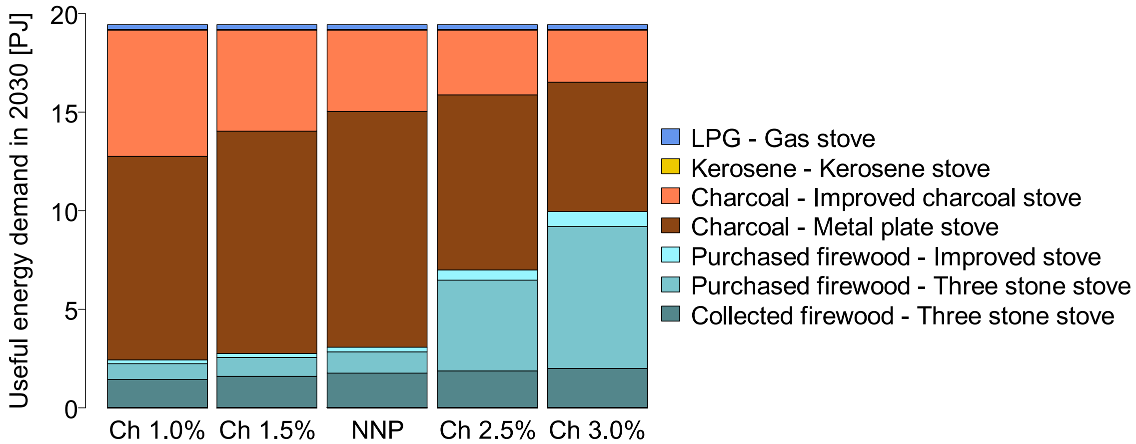

Figure 6-20. Useful energy demands in urban areas in 2030 under different charcoal price scenarios

The reason for this peculiar trend is due to the saturation of charcoal demand in U3. The energy choice trend of U3 shows that, with the 2% rate of increase in price, almost all of the demand is supplied by non-firewood technologies. Therefore, a decrease in the price of charcoal does not help to increase charcoal use and only makes some users to shift to improved charcoal stoves. On the other hand, rate of increase higher than 2% causes a switch back to firewood, as seen in rural areas. These two trends combined creates an odd peak of metal plate stove use around the 2% rate, which is the NNP scenario (Figure 6-20).

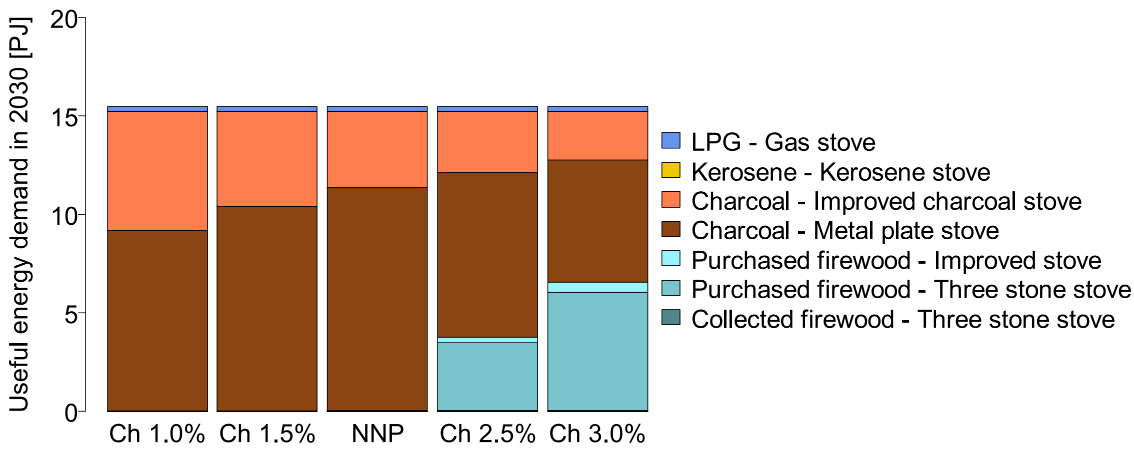

Figure 6-21. Useful energy demands in U3 under different charcoal price scenarios

6.6.2 Change in biomass consumption

An increase in the price of charcoal causes a shift towards direct burning of firewood. When the annual rate of increase in price changes from 1% to 3%, direct firewood consumption increases by 75%. However, because of the inefficiency of charcoal production, the shift back to direct firewood use actually has a positive impact of reducing the total firewood use. The total firewood consumption is 1.46 EJ with a 1% annual rate of increase, but the consumption becomes 1.04 EJ with the rate of 3%.

If a modern charcoal production process is adopted, the amount of firewood consumption can be cut back drastically. An improved charcoal production process would lead to a decrease of 0.68 EJ or about half of the firewood consumption in the 1% rate of increase scenario, and a 0.28 EJ decrease even with 3% rate of increase. As the result of improved conversion efficiency, firewood consumption among all cases becomes about 0.77 EJ, as seen in Table 6-4. The charcoal production process could become a key determining factor for the deforestation rate and also the prices of charcoal.

Table 6-4. Consumption of firewood in charcoal price scenarios with two different charcoal conversion rates

[EJ]			10kg firewood = 1kg charcoal		4kg firewood = 1kg charcoal	
	2005	2010	2020	2030	2020	2030
ch_1.0	0.32	0.40	0.64	1.46	0.48	0.78
ch_1.5	0.32	0.40	0.62	1.34	0.48	0.77
NNP	0.32	0.39	0.60	1.26	0.48	0.77
ch_2.5	0.32	0.39	0.58	1.13	0.48	0.77
ch_3.0	0.32	0.39	0.56	1.04	0.48	0.76

6.7 Analysis and discussions

Despite the many blessings offered by technological advancements and economic growth, their benefits are yet to trickle down to low-income countries. Among the poor, cooking energy use has remained relatively unchanged over the last century. With their chronic reliance on solid fuel consumption, demand for wood and charcoal is expected to continue growing over the coming decades. This means women and children will continue gathering firewood, spending less time in education or other income generating activities. Harmful particles produced from burning firewood and charcoal for cooking will continue causing respiratory diseases. Cutting down forest trees for charcoal production will continue degrading the environment.

Energy access policies must be combined with other poverty eradication goals. Dedicated energy access policies should enable consumers to make the transition to more convenient and less physically demanding cooking technologies. The switch would not only bring financial savings but also improve social and environmental situations. However, in order to make the transition to sustainable clean cooking technologies, there must be well-targeted policies backed by significant additional funding. Policies need to be designed to deliver acceptable solutions to the local communities and also be independently sustainable, not requiring constant additional assistance from the government or outside communities. Finally, they need to lead to a business cycle, allowing assistance efforts to fade away with time.

6.7.1 Fuel price support and credit access policy

Providing fuel support on LPG can facilitate the transition to non-solid cooking technologies. The population using clean cooking technologies was a mere 0.5% under the No New Policies scenario in 2030. This number drastically improves when the LPG price support is provided. With a 75% price support the access rate increases to 17%, and with an 85% price support the rate increases to 40%. Combining credit access policy with fuel price policy further improves the situation. Providing a 15% credit access to purchase stoves, in addition to the 85% price support, can result in 65% of the population using clean cooking technologies.

However, providing subsidies is often fiscally demanding, and it can reduce motivation for energy efficiency measures while crowding out funding for other priorities. Providing a high amount of subsidy on fuels can also lead to market distortion. When extremely low subsidised fossil fuels prices are offered, it is a common problem for the fuel to be smuggled out of the country and be resold at much higher prices or for a black market to exist within the country. It has been reported that approximately 40% of subsidised kerosene ends up in a black market in India (Our Economy Bureau 2005). A price gap can cause consumers to practice such illegal activities as seen in Iran and India, and this is difficult to control (IEA 2010a, Shenoy 2010). LPG subsidies can also be diverted to non-residential sectors. India has seen LPG sold to commercial and transport sectors, where the fuel was not subsidised (Shenoy 2010).

Another concern with providing subsidy is getting rid of it. Once a subsidy is set in place, it becomes extremely difficult to remove the price support. India implemented kerosene subsidy in 1957 to stabilise the price for residential consumers, and the subsidy still continues today despite many attempts for a reform. There is a strong political pressure to maintain the subsidy, as the life of low-income households depends heavily on it (Shenoy 2010). The pressure also comes from participants in the black market, who make a profit from the subsidy. In order to push a reform forward, a public information campaign to convey the shortcomings of subsidies may be necessary, as it has been done in Gabon, Ghana and Indonesia (Arze del Granado et al. 2012).

Additionally, fuel price support policies often lead to supporting the high-income households rather than the low-income households, especially for fuels whose consumption increases with income. Arze del Granado et al. (2012) examined welfare impacts of increasing fuel prices in 20 developing countries and found that the richest 20% benefited on average six times more from fuel subsidies than the poorest 20%. Similarly, Coady et al. (2010) estimate that 80% of the benefits of universal petroleum subsidies goes to the richest 40% of the households. A similar trend has also been observed in this study. Even with an 85% price support, the low-income groups were not able to switch to LPG, whereas the highest income group in urban areas made a complete switch to gas stoves, receiving all the benefits.

The credit access policy to provide financing for stove purchase is financially more sustainable. The lifetime of a gas stove is roughly 10 years, so the financial need occurs only once in a decade for a household. In addition, the credit provided should be repaid over time, technically not costing the government anything other than the difference between the credit rate given and the inflation rate. Nevertheless, it does require the government to mobilise and prepare money for lending out. Amassing such a large financial resource will be a challenge especially in a country like Uganda with limited funding.

Although the financial burden is much less than the fuel price support, as model results have shown, credit access by itself has a very limited effect on providing access to clean cooking technologies. The high fuel prices remain as the main hindrance in making the transition. The model results showed less than 1% access level in 2030 when credit access was the only energy access policy offered. Unless fuels also become affordable, consumers have no motivation to switch to new stoves, even if stoves become accessible. For a credit access policy to become effective, it must be combined with fuel price support policies.

6.7.2 Bridging policies

Fuel price support has been implemented in various countries despite the many drawbacks, and on the upside it is an attractive policy to rapidly approach the target of universal access by 2030. One of the drawbacks is the substantial financial burden, however, which the government of Uganda is unlikely to be able to afford without international help. The LPG price support of 85% would require nearly 2.5 billion USD over 15 years. Credit access of 15% on top it requires preparing 800 million USD to finance the purchase of gas stoves. Preparing 3.3 billion USD for energy access problem alone is an enormous task for a country expected to have a GDP of about 30 billion USD in 2020. With so much financing required to implement the policies, a new financial and institutional framework will be required by the government (IEA 2010b). Additionally, capacity building at local levels will also be necessary to rapidly scale up access to modern energy services in the region.

With limited resources available for financial policies, improved cookstoves need to be considered as a bridging option. Although improved stoves are not at the same level of convenience as gas stoves, they can still alleviate problems associated with cooking by reducing negative health impacts and the labour of collecting firewood, all while still using the same fuel. This is why some institutions, consider improved biomass cooking stoves to be a clean cooking technology solution. IEA supports this idea of treating improved cookstoves as a bridging option. In their analysis towards universal access by 2030, an assumption is made that only 30% of the rural households will be supplied by gas stoves. The rest of the rural population will be supplied by advanced biomass stoves and biogas home systems (IEA 2012c). For Uganda, that value likely will be lower considering the economic development level. The government of Uganda does realise the importance of improved cookstoves. In the *Renewable Energy Policy of Uganda* published in 2007, the MEMD sets a goal of having 4 million improved firewood stoves and 250,000 improved charcoal stoves by 2017 (MEMD 2007). These were ambitious targets, especially for the improved firewood stoves, which stood at 170,000 as of 2007.

As of 2010, the number of improved charcoal stoves was estimated to be roughly 70,000 (MEMD 2012).

This is not to suggest that policies to promote LPG should be taken lightly but rather that they should to be implemented with great care. The low economic status in rural areas means a forceful promotion of LPG may require an unsustainable amount of support. LPG is hardly a recommendable solution with the current purchasing power of rural Uganda, thus alternative plans must be sought. The promotion of gas stoves should begin with urban areas then be expanded to include rural areas once economic development takes place. There is a possibility that discovery of oil and gas in Lake Albert could provide cheaper LPG gas in the coming decade. However, the scenario analysis of fuel price support shows that even if the LPG price were as low as 0.3 USD/kg (roughly the ps75 case), access to clean cooking technologies remains at 10%. Even with a discovery of a domestic energy source, some degree of support from the government will be imperative to make the fuel affordable for the rural population. Improved cookstoves could be the necessary stepping-stone toward a full transfer to modern technologies.

6.7.3 Acceptance of improved cookstoves

Although it seems reasonable to assume that consumers would prefer to use improved cookstoves that can reduce fuel consumption and indoor pollution, there are some doubts as to whether this is actually the case in Uganda. Uganda has been one of the failure examples in commercialising improved cookstoves. According to a study published in 2000 (Energy for Sustainable Development Ltd. 2000), improved cookstoves were more popular among the low-income groups than the high-income groups in Uganda. The reason behind this phenomenon seems to be that Ugandans tend to view improved cookstoves as an item for the poor. Without a change in this mindset, these cost-saving and harm-reducing stoves will not reach many of the potential users, and access issue in Uganda will continue for decades to come. Educating consumers about the benefits of improved cookstoves to bring up their image is a useful and important tactic that can be put into action today.

One way to quantify how much each cooking technology is valued in each group is to use price premium, which is the average price that consumers in the group are willing to spend on the technology. The price premium *(PP)* in this study is defined as the average expenditure or premium that the respondents of the household survey were willing to accept in order to avoid obtaining cooking services using a lower cost substitute technology. The price premium for a cooking technology type is calculated using Eq (9). The group specific data is based on the demand curves derived from the survey.

$$pp_{pe}^{f} = \int_{0}^{UD_{pe}} a_{pe}^{f} x^{b_{pe}^{f}} \, dx \Big/ UD_{pe} \quad (9)$$

Where,

a and b are the coefficients of the demand curves

Comparing price premiums provides an idea on how each group views the various cooking options. Table 6-5 shows the price premiums for different stoves in 2005 by expenditure groups. For collected firewood and purchased firewood using three stone stoves, the price premium could not be derived because demand curves could not be derived.

Table 6-5. Price premiums by stove types and expenditure groups in 2005

[$/GJ]	R1	R2	R3	U1	U2	U3
Charcoal - Metal plate stove	1.29	4.53	11.70	8.44	16.74	19.63
Charcoal - Improved charcoal stove	1.03	1.65	5.37	17.89	6.40	5.61
Kerosene - Kerosene stove	0.72	1.38	2.77	0.39	0.88	5.02
LPG - Gas stove	4.95	9.86	19.37	5.70	12.95	24.88

When a technology is considered to be a superior good, the price premium increases from low-expenditure groups to high-expenditure groups. When a technology is seen as an inferior good, the price premium decreases as the expenditure rate increases. The analysis of price premium shows that all of the stoves are superior goods except for improved charcoal stoves in urban areas. This supports the analysis done by Energy for Sustainable Development Ltd. and also shows the existence of a mental block in using improved charcoal stoves. A report by MEMD (2011b) also highlights the low acceptance rate, despite the obvious budget improvement that comes from adopting improved cookstoves. MEMD suggests several reasons for this tendency, such as the high investment costs and a lack of space to install the stoves, but most likely the main reasons are the negative image and the lack of awareness about their benefits. As long as improved cookstoves are considered socially "unfashionable", an economic approach will not be very effective in selling their appeal. Challenges remain in understanding the development of cooking energy systems and the drivers of transition in different social and economic conditions.

For improved cookstoves to be accepted and become a part of the transition to cleaner fuels in Uganda, it is crucial to understand the multiple linkages between access to energy services and social, economic and human development (Karekezi et al. 2012). The benefits of using improved cookstoves need to be understood by consumers. There are some positive examples of improved cookstove uptakes where the benefits were realised. A free distribution of improved cookstoves in a village in Senegal has observed a very high adoption rate, close to 100% (Bensch et al. 2012). Offered in a right form at a right condition, improved cookstoves can greatly contribute to energy access issues and be a bridge technology in transition to clean cooking technologies.

6.7.4 Economic growth

In these scenario analyses, a constant Gini coefficient of 45 was assumed during the study period of 2010-2030. The trends observed in the past decades do not point to a rapid improvement, but government policies could alter the path. Reducing the gap between the rich and the poor can have a very positive effect on future energy outlook.

The results of energy use in R1, R2 and U1, U2 show a strong need to get people out of these groups of expenditure levels below 4.00 USD per day. As Figure 6-22 shows, the majority of consumers in low-expenditure groups continue to rely on firewood as their main source of energy. An analysis of the residential energy mix of India in 2050 by van Ruijven (2008) evaluated two scenarios under two different income distributions using TIMER global energy model. The result showed that the improved equality scenario reduced the population relying on solid fuels by about 10%. If a more equal distribution of wealth among households could be achieved, the problem of energy access can be eased even under the same economic growth assumption.

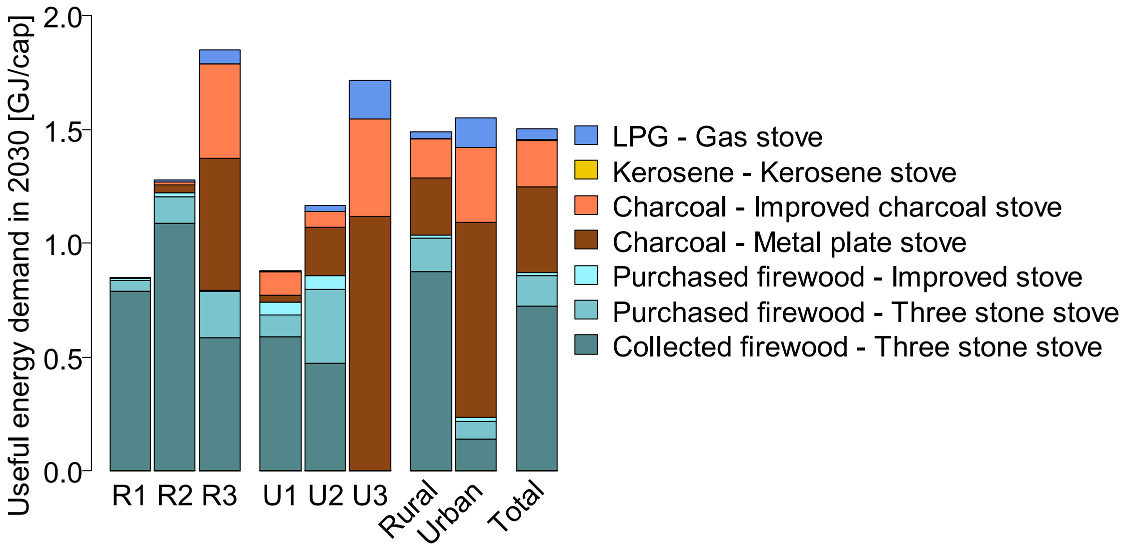

Figure 6-22. Useful energy demand per capita in household groups under fuel price support of 50% in 2030

6.7.5 Deforestation and climate change

There are two main environmental problems facing energy use in Uganda. First is the overexploitation of forests for biomass harvesting. The forest cover was over 13 million hectares in the 1950s, but since then forest areas have shrunk by three quarters to around 3 million hectares. The trend is yet to slow down, and charcoal prices are rising due to shortages of firewood. Second is the rise in CO_2 emissions caused by switching from biomass based energy to LPG or fossil fuel based energy sources. If biomass is considered to be carbon neutral, any policy that assists transition to modern fuels will increase CO_2 emissions. It is also important to realise that deforestation problems are directly linked to the emissions of GHG. Although emissions are not from fossil fuel combustions, deforestation converts a land, which was an absorber of CO_2, into a neutral or emitting land. The Ministry of Water and Environment has announced their commitment to increase forest cover to 21% in 2030 from approximately 14% in 2013 in the Intended Nationally Determined Contributions (INDC) in 2015. However, INDC also notes that the target is "highly ambitious considering that 89.5% of the country's energy needs are currently met by charcoal and firewood" (MWE 2015).

Deforestation problems lead to higher charcoal and firewood prices, and climate change policies lead to higher fossil fuel prices. Both factors can make the transition to modern fuels even more challenging for Uganda. Both issues are important in preserving land, but the negative impacts occur at different time spans. Overexploitation of forests is an imminent issue, which already directly impacts the daily lives of the population. CO_2 emissions should have impacts in the long-term through climate change, but it is unlikely that emissions from Uganda, less than 0.1% of the world's total GHG emissions in 2011, would have a strong influence on climate change occurring at a global level.

One highly effective measure to reduce the environmental burden of deforestation from cooking energy use is improvements in the method of charcoal production. Demand for charcoal is projected to increase in the coming decades, while policies to shift people to clean cooking technologies are unlikely to happen before 2030. A quicker solution would be a shift in the method of charcoal production to reduce the relative amount of firewood required to produce charcoal. From the deforestation point of view, promoting efficient production of charcoal would have a much bigger impact in slowing down deforestation within a reasonable time than pushing for a shift away from solid fuels. The pace of implementation is important in determining which measure should be given a preference. Charcoal production sites are already known, and production is economically driven. Offering casamance earth mounds at an economic price could help reduce deforestation much faster than distributing improved cookstoves around the country.

Carbon neutrality of biomass can also be argued. Carbon neutrality of biomass assumes a cycle of replanting, which continuously absorbs CO_2 from the air. If the plants are not replanted, in their life cycle the biomass fuels do "emit" GHG. According to an estimate by Bailis et al. (2015), 61-62% of woodfuel harvested in Uganda was unsustainable (35-41% in Africa as a whole). In addition, the incomplete combustion of firewood and emissions during the production of charcoal can emit significant amounts of GHG and other particulate matter that are associated with severe health problems. Black carbon, which is often emitted from firewood, has a global warming potential (GWP) of 1600 over 20 years and 460 over 100 years (Fuglestvedt et al. 2010). The use of charcoal is a part of the cause of deforestation. A careful plan to keep the biomass use at a sustainable level is strongly requested, and governments need to act accordingly.

Making a shift to cleaner, yet GHG-emitting, cooking fuels such as petroleum based LPG and kerosene appears at odds with current global efforts towards a low-carbon economy. However, shifting away from firewood and charcoal, which are carbon neutral, is an important step for development. All of the industrialised countries followed the same process in their course of development, and it would be cruel to hinder development in the rest of the world on account of climate change problems caused by emissions from developed countries. Climate change is a serious problem, and in time, Uganda should also do its part in the global effort of reducing emissions. However, getting people out of poverty should be the number one priority, and in order to facilitate development, some emissions need to be tolerated.

Chapter 7. Key findings, conclusion and recommendations

7.1 Key findings

The results and analyses presented in Chapter 6 using the cooking technology choice model lead to the following findings.

1. **A universal energy access in Uganda can be achieved by 2030 with a combination of fuel price support and credit access policies:** The model results show that providing assistance only for modern fuels or clean stoves will not be enough for the poor to make the transition to clean cooking technologies. Achieving universal access by 2030 requires a combination of access policies, for supporting purchases of modern fuels and clean stoves, and requires 8.14 billion USD over 15 years (2016-2030). The majority of the cost for support, 6.97 billion USD, is required for LPG price support of 95%, and the remaining 1.17 billion USD is required for credit access of 15% to purchase gas stoves. Such a high cost seems difficult to afford for a country with an annual GDP of 20 billion USD (in current USD) in year 2012. However, the projected GDP of Uganda is to reach 27 billion USD in 2020 and 73 billion USD in 2030 (both in MER). If the support can be evenly spread out over 15 years, only 550 million USD or 0.75% of the national GDP in 2030 is needed annually. With international assistance until the Ugandan government is able to support the policy on its own, universal access can be achieved.

2. **An effective transition requires immediate action:** With no new additional access related policies in Uganda, the price of LPG, kerosene and clean cooking stoves will remain out of reach for most (over 99%) of the population. The population using clean cooking technologies will remain below 1% in 2030, relatively unchanged from the access rates of 2005. The transition to clean cooking technologies cannot take place overnight, and immediate action is needed to shift the cooking technology choice of over 99% of the population by 2030.

3. **Access policies need to reflect the level of support required to reduce income inequality:** Equal support for all consumers will provide excessive support for urban areas, resulting in widening the income gap between the rural and urban areas. Consumers in high income groups in urban areas can all achieve access to clean cooking technologies with an 85% prices support without credit access, but low-income groups in urban areas require a 95% price support and credit access of 15%. If equal support is provided to all consumers, the government could spend in excess of 350 million USD or 23 million USD annually over 15 years for support not needed by high income consumers in urban areas.

4. **Higher fossil fuel prices will decelerate transition to clean cooking technologies and increase CO_2 emissions:** Climate change policies should not be implemented in a manner that leads to rising fossil fuel prices in developing countries. With credit access of 15% and fuel price support of 95%, Uganda could potentially achieve universal access in 2030. However, if climate change policy increases the price of LPG in Uganda by 0.23 USD/kg, the same policy would only achieve an access rate of 64% in 2030. Slower uptake of clean cooking technologies leads to an increased use of biomass, which could result in higher emissions when biomass is used in an unsustainable manner.

5. **Assistance for improving charcoal production technology must be prioritised:** Under no new additional access related policies, the annual demand for firewood (including use for charcoal production) could reach as high as 84 million tonnes in 2030 or four times the amount of consumption of 2005. If earth kiln with a conversion efficiency of 10% is replaced by casamance kiln with an efficiency of 25%, the consumption of firewood in Uganda can be reduced to 52 million tonnes in 2030. An unsustainable consumption of firewood must be avoided to reduce the environmental impacts from deforestation and increasing CO_2 emissions.

7.2 Conclusion, discussion and recommendations

The dissertation concludes that current cooking energy modelling have major deficiencies in representing dynamic cooking energy transitions and the heterogeneity of consumer preferences in the types of fuels and technologies chosen for cooking. Key points to include in the energy model to improve model analyses of cooking energy transition are:

- *Divide consumers into groups based on barriers for transition to modern energy transition*
  Using average or aggregated data can significantly misrepresent the situations in rural areas and in low-income households.
- *Observe end-use technology specific heterogeneity in consumer preferences*
  Decision making process for goods such as cooking technology, which provides basic needs and is used everyday, is complex and strongly influenced by living conditions. Each end-use technology should be evaluated separately, and generalisation of cooking technologies should be avoided even between technologies using same fuels.
- *Derive consumer preferences based on empirical observation of consumption data*
  Cooking technology choice patterns, espcially among new technologies such as improved charcoal stoves, could have asymmetric information barriers, which can give a counterintuitive acceptance rate, as it was the case in Uganda.

Three issues need some more discussions: Survey data quality, choice of global model and the scope and limitations of this research.

Analysing detailed energy use and purchasing behaviour need to rely on consumer surveys, but surveys have their limits. Surveys in developing countries are known to suffer from consistency and reliability. How well a collected dataset represents a nation relies heavily on survey design. The quality of data can also suffer from the level of education of the respondents. For example, illiteracy rate of Uganda is 27%, which means much of the data is bound to rely on people's memory rather than written records. The consumers are reminded to keep track of their purchases, but a person can forget or remember the wrong figures.

This cooking technology choice model relies heavily on the survey data of Uganda. Some could argue that a model derived from consumer survey data does not have a solid base. However, the calculated data are comparable to energy statistics provided by the Ugandan government, and consulted experts from developing countries found the data to be workable sets of quality data.

With respect to survey data in general:

- Cooking preferences can be observed from analysing the purchasing pattern of household survey data. However, a careful attention needs to be given to data interpretation, and some fuels, such as firewood, are not always covered.
- The quality of data and the way the questions were asked need to be understood to minimise the misuse of data. Firewood collection can be affected by season and weather, so the date when the survey was performed is also important to keep in mind.
- Humans do make errors and some datasets needs to be disregarded if numbers are shown to be outliers or contain unrealistic values. One of the common mistakes observed in the Ugandan survey was writing down the wrong units, which made some figures to be an outlier.

A choice of MESSAGE as the energy model to provide global fossil fuel prices also influences the result of cooking technology choice model calculation. When the model is connected to other global energy models, fuel prices will differ from the numbers seen in this analysis. However, MESSAGE model has participated in many inter-model comparison studies (LIMITS[9], AMPERE[10]), and the model results have been compared to other similar global energy models (GCAM, IMAGE, WITCH, etc). Methodological background of the models do differ, but the models have been compared and adjusted to make sure the parameters among the models are reasonable and trustworthy. Therefore, the derived prices can be taken to be within the trend of the energy modelling community.

With respect to the choice of energy model for fossil fuel prices in general:

- Fossil fuel prices are key determining factors, so a reliable global energy model is necessary to produce sound results. It is preferred to use a model that has been tested and compared against other models in the energy modelling community.
- A global energy model is required to evaluate the price of a global commodity such as fossil fuel and to capture the effects of global policies such as climate change policies.

The cooking technology choice model developed in this dissertation is designed to overcome the issues mentioned above. However, certain aspects of social structure and energy modelling were simply beyond the scope of this research. Recommendations certainly exist, and further development of the model should provide a deeper understanding of the cooking energy transition mechanisms in developing countries.

With respect to limitations of cooking technology choice modelling and overall recommendations:

- The model focused on the cooking energy transition, but electrification problem is also a significant barrier to poverty eradication. The two issues are not the same but strongly related. Any policy to promote energy access should take both issues into consideration and look for a synergy in tackling both problems.
- Energy is related to many aspects of life, and policies in other fields, such as agriculture, forestry and air-pollution, could have a synergy and improve the access issue indirectly. The goal to achieve universal clean cooking technologies needs to be decided in a balance with other targets such as universal access to clean water and universal healthcare.
- In many rural areas, road constructions are necessary and a priority to open up the market to outside villages and to stimulate rural economic development.

[9] "Low climate IMpact scenarios and the Implications of required Tight emission control Strategies" is funded by the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 282846. The project aims to generate insight into implementable policies and targets to achieve the the 2°C target.

[10] "Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates" is an EU-funded international project to assess possible outcomes of various climate policies.

Infrastructure can play a key role in delivering energy, and improvement in infrastructure such as pipeline could increase the availability and reliability of fuel supplies increasing consumer confidence in modern fuels.

- Spatial data is not explicitly modelled, and regional information and characteristics are reflected only indirectly in the model through the disaggregation of population into regional groups and group specific fuel prices. Lack of wood fuels and regional imbalance in prices could become a major issue in the coming decades.
- The cultural aspects included in the model can be better understood through exchange of data with the local population. How to improve the current status or acceptance of improved cookstoves among the upper class is something that is not covered in this dissertation.
- Additional analyses using household survey data from more countries could improve the understanding of social aspects involved in cooking choices. Uganda model developed in this dissertation is just one of the many countries facing the energy access problem. Getting more countries involved in gathering raw data can greatly contribute to the knowledge pool of cooking situations in developing countries.
- Only one type of climate change policy was analysed. There are numerous ongoing debates on other approaches and targets. Setting the global energy model to allow further investigation can provide valuable information on how cooking access could be affected by climate negotiations and policies.

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Appendix

A.1 Fuel Conversion

Conversion factors from fuels to energy are based on the estimates by the UN DESA's energy statistics (UN DESA 1987). The conversion chart is shown in Table A-1. The conversion rate of firewood and charcoal can vary significantly depending on factors such as moisture content. It is not possible to know in the survey the conditions at which each fuel was used or how it will be used in the future. Therefore, the average energy content is used throughout the calculation.

Table A-1. Fuel conversion table

Firewood	1 kg =	15 MJ
Charcoal	1 kg =	30 MJ
Kerosene	1 L =	34.9 MJ
LPG	1 kg =	45.3 MJ

A.2 Survey results

A.2.1 Energy use by groups

Per capita final energy use for cooking calculated in quintile base in rural and urban areas is shown in Table A-2 and Table A-3. The quintile data trend is similar to the trend seen in the expenditure groups, which is used in the dissertation. One thing that is more evident in this group definition is a rapid increase in the top quintile of rural areas. In urban areas, a drastic drop in the amount of collected firewood is seen between the fourth and the fifth quintile. An odd increase in the use of improved firewood cookstoves is seen in the fourth quintile. This is due to the low number of improved firewood cookstove users in the household survey. One household using a large amount of energy can easily affect the quintile average. There were only a total of six households in the fourth quintile that responded as using improved firewood cookstoves.

Table A-2. Final energy use by expenditure quintiles in rural area

[MJ of final energy per capita]

	Rural				
fuel - stove	Q1	Q2	Q3	Q4	Q5
collected firewood - three stone stove	5219.9	6596.5	7569.7	8236.1	8057.1
firewood - three stone stove	314.5	489.6	501.5	797.9	1374.0
firewood - improved firewood stove	76.9	20.2	32.5	69.6	90.3
charcoal - metal plate stove	5.0	30.9	56.5	252.7	1244.6
charcoal - improved charcoal stove	17.3	13.5	41.4	58.2	165.7
kerosene - kerosene stove	0.0	0.0	0.0	0.0	1.8
LPG - gas stove	0.0	0.0	0.0	0.0	0.0
TOTAL	5633.7	7150.8	8201.6	9414.5	10933.5

Table A-3. Final energy use by expenditure quintiles in urban area

[MJ of final energy per capita]

	Urban				
fuel - stove	Q1	Q2	Q3	Q4	Q5
collected firewood - three stone stove	3502.9	2269.2	1399.9	1385.6	211.9
firewood - three stone stove	867.8	1284.5	1842.0	790.9	575.6
firewood - improved firewood stove	237.6	221.3	76.4	227.3	23.6
charcoal - metal plate stove	611.9	1945.4	3013.4	4370.8	6390.4
charcoal - improved charcoal stove	506.5	499.8	537.3	356.9	390.4
kerosene - kerosene stove	0.0	1.2	0.6	2.1	12.1
LPG - gas stove	0.0	0.0	0.0	0.0	25.4
TOTAL	5726.6	6221.4	6869.6	7133.7	7629.4

A.2.2 Cooking time

Depending on regions and income levels, the average cooking time changes. The reason for the differences could be the time required to start a fire, types of meals cooked and the number of times eaten outside. Average hours spent on cooking per week by regions are shown in Table A-4.

Table A-4. Average hours spent on cooking per week
by regions and expenditure groups

	Central	Eastern	Northern	Western
R1	3.96	5.60	4.00	3.69
R2	4.14	5.29	3.82	4.08
R3	2.89	2.67	1.49	2.59
U1	3.36	3.15	4.68	3.52
U2	3.59	3.44	4.45	3.63
U3	3.20	2.88	3.16	3.76

A.2.3 Purchase unit

Purchased units of firewood, charcoal and kerosene reported in the survey are chosen by the respondent. Firewood is most often reported in bundles, which is not a specific size and varies from region to region and from time to time. Charcoal is often sold in a large sack, but low-income groups also make a purchase in smaller sizes such as a tin of 5 to 20 litres. Kerosene is often purchased in bottles, but purchasing in smaller amounts is also not uncommon. When it is purchased in a small amount, "akendo", a small cup with a handle, is most often used. Table A-5 shows the reported units in the survey per fuel.

Table A-5. Reported unites in the survey

unit of quantity	Firewood	Charcoal	Kerosene
Litre	0	0	1,791
Small cup with handle	0	0	2,028
Sack (120 kgs)	0	31	0
Sack (100 kgs)	3	477	0
Sack (80 kgs)	0	70	0
Sack (50 kgs)	0	49	0
Jerrican (10 lts)	0	0	1
Jerrican (5 lts)	0	0	18
Jerrican (3 lts)	0	0	12
Jerrican (2 lts)	0	0	1
Jerrican (1 lt)	0	0	6
Tin (20 lts)	0	41	0
Tin (5 lts)	0	123	0
Plastic Basin (15 lts)	0	242	0
Bottle (750 ml)	0	0	4
Bottle (500 ml)	0	0	604
Bottle (350 ml)	0	0	121
Bottle (300 ml)	0	0	1,541
Bottle (250 ml)	0	0	237
Bottle (150 ml)	0	0	341
Basket (20 kg)	0	5	0
Basket (10 kg)	0	4	0
Basket (5 kg)	0	5	0
Basket (2 kg)	0	4	0
Bundle (Unspecified)	5,516	0	0
Total	5,519	1,051	6,705

A.2.4 Questions from survey

The following section presents excerpts from the UNHS household survey on cooking energy use conducted in 2005 to 2006. All the questions are taken from the report published by the Uganda Bureau of Statistics (UBOS 2006).

Table A-6 shows questions about activities performed by household members. Question 7 and 8 ask cooking fuel related questions: time spent on collecting or fetching firewood and on cooking in the last 7 days.

Table A-6. Section 7B: Activities of Household Members

PERSON ID	What was your main employment status during the last 7 days? **Self-Employed persons** 1=Employer 2=Own account worker 3=Unpaid family worker **Paid Employee** 4=Gov't Permanent 5=Gov't Temporary /casual 6=Private Permanent 7=Private Temporary/ casual	What was the nature of work (for the main employment status) that you did during the last 7 days? **(OCCUPATION)**		What was the main economic activity of your place of work? **(INDUSTRY)**		In addition to the main occupation, did you also work in any subsidiary occupation during the last 7 days? 1= Yes 2= No	During the past 7 days, how many hours did you spend fetching water for the household including travel time? **If none, write 0** Hours	During the past 7 days, how many hours did you spend fetching fire wood for the household including travel time? **If none, write 0** Hours	During the past 7 days, how many hours did you spend in cooking for the household? **If none, write 0** Hours	During the past 7 days, how many hours did you spend in taking care of children and the elderly? **If none, write 0** Hours	What were your main and secondary employment statuses during the past 12 months? 1=Employer 2=Own account worker 3=Unpaid family worker 4=Gov't Permanent 5=Gov't Temporary /casual 6=Private Permanent 7=Private Temporary/ casual 8= Fulltime student 9= Pensioner/retired 10= Children not at school 11= Other (specify)		During the past 12 months (including the last 7 days), did you work for a salary or wage? 1= Yes 2= No
		Describe in not less than 2 words	Code	Describe in not less than 2 words	Code						Main	Secondary	
1	**2**	**3a**	**3b**	**4a**	**4b**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

In Section 11, questions about housing conditions are asked. Topics covered in the section include construction materials of the house, material of the floor and the main source of water for drinking. As seen in Question 13 (see Table A-7), the survey asks about eight different types of stoves for 2001 and 2005.

Table A-7. Section 11: Housing Conditions

11. What is the main source of lighting in your dwelling?
    1= Electricity
    2= Paraffin, kerosene or gas lantern Now
    3= Tadooba
    4= Firewood
    5= Solar
    6= Biogas 2001
    7= Other (specify)

12. What type of fuel do you use most often for cooking?
    1= Firewood Now
    2= Charcoal
    3= Paraffin/kerosene
    4= Electricity
    5= Gas
    6= Solar 2001
    7= Biogas
    8= Saw dust
    9= Other (specify)

13. What type of cooking technology do you use in your household?
    1= Traditional metal stove (Sigiri)
    2= Traditional 3-stone stove Now
    3= Improved charcoal stove
    4= Improved firewood stove
    5= Gas stove
    6= Paraffin stove
    7= Saw-dust stove 2001
    8= Electric plate
    9= Other

Section 14 asks how much non-durable goods were purchased in the last 30 days. Code numbers 306 to 311 in Table A-8 are cooking fuel related questions. The questions ask not only about purchased fuel but also about home produced and received in-kind fuel. In rural areas charcoal is often home produced, and many families receive firewood in-kind. By having these sections, the survey of Uganda provides vital information on cooking energy use in developing countries.

Table A-8. Section 14B: Household Consumption Expenditure

(Part B) Non-Durable Goods and Frequently Purchased Services (During the last 30 days)

Item Description	Code	Unit of Quantity	Purchases		Home produced		Received in-kind/Free		Unit Price
			Qty	Value	Qty	Value	Qty	Value	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Rent of rented house/Fuel/power									
Rent of rented house	301								
Imputed rent of owned house	302								
Imputed rent of free house	303								
Maintenance and repair expenses	304								
Water	305								
Electricity	306								
Generators/lawn mower fuels	307								
Paraffin (Kerosene)	308								
Charcoal	309								
Firewood	310								
Others	311								
Non-durable and Personal Goods									
Matches	451								
Washing soap	452								
Bathing soap	453								
Tooth paste	454								
Cosmetics	455								
Handbags, travel bags etc	456								
Batteries (Dry cells)	457								
Newspapers and Magazines	458								
Others	459								
Transport and communication									
Tires, tubes, spares, etc	461								
Petrol, diesel etc	462								
Taxi fares	463								
Bus fares	464								
Boda boda fares	465								
Stamps, envelops, etc.	466								
Air time & services fee for owned fixed/ mobile phones	467								
Expenditure on phones not owned	468								
Others	469								

A.3 Demand Curves

The complete sets of demand curves used in the cooking technology choice model are shown here.

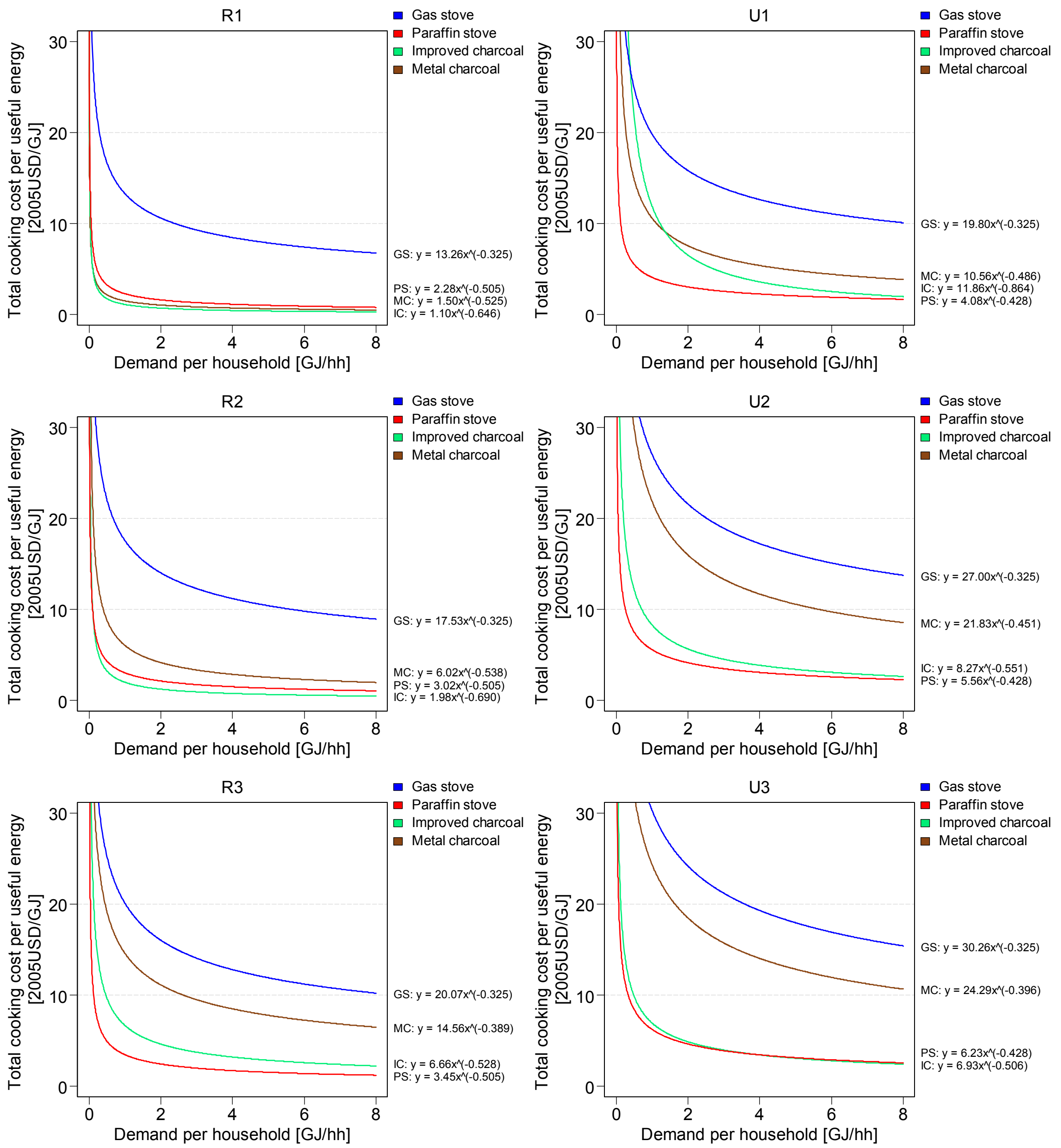


Figure A-1. Demand curves of each demand groups

In the dynamic groups, the demand curves shift upwardd as income grows. The demand curves in R3 and U3 in 2030 are shown below.

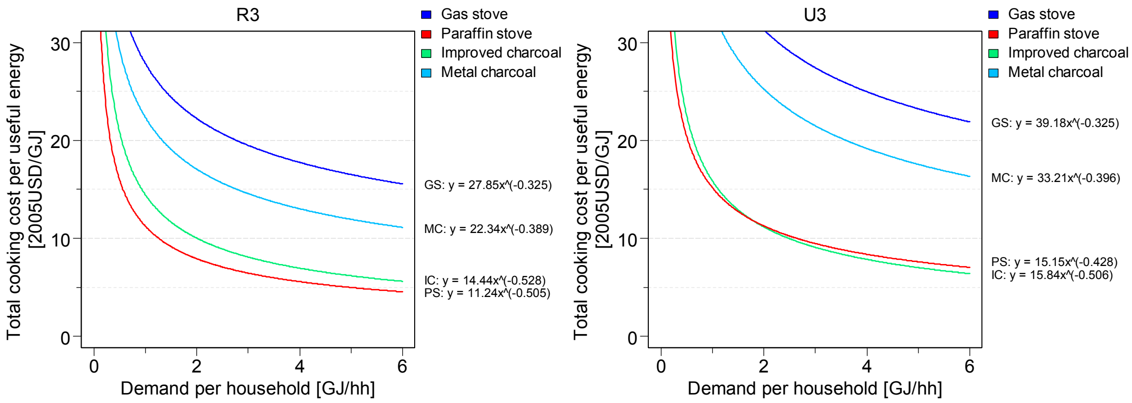


Figure A-2. Demand curves in 2030 for R3 and U3

The demand curves by cooking technology are shown below. With a few exceptions, the demand curves move higher as income increases.

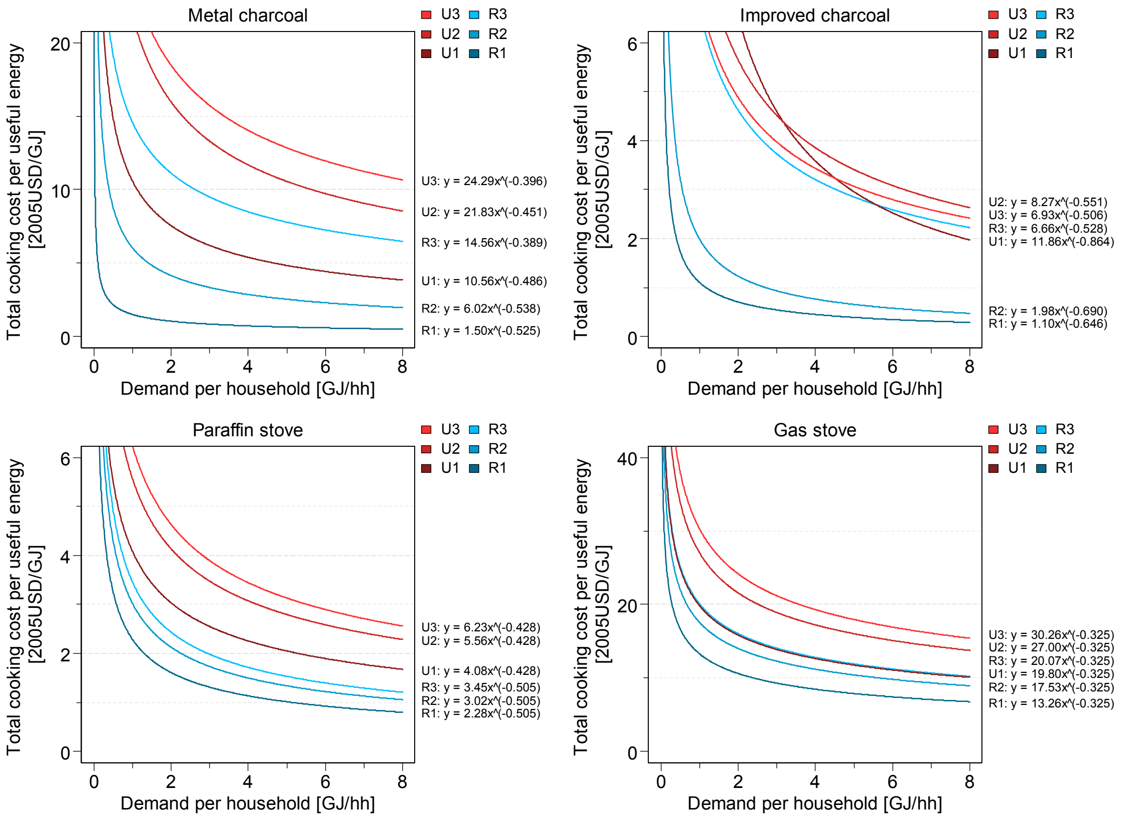


Figure A-3. Demand curves of each cooking technology

A.4 Model results

A.4.1 Cooking energy use in 2005

Per capita final energy use for cooking in 2005 calculated using the fuel cooking choice model is shown in Table A-9. The firewood use in the U3 group is zero in the model calculation despite some use in the survey results. This is because the A3 group demand curve derived for charcoal showed that the entire population in the group should be willing to purchase charcoal at the price given in the model

Table A-9. Cooking demand per group by cooking technology in 2005

[MJ of final energy per capita]

fuel - stove	R1	R2	R3	U1	U2	U3
collected firewood - three stone stove	6545.2	8634.0	6272.8	4154.4	1822.7	0.0
firewood - three stone stove	373.1	932.6	1967.9	660.9	1236.0	0.0
firewood - improved firewood stove	37.1	76.4	22.4	223.2	129.4	0.0
charcoal - metal stove	19.9	411.7	2927.3	415.4	3078.7	6846.3
charcoal - improved charcoal stove	23.7	97.5	656.0	566.5	494.4	540.7
kerosene - paraffin stove	0.0	0.0	0.0	0.0	0.0	0.0
LPG - gas stove	0.7	2.2	8.2	0.0	7.5	15.9
TOTAL	6999.6	10154.3	11854.5	6020.5	6768.7	7402.9

A.4.2 No New Policies

The figures below show useful energy demand in 2005 and 2030 by expenditure group in NNP scenario.

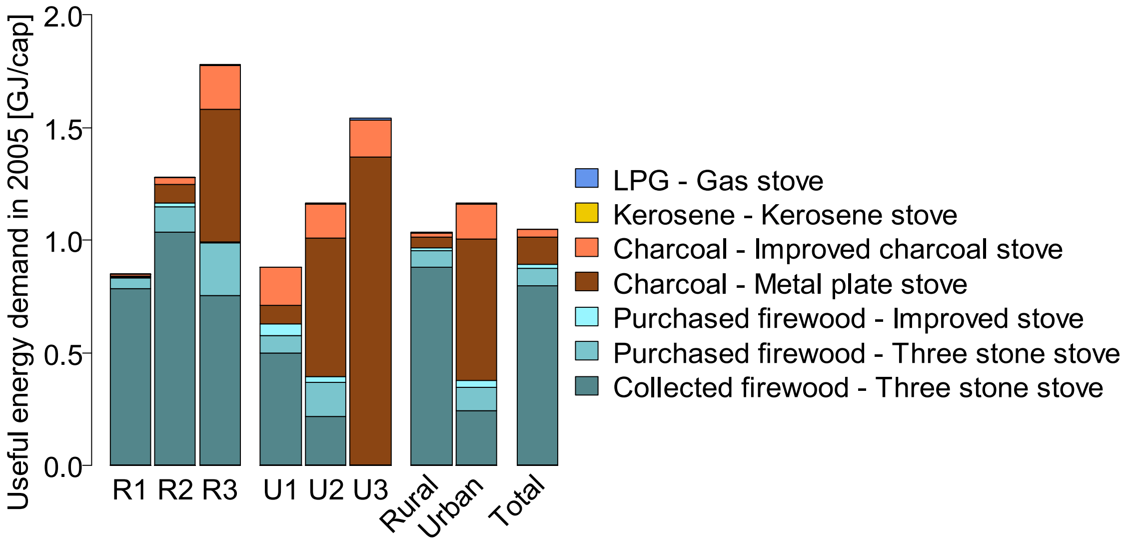


Figure A-4. Energy use by expenditure groups in no new policy scenario in 2005

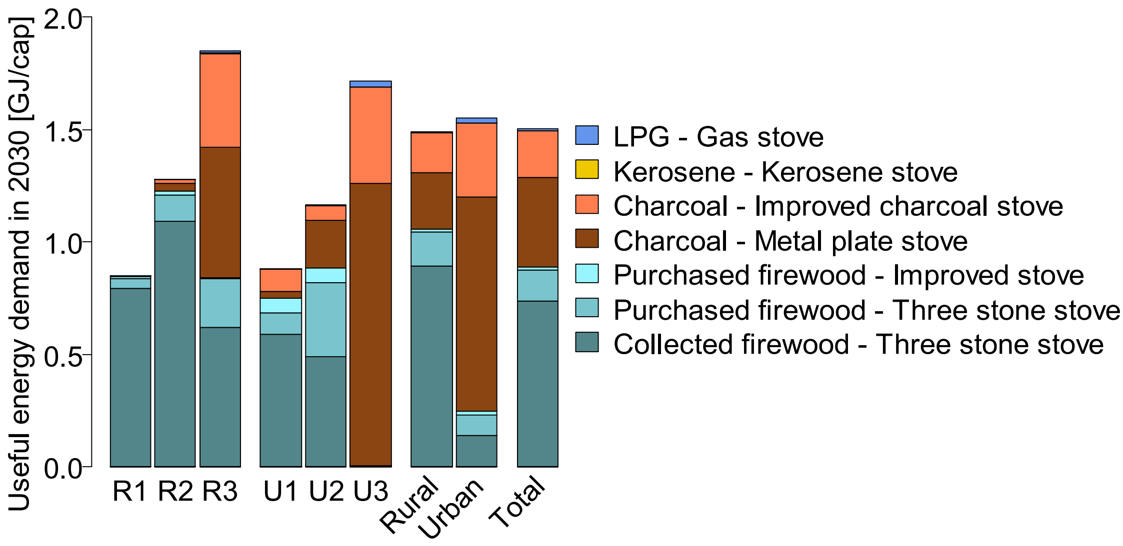
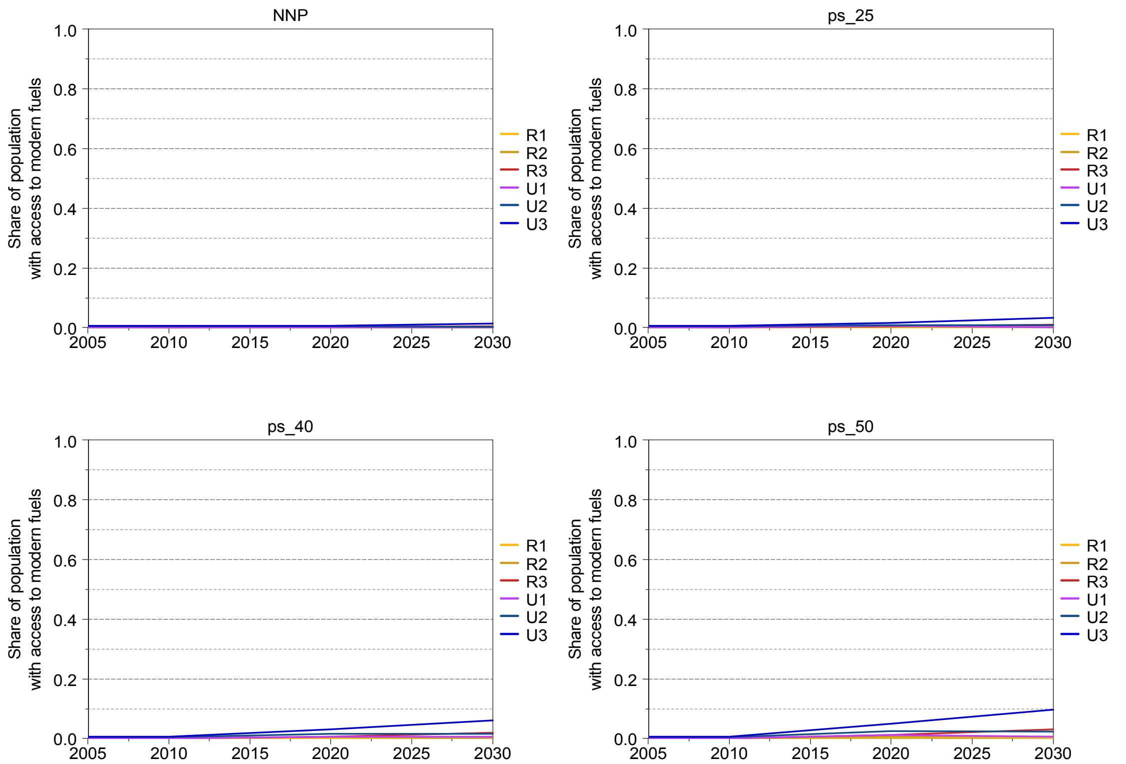


Figure A-5. Energy use by expenditure groups in no new policy scenario in 2030

A.4.3 Fuel price policies

Shares of population with access to modern fuels with different levels of fuel price support are shown below.



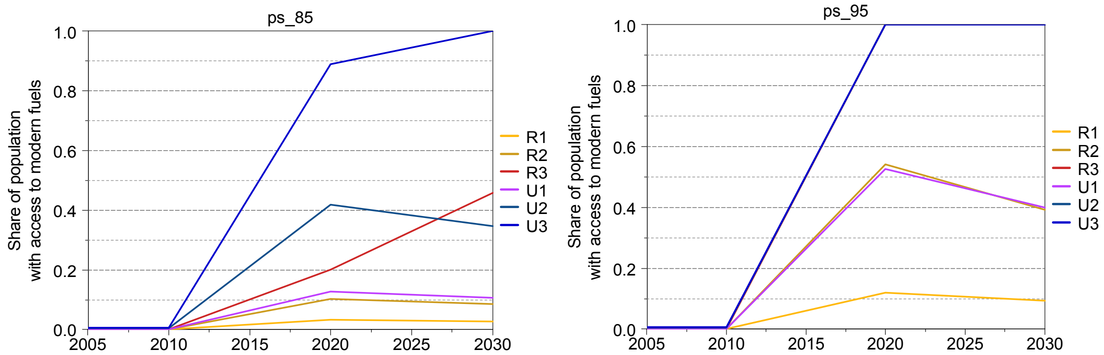


Figure A-6. Shares of population with access to modern fuels with different levels of fuel price support

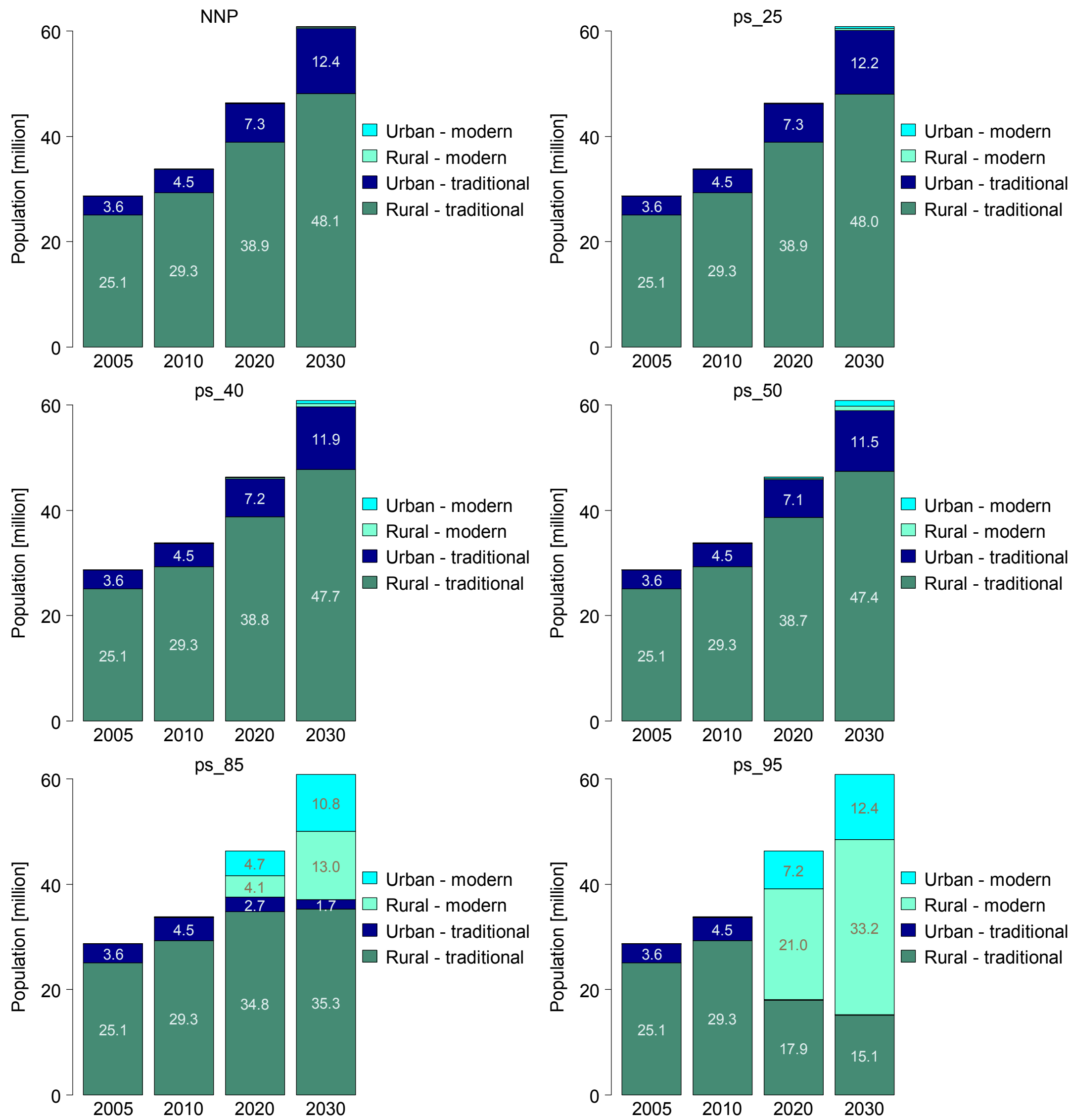


Figure A-7. Number of people using traditional and modern fuels with different levels of fuel price support

The below 3 figures show energy use in 2030 under different scenarios.

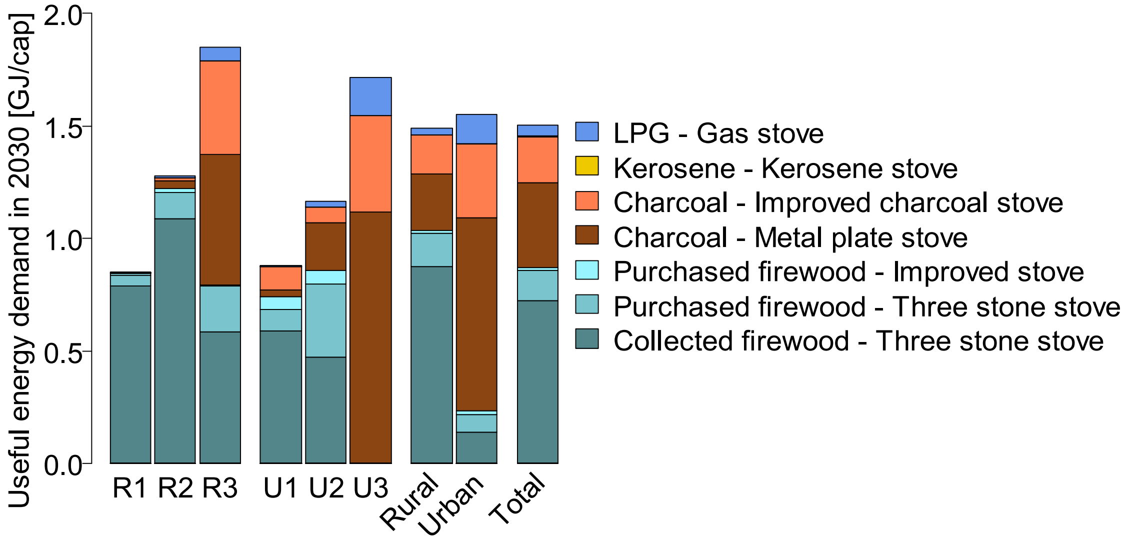


Figure A-8. Useful energy demand in ps50 case in 2030

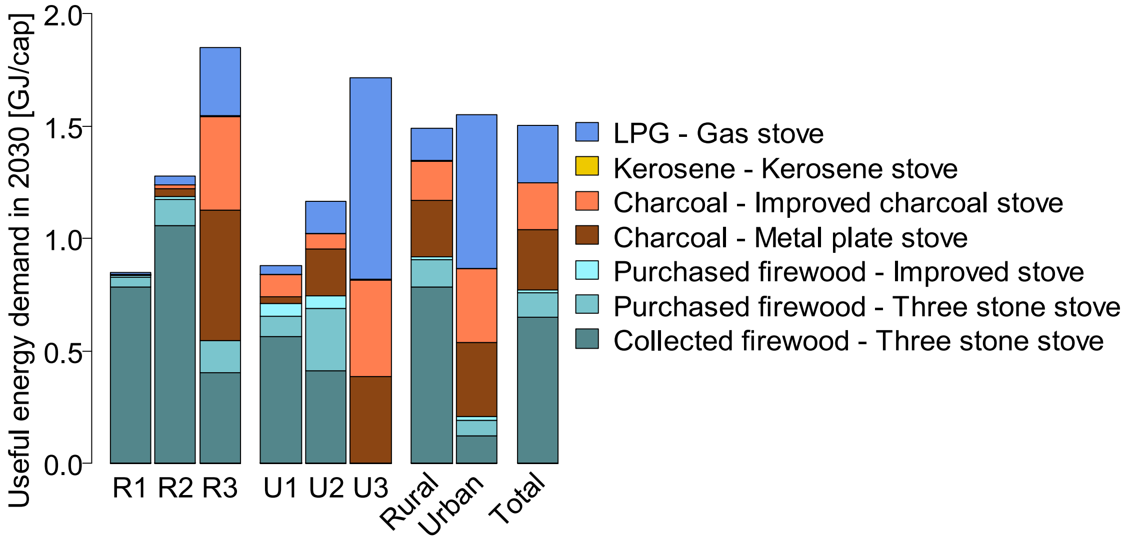


Figure A-9. Useful energy demand in ps75 case in 2030

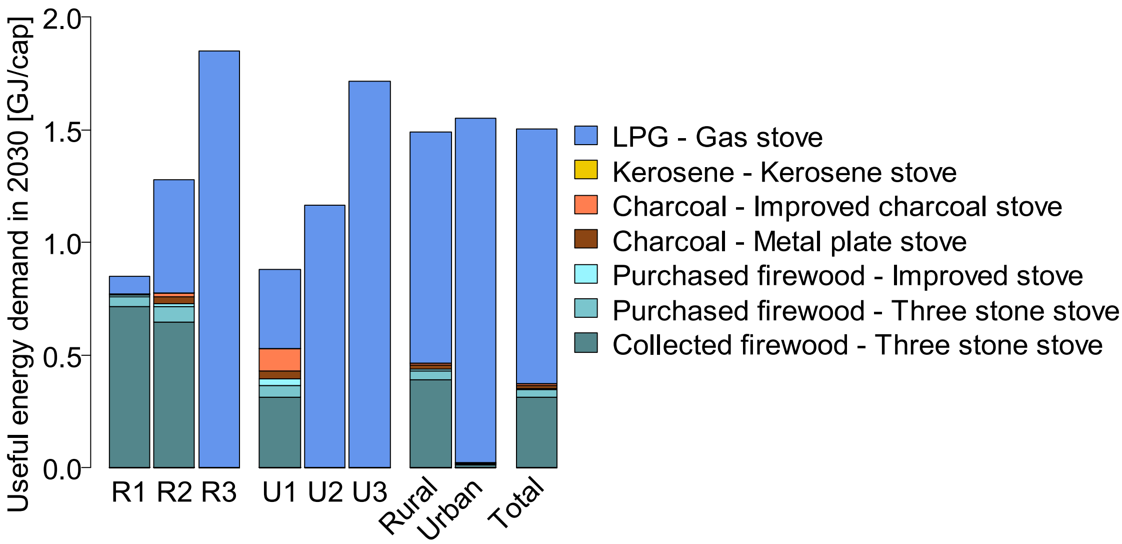


Figure A-10. Useful energy demand in ps95 case in 2030

A.4.4 Fuel price support policy costs

The following tables show the cumulative cost to implement fuel price support policy under fuel support scenario and combination scenario.

Table A-10. Cumulative cost of fuel price support policy (2016-2030)

[million USD]

	ps10	ps25	ps40	ps50	ps60	ps75	ps85	ps95
R1	0	0	0.1	0.1	0.3	1.1	3	11.8
R2	0.4	1.5	4.2	8.3	17.4	64.4	201.8	1040
R3	1.9	7.8	22.6	45.2	95	353.4	1119.6	2733.7
U1	0	0	0.1	0.1	0.3	1.1	3.2	13.5
U2	0.2	0.6	1.7	3.4	7.2	26.3	83.4	268.8
U3	2.5	10.4	30.4	61.3	129.5	489.9	1062.1	1187.1
Rural	2.2	9.2	26.8	53.6	112.7	419	1324.4	3785.5
Urban	2.7	11	32.2	64.8	137	517.4	1148.7	1469.3
Total	4.9	20.2	59.1	118.4	249.7	936.4	2473.1	5254.9

Table A-11. Cumulative cost of fuel price support policy under credit access of 30% (2016-2030)

[million USD]

	ps25	ps50	ps75	ps85	ps95
R1	0.1	0.3	2.3	8	55.8
R2	1.7	10.5	98.2	369.4	2645.8
R3	8.7	53.5	472.8	1691.3	2733.7
U1	0.1	0.3	1.9	7.1	33.8
U2	0.7	4.2	38.7	144.3	268.8
U3	11.3	69	602	1062.1	1187.1
Rural	10.5	64.3	573.2	2068.7	5435.2
Urban	12.1	73.5	642.6	1213.6	1489.6
Total	22.6	137.8	1215.9	3282.3	6924.9

Table A-12. Cumulative cost of fuel price support policy under credit access of 15% (2016-2030)

[million USD]

	ps25	ps50	ps75	ps85	ps95
R1	0.1	0.3	2.9	11	102.6
R2	1.8	11.7	117	480.3	2645.8
R3	9.5	60.1	584.5	2313.9	2733.7
U1	0.1	0.3	2.5	9.7	33.8
U2	0.7	4.7	46.5	189.5	268.8
U3	12.3	78	752.1	1062.1	1187.1
Rural	11.4	72.1	704.4	2805.2	5482.1
Urban	13.1	83	801	1261.3	1489.6
Total	24.5	155	1505.4	4066.5	6971.7

A.4.5 Credit access policy costs

The following tables show the cumulative cost to implement credit access policy under credit access scenario and combination scenario.

Table A-13. Funding required for credit access policy of 30% (2016-2030)

[million USD]

	ps25	ps50	ps75	ps85	ps95
R1	0.051	0.097	0.552	1.689	10.518
R2	0.662	2.627	17.787	59.723	384.161
R3	3.991	16.417	106.531	340.493	493.067
U1	0.046	0.086	0.409	1.335	5.638
U2	0.286	1.096	7.348	24.451	40.79
U3	4.899	21.763	142.581	223.711	223.711
Rural	4.704	19.141	124.87	401.906	887.746
Urban	5.231	22.945	150.338	249.497	270.138
Total	9.936	42.085	275.208	651.403	1157.88

Table A-14. Funding required for credit access policy of 15% (2016-2030)

[million USD]

	ps25	ps50	ps75	ps85	ps95
R1	0.051	0.097	0.688	2.327	19.346
R2	0.764	2.974	21.293	77.757	384.161
R3	4.8	18.98	132.465	466.331	493.067
U1	0.046	0.086	0.529	1.818	5.638
U2	0.306	1.262	8.876	32.149	40.79
U3	5.739	25.144	178.848	223.711	223.711
Rural	5.615	22.052	154.447	546.415	896.574
Urban	6.091	26.492	188.253	257.678	270.138
Total	11.706	48.544	342.7	804.093	1166.71

A.5 Fuel prices

Figure A-11 shows changes in fuel prices from fuel price support in future years. After the initial drop in 2020 from the introduction of the support, fuel price slowly rises due to an increase in global demand for oil.

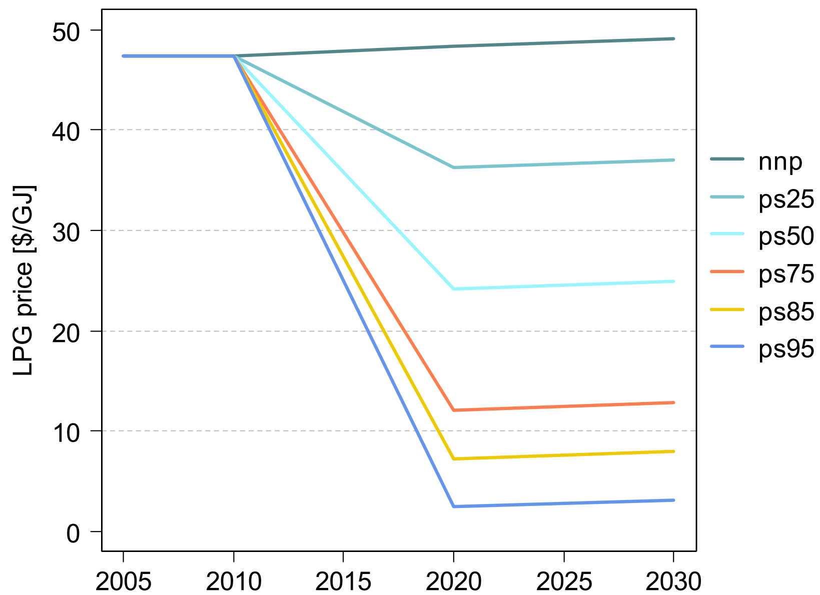


Figure A-11. LPG price changes at different fuel price subsidy rates

A.6 MESSAGE model

MESSAGE is a systems engineering optimisation model used for medium to long term energy planning. The model can be used to analyse energy policies through the use of scenario planning, and it has been used in many reports including the IPCC reports. The model evaluates many possible energy flows and finds the least cost solution under given constraints.

A.6.1 Regions

MESSAGE divides the world into the following 11 aggregated regions:

- AFR - Sub-Saharan Africa
- CPA - Centrally planned Asia and China
- EEU - Central and Eastern Europe
- FSU - Former Soviet Union
- LAC - Latin America and the Caribbean
- MEA - Middle East and North Africa
- NAM - North America
- PAO - Pacific OECD
- PAS - Other Pacific Asia
- SAS - South Asia
- WEU - Western Europe

Uganda is included in the Sub-Saharan region along with the following countries: Angola, Benin, Botswana, British Indian Ocean Territory, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Cote d'Ivoire, Congo, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Saint Helena, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe. Figure A-12 shows the regional divisions used in MESSAGE (IIASA 2013).

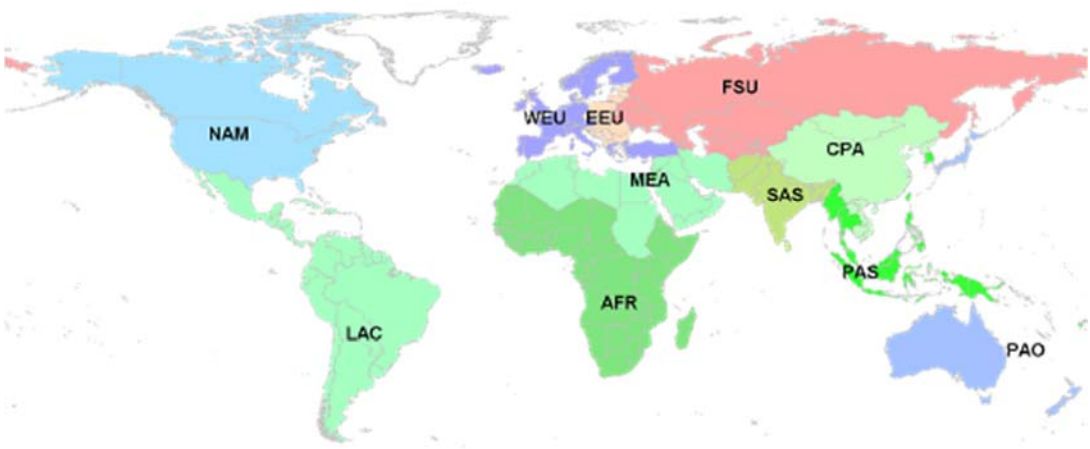


Figure A-12. Aggregated regions used in MESSAGE

A.6.2 MESSAGE-MACRO

MESSAGE is a linear optimisation model, so it links its own derived fuel prices with a non-linear macroeconomic model (MACRO) to adjust demands accordingly. MACRO maximizes the utility function in each region. The main variables in the model are capital stock, labour and energy inputs. Energy demands are divided into two categories, electricity and non-electricity. The two models, MESSAGE and MACRO, are run iteratively until convergence is achieved. In the dissertation, an already calibrated scenario set was used.

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