THE SUSTAINABILITY OF COOKING ENERGY IN SUB-SAHARAN AFRICA

A Case of Uganda

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DEDICATION

This thesis is dedicated to my wife Noeline Kuteesakwe and my children: Deborah, David and Anita, who have been has been by my side in the time of my greatest trial.

ABSTRACT

The Sub-Saharan Africa (SSA) is primarily dependent on biomass for its cooking energy. However due to poverty and population increase, biomass declines and there is woodfuel scarcity in many countries of SSA, including Uganda. Uganda is dependent on traditional biomass for cooking, contributing over 90%, but its supply is dwindling. Therefore, the Sustainability of Cooking Energy in Sub-Saharan Africa – a case of Uganda, is a study to answer the question whether "Uganda's biomass is sustainable given the forces of its depletion". Sustainability means, "the annual outtake should not exceed the annual increment of biomass". Therefore, the main objective of this study was to analyze the highway to sustainability of the cooking energy in Uganda.

This was done by analyzing the demand and supply of woodfuel. In case the supply exceeds the demand, it would be inferred that Uganda's biomass utilization is sustainable in the near future. If the demand exceeds the sustainable supply, there is no question that the biomass consumption is unsustainable for Uganda. This would call for alternatives for now and for the future.

The evolution of biomass consumption shows that demand increases in tandem with population growth. Household fuelwood constitutes the major share and estimated to have risen to 79% – 81% in 2009 – 2011 of biomass harvest. According to the trend, the least woodfuel consumption in the rural and urban residences is 94.1% and 85.2% respectively, while the maximum substitution in urban areas was 14.7%. A combination of poverty, fuelwood cheapness and cultural factors, combine to inhibit progress towards fuel switching. The only switching is from firewood to charcoal, which requires twice the amount of primary wood due double conversion. There is a positive linear relationship between the percentage using charcoal and the percentage of the middle class; yet there is a negative relationship between the percentage of those who are below poverty line and those using charcoal. Consequently, even the development of middle class does not affect wood transition.

On the wood supply side, two technical reports were used. To establish the sustainability of biomass supply, the sustainable yield was estimated from private areas. In order to investigate the supply in each district, the population and its growth rate were considered in this estimation. Overall, the sustainable yield had declined from 35 million tons in 1990 to 26 million tons in 2005, yet the demand of woodfuel was estimated to have been 45.5 million tons by 2014. Apart from the tropical high forests (forest reserves) and woodlands, which had an increase the rest the land cover biomass declined. The greatest biomass decline was the Small-Scale Farmland reducing 112.6 million tons to 53.2 million tons. The depletion is too fast, and the adoption of cooking alternatives is too slow. The woodfuel gap exists but it happens in certain irrefutable hotspots. It was confirmed that Uganda biomass is indeed unsustainable (though different spots have some level of sustainability). Because land scarcity increases as the population density shoots up, the option to plant trees or reforestation is not viable. The area depleted in 10 charcoal producing districts in 15 years is equivalent to the average of 3 district area – one district for every five years.

Then the assessment of the technological options (stoves and fuels) was carried out by four cooks. Each was assigned the task of bringing 1 kg of rice to boil in 1 litre of water for each of the ten cook stoves. Analysis to determine the statistical significance using SPSS, was carried out. Several statistical operations were conducted to manipulate data to obtain the mean, median, mode, standard deviation, Coefficient of Variation and ANOVA.

Lastly, three scenarios were analyzed using a model created in excel: Business as Usual scenario, Efficiency – Improved Cook Stove (ICS) and substitution by gas for commercial sector and Efficiency ICS, and substitution by gas for commercial sector and for a third of the middle class. These actions will be effective in reducing the demand of woodfuel. These scenarios are part of the solution to the woodfuel scarcity in Uganda.

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LIST OF ABREVIATIONS AND ACRONYMS

APP	Africa Progress Panel
VENRO	Association of German Development NGOs
CAI	Current Annual Increment
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IEA	International Energy Agency
NGO	Non-Governmental Organization
THF	Tropical High Forest
UN	United Nations
AFREA	Africa Renewable Strategy
ADB	African Development Bank
ANOVA	Analysis of Variance
ATP	ATP
BEST	Biomass Energy Strategy
BUA	Built Up Area
CO	Carbon Monoxide
CO2	Carbon dioxide

COPD	Chronical Obstruction Pulmonary Disease
R2	Coefficient of Determination
CV	Coefficient of Variation
COFO	Committee on Forestry
CP	Coniferous Plantations
CCT	Controlled Cooking Test
DHS	Demographic and Health Survey
DFID	Department for International Development
Fd	Dry Fuel
EIU	Economist Intelligence Unit
ESD	Energy for Sustainable Development
ESMAP	Energy Sector Management Assistance Program
EQ	Equivalent
EU	European Union
EUEI-PDF	European Union Energy Initiative Partnership Dialogue Facility
FAO	Food and Agricultural Organization
GTZ-GATE	German Technical Cooperation German Appropriate Technology Exchange
GDP	Gross Domestic Product
HWP	Hard Wood Plantation
HEP	Hydro Electric Power
ICS	Improved Cook Stoves
IAP	Indoor Air Pollution
KCJ	Kenya Ceramic Jiko
KNUST	Kwame Nkrumah University of Science and Technology
LCCS	Land Cover Classification System
LSF	Large Scale Farmland
LPG	Liquified Petroleum Gas
MDG	Millennium Development Goal
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MOE	Ministry of Energy (Kenya)
MEMD	Ministry of Energy and Mineral Development
MOLG	Ministry of Local Government
MCdb	Moisture Content dry basis
MCwb	Moisture Content wet basis
NBS	National Biomass Study
NEMA	National Environment Management Authority
NFA	National Forestry Authority
NHPC	National Housing and Population Census
NHVdb	Net Heating Value dry basis

NHVwb	Net Heating Value wet basis
NY	New York
PC	Per Capita
Q1	Quarter one
RWEDP	Regional Wood Energy Development Programme in Asia
REPU	Renewable Energy Policy for Uganda
SC	Specific Consumption
StDev	Standard Deviation
SUPRE	State of Uganda Population Report
SPSS	Statistical Package for Social Science
SSA	Sub-Saharan Africa
SSF	Subsistence Farmland
TV	Television
TFR	Total Fertility Rate
THFls	Tropical High Forest low stocked
THFws	Tropical High Forest well stocked
HSD	Tukey's Honestly Significant Difference Test
UBOS	Uganda Bureau of Statistics
MFPED	Uganda Government Ministry of Finance, Planning and Economic Development
UPHS	Uganda Population and Housing Census
UN	United Nations
UNDP	United Nations Development Program
UNDF	United Nations Population Fund
WBT	Water Boiling Test
WB	World Bank
WEO	World Energy Outlook
WHO	World Health Organization

UNITS, SYMBOLS AND CURRENCY

GJ	Gigajoules
Ha	Hectares
Kg	Kilogram
MJ	Megajoules
MTOE	Million Tons of Oil Equivalent
TOE	Tons of Oil Equivalent
UGX	Uganda Shillings
US$	United States Dollar
η_{kiln}	Kiln Efficiency
%	Percentage

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CHAPTER 1

INTRODUCTION

In this introduction, the topic "Sustainability of Cooking Energy in Sub-Saharan Africa – a case of Uganda" is presented. The relationship between energy and poverty trend in developing countries as measured by per capita final energy consumption and income in Africa is described. Africa is divided into 3 subregions based on the source of energy: North, South and Sub-Saharan. A percentage comparison of energy consumption based on population without electricity and clean cooking facilities in Africa compared to other regions of the world is portrayed. The increase in population with access to clean cooking compared to the total increase in population in Africa (excluding North Africa) and Asia Pacific in 2012 – 2014 indicates that clean cooking increases 1.35 times in Asia Pacific whereas in Africa lack increases 6 times. The average time spent for collecting firewood is over 2 hours. The increased population decreases land availability for wood and makes woodfuel scarce, yet the alternatives are very expensive. Traditional cooking with solid fuels results into many vulnerabilities particularly if they are burnt in inefficient stoves in poorly ventilated conditions. It leads to health dangers, especially the Indoor Air Pollution. The hypothesis indicates that there no sustainability with biomass as a cooking fuel – the biomass stock can no longer provide woodfuel to the growing population. The research flow chart having the data, model, analysis, results and conclusion is indicated. Then the research scope and limit are illustrated. Lastly the main objectives is stipulated as to study and to analyze the highway to sustainability of the cooking energy in Uganda.

1.1. Energy Poverty

1.1.1. The link between energy and poverty

In order to have all the basic human needs addressed, energy plays a central role. Sustainable development requires access to adequate, affordable, reliable, safe and environmentally friendly energy. Studies show that "in order to achieve any one of the eight MDG for the poorest section of the society, energy must be provided MDGs (Modi, 2006)". The 2010 edition of the World Energy Outlook (WEO) assesses two indicators of energy poverty at the household level: lack of access to electricity and reliance on the traditional use of biomass for cooking. Around 2.7 billion people rely on traditional biomass like wood, charcoal and dung for cooking energy (IPCC, 2010a, p.9). The number of people relying on traditional use of biomass is projected to rise from 2.7 billion in 2010 to 2.8 billion in 2030 (IEA, 2010, p. 7). Lack of electricity and heavy reliance on traditional biomass are hallmarks of poverty in developing countries (IEA, 2002).

As illustrated in **Figure 1.1**, there is a strong correlation between low household income and use of low-quality fuels, so it means that it is the poorest of the population who depend on biomass.

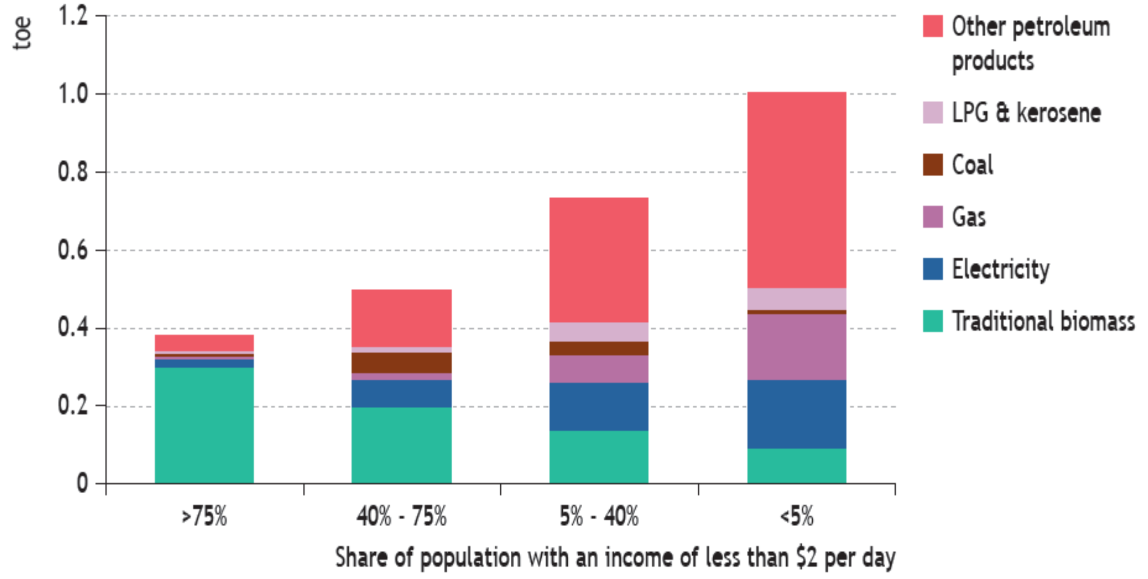


Figure 1.1**:** The relationship between per capita final energy consumption and income in developing countries

Source: (IEA, 2010b, p. 266)

The World Bank poverty monitoring update report shows a general reduction in the population living in absolute poverty in developing countries in the period 1981-2008 (World Bank, 2012). Similarly, the Association of German Development NGOs (VENRO, 2009), indicates that the global poverty has fallen sharply, making the proportion of the world's population living in poverty fall by half – to 26% in 2005 from 52% in 1980.

1.1.2. Poverty and biomass dependence in the sub-Saharan Africa

Despite a global improvement in the socio-economic, a comparison of the regional trends exposes an inequality in the poverty reduction patterns. While the exceedingly populated regions with substantial decline in poverty tend to dominate the overall trend, the less populated regions with lower populations are not easily noticed. For example, China's increasing prosperity over the past two decades has led to significant poverty reductions (VENRO, 2009). Poverty in East Asia has fallen from 92.4% of the population living on $2 per day in 1981 to 33.2% in 2008, and the number of people living below this poverty line is almost halved: from 1,312.9 million in 1981 to 659.2 million in 2008 (World Bank, 2012, p. 6). However, in the South Asia, the proportion of the population living on $2 a day fell from 87.2% to 70.9%, but the number of people increased by 39% (from 810.6 to 1124.6) over the 1981–2008 period.

The Sub-Saharan Africa (SSA) presents the most severe case. **Figure 1.2** shows the proportion of the population living below $2 per day gradually increased from 72.2% in 1981 and reached a maximum of 78.1% in 1993, and then began declining slowly, reaching the minimum of 69.2% in 2008. However, due to the increasing population this reduction in proportions has not cut down the increasing number of people living in poverty: the number of poor people has nearly doubled from 287.6 million in 1981 to 69.2 million in 2008 (World Bank, 2012, p. 6).

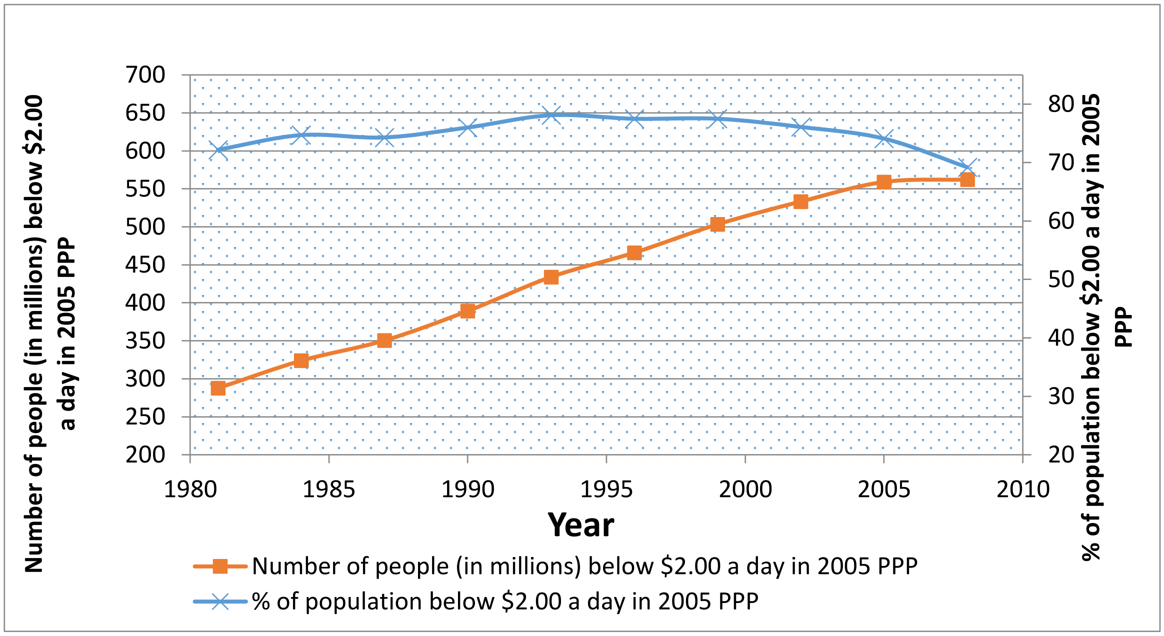


Figure 1.2**:** Poverty trend in the Sub-Saharan Africa for $2 a day 1981 - 2008

Source: Author based on data from the poverty monitoring update report (World Bank, 2012)

The persistent high levels of poverty in the SSA sustain an extreme degree of dependence on traditional biomass. The proportion of people relying on the traditional use of biomass (people without clean cooking facilities) in the SSA is close to 80% (IEA, 2010; UNDP, 2014), and the percentage of the population without electricity is 68% (**Table 1-1**).

Table 1-1: Energy Consumption by Type in Africa (%)

REGIONS	SUB-REGION	Proportion Without Electricity (%)	Proportion without clean cooking facilities (%)
AFRICA	Africa	67	57
	SSA	79	68
	North Africa	1	1
DEVELOPING ASIA	Developing Asia	17	51
	India	66	25
	Pakistan	6	31
	Indonesia	42	27
	China	33	0
LATIN AMERICA	LATIN AMERICA	15	5
Brazil	Brazil	6	1
Middle East	Middle East	4	9
The World	The World	18	38

Source: (UNDP, 2014)

Since these two proportions are the highest compared to other regions (and highest in the whole of Africa), acting as part of the fundamental energy poverty indicators, it illustrates how less developed the continent of Africa is in comparison to other regions. In particular the indicators show how heavily dependent on traditional biomass the SSA is, in an attempt to meet the cooking needs of the poor residents.

Surprisingly, a comparison with the whole World indicates that the proportion without electricity and without clean cooking facilities is only 18% and 38% respectively. A comparison with North Africa indicates that the proportion of people without electricity and clean cooking facilities is only 1% in both cases. This indicates that the energy poverty in SSA is a phenomenon unique to this region – in particular, it relates to shortage in households.

In connection to population, the New York State consumes as much energy as the entire population of SSA (excluding South Africa), yet SSA has a population of 791 million people, whereas New York has 19.7 million people. In regard to the area, Midtown

Manhattan uses more energy than all of Kenya, yet Midtown Manhattan has 5 square miles and Kenya, 224,961 square miles. Generally, the African Energy Sector can be divided into 3 distinct sub-regions according to the dominant source of fuel: North, South and Sub-Sahara (IEA, 2010); see **Figure 1.3**.

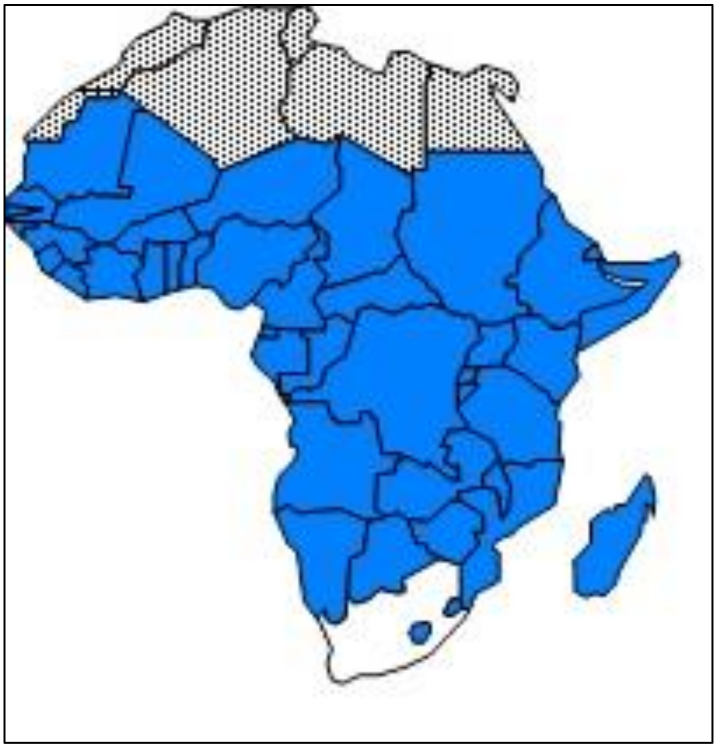


Figure 1.3: Division of African energy sector
Source: (APP, 2015, p. 41)

North Africa is called the oil and gas sub-region (the two contributing nearly 80% of the consumption); South Africa is the coal sub-region which contributes 75% of total primary energy consumption in the country (Balmer, 2007) and Sub-Saharan Africa is the biomass sub-region (SSA) – with 47 countries mainly in rural and urban areas relying on wood-based biomass, constituting 81% of the households energy mainly for cooking (AFREA, 2011, p. 1). This comparison emphasizes the absolute poverty of SSA, both in terms of financial capacity and energy supply. The annual population of Africa (excluding north Africa) increased by 25 million in 2012 – 2014, yet the annual access to clean cooking increases by only 4 million (lack increases over six times). On the other hand, the population of Asia-pacific increased by 40 million, whereas the population adopting clean cooking was 54 million in the same period (**Figure 1.4**). This means adoption of modern cooking increases by 1.35 times.

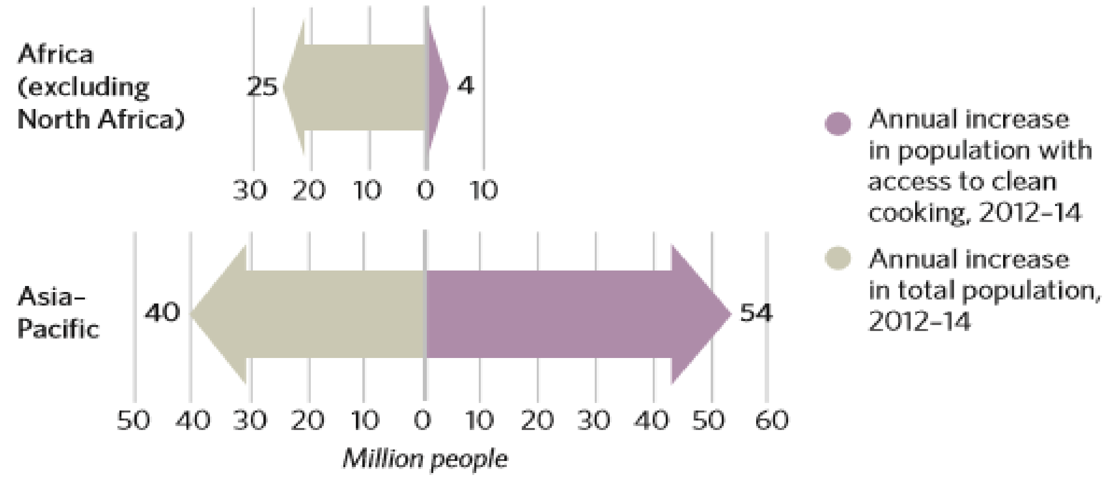


Figure 1.4: Annual Increase in Population with Access to Clean Cooking and Total Annual Increase in Population, 2012–14

(WB and IEA, 2017, p. 7)

Generally, the poorer the country, the greater is its reliance on traditional biomass particularly, for cooking. The level of poverty can be measured in terms of time (hours) the women (or children) spend when collecting firewood for the household (**Figure 1.5**).

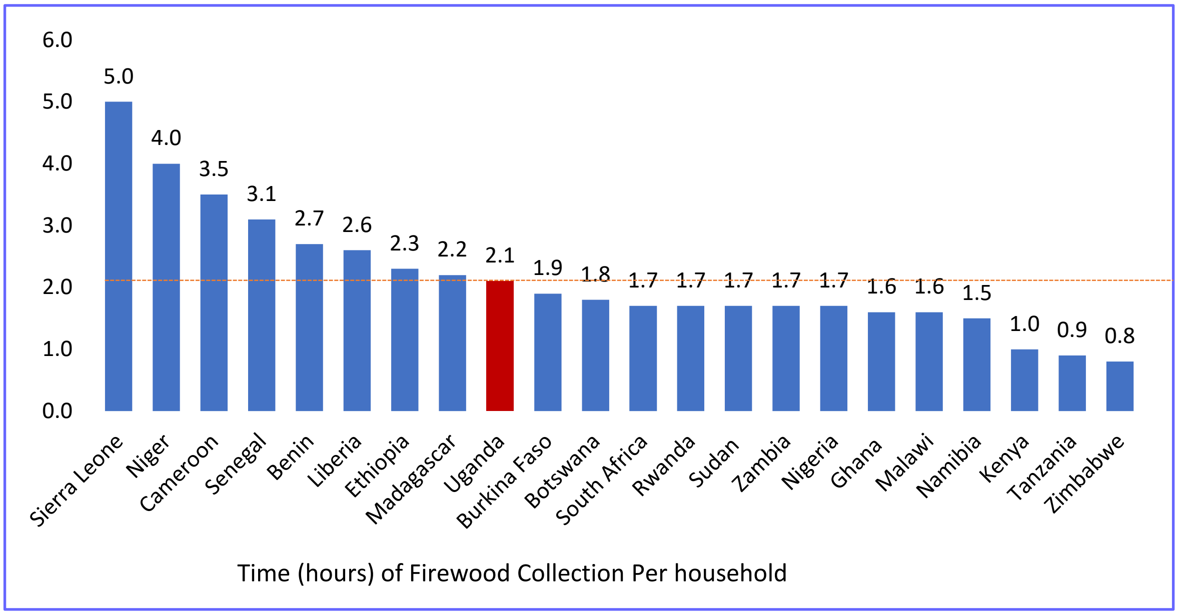


Figure 1.5: Hours spent gathering fuelwood in a selection of 22 Sub-Saharan African countries

Source: (Rysankova, 2014)

The Sub-Saharan Africa region compares poorly with others in the developing world in terms of the proportion of the population relying on traditional biomass for cooking (Brew-Hammond, 2007). Uganda (the focus of this research), lies right at the average point of all those countries and so it is appropriate to the study of consumption and production of biomass for cooking. Because of poverty and socio-cultural setting there is no substantial switching to other cooking fuel alternatives. Moreover, due to rapid increase in population, demand for woodfuel for cooking in household, institution, commercial and industrial; along with wood for non-energy purpose, including sown timber and poles increases. Yet the land allocated to forests declines as increased population and economic activities increase. The consequences of cooking fuel scarcity in households in Uganda include, first, the reduction in number and quality of meals; second, using crop residues, small sticks, leaves and grass for cooking and even using plastics to cook and third, walking a long distance in search of fuelwood (**Figure 1.6**).

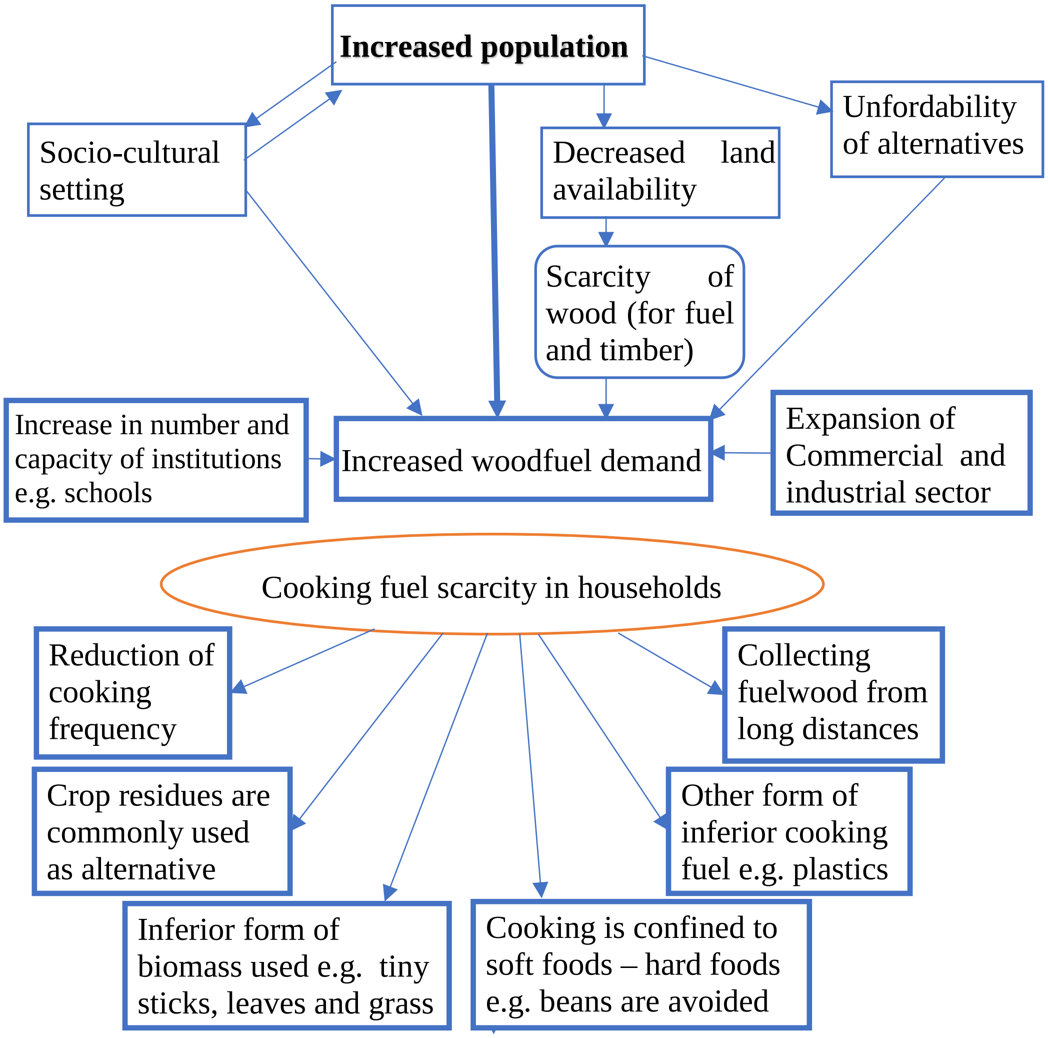


Figure 1.6**:** How population growth increases the cooking fuel scarcity

1.2. Dangers related to use of traditional biomass

Traditional cooking with solid fuels, particularly biomass and coal, results into a double complexity. First, the burning of solid fuels in inefficient stoves in poorly ventilated conditions leads to health dangers, especially the Indoor Air Pollution (IAP). The main health damaging components are the tiny soot particles that are capable of penetrating deep into the lungs. According to the World Health Organization (WHO), indoor smoke can be 100 times higher in poorly ventilated dwellings than acceptable levels for small particles.

Women and children are most exposed than men since they spend most time by the fireside. When health-damaging pollutants are inhaled, they result into serious disease burden.

WHO estimates that nearly 4.3 million people worldwide die prematurely from illness attributable to indoor air pollution due to solid fuel use (2012) data. Among these deaths, 12% are due to pneumonia, 34% from stroke, 26% from ischemic heart disease, 22% from chronic obstructive pulmonary disease, and 6% from lung cancer (WHO, 2012). This reality is better visualized by the map of percentage of population using solid fuels (**Figure 1.7**).

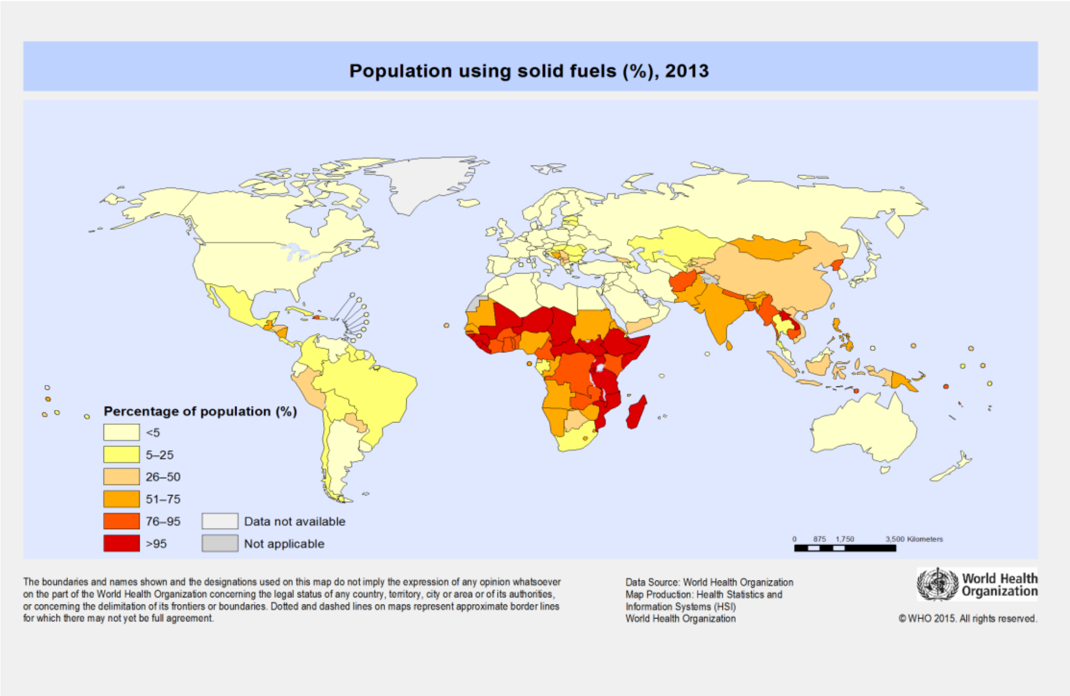


Figure 1.7**:** Population using solid fuel (%), 2013

When this is compared with the map of the country income groups. A very close association appears between the low income countries and the proportion of the population using solid fuels and the country income groups (**Figure 1.8**). This is true for most countries of the world as can be seen from the two maps which appear so closely related, but it is most pronounced in African when the SSA region is considered.

The second risk of IAP is the exposure to carbon monoxide (CO). CO's affinity for haemoglobin (Hb) is 240–270 times greater than that of oxygen: it decreases the capacity of Hb for carrying oxygen, and causes a leftward shift in Hb dissociation curve and the decrease in oxygen delivery to the tissues the intoxication by hypoxia (Holmes, 2010).

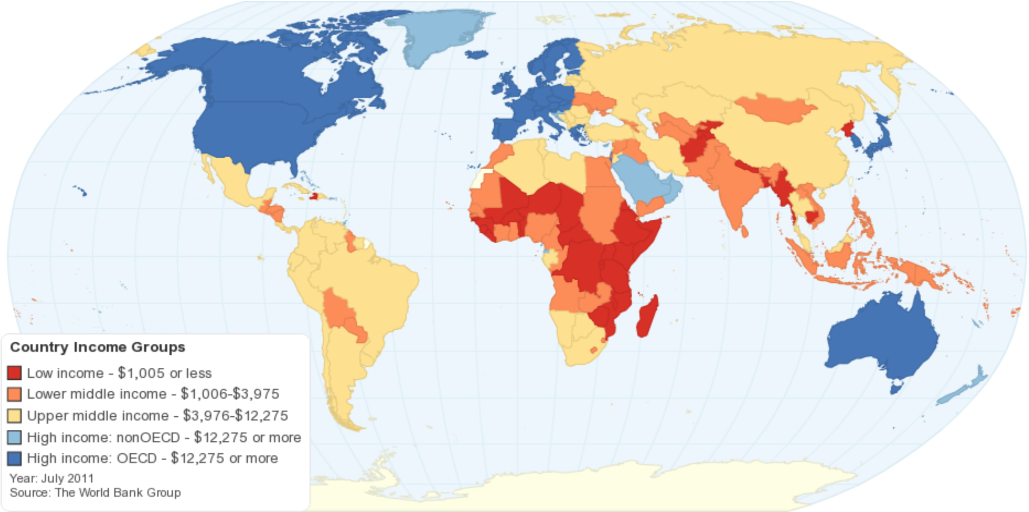


Figure 1.8: Country Income Groups

Apart from the IAP, inefficient biomass use leads to high levels of fuel wastage, which when coupled with intensified demand results into wood scarcity. The consequences of woodfuel scarcity affect the poor, capable of resulting into reductions in quality and quantity of food cooked, increased distance, burden and time of wood collection that is also accompanied by intensified risks associated during fuelwood collection.

Due to continued poverty in the SSA region, which sustains the dependence on solid fuels particularly biomass, the resulting negative effects are likely to be prolonged and amplified under business-as-usual scenario. In other words, countries with most proportion of poor population are likely to experience most severity.

1.3. Hypothesis

The researcher has chosen Uganda as a case study in the SSA, and the hypothesis is as follows:

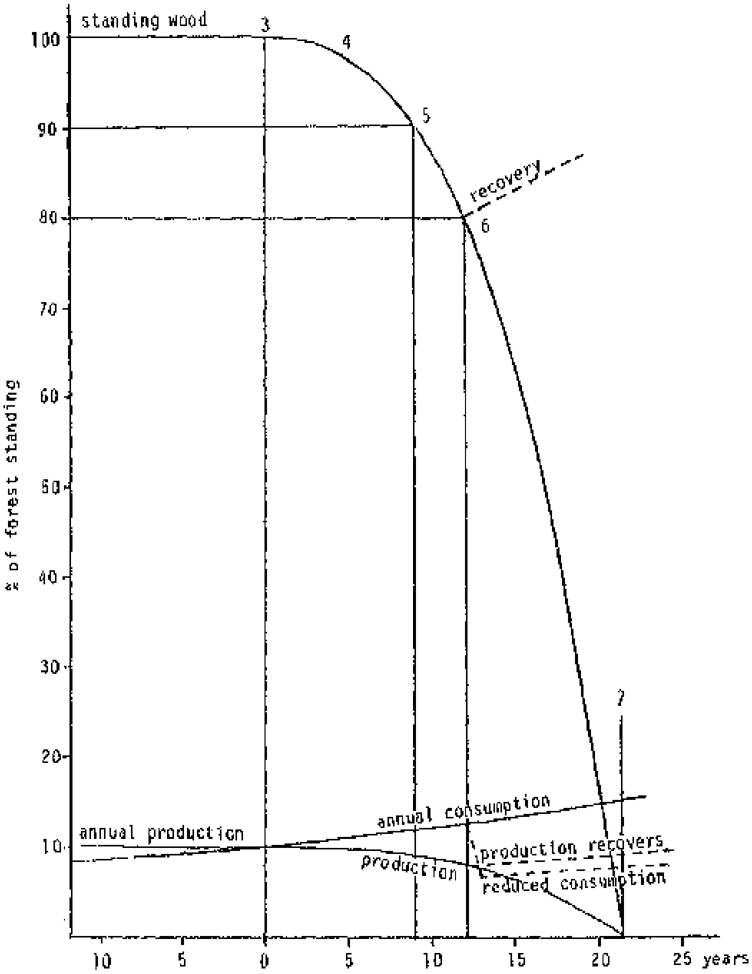
The cooking energy needs of the Ugandan population cannot be sustainably met by biomass because the biomass resource base, which provides the major share of the cooking fuel, is subjected to accelerating depletion levels.

The sustainability of biomass in the perspective of this research is that the annual outtake of woodfuel should not exceed the annual consumption. From a strategic foresight, efficiency is essential but insufficient. The effort to disseminate biomass energy efficient technologies as a prospective road to cooking energy sustainability faces two limitations: dragging socio-economic forces slows it down and the threat of ultimate impending wood resource extinction. That is, on the one hand dissemination of improved stoves is slowed down by tough socio-cultural and economic barriers that challenge sustainable technology diffusion and capacity to attain a substantial coverage. This would have reduced demand hence counteracting the biomass resource shrinkage. On the other hand, even if these efforts were successful, still the sustainability of biomass utilization gets contested by the increasing population whose resulting rise in energy demand would finally sweep away the gains acquired from efficiency.

A thorough approach would be an integration of the biomass energy demand reduction through efficiency with efforts to increase the supply by promoting tree planting. However, the rising population, increased economic activities (like farming and expanding urbanization) tend to compete for the same land, hence diminishing the space for biomass resource expansion or regeneration. This is a critical contest of energy against food that tends to push tree planting at the peripheral. The limited fuel switching in Uganda, like many SSA countries, leaves the question of sustainability of cooking energy in balance.

This hypothesis argues that meeting the cooking needs sustainably will require a re-orientation from the “business as usual” scenario to a dynamic approach. Unlike the case of other renewable energies, the biomass resource can be lost, consequently, all the accompanying benefits it offers may vanish. For example, biodiversity, climate regulation (e.g. cooling, CO_2 absorption), air cleaning, reduction of evaporation, water filtration, soil erosion reduction, and medicinal and food (fruit) values can become extinct.

In the last 30 years, forests have been destroyed than those depleted for past 2,500 years. A size of natural forests that is equivalent to the football field is destroyed only every 2 seconds (Greenpeace, 2016). The extinction takes place in inconspicuous stages, the first and most decisive one being the greater consumption than the production in a given period, which entails taking the required balance from the capital wood stock, hence weakening its productive capacity. **Figure 1.9** illustrates how unexpected shock of complete loss of biomass resource. Although this normally happens in isolated places if ignored can spread under "business as usual" it can spread in the entire the country.



For centuries, the inhabitants of a region have obtained their supplies of wood from their supplies of wood from their local forest

However, population rises and more wood is consumed (+2% a year).

At a certain moment, wood consumption will equal natural production.

At the beginning, little change is observed.

After 9 years, 10% of the forest has disappeared. Some concerns begin to be felt.

After 12 Years, 20% of the forest has disappeared.

Only 10 years later, the forest has been completely felled. This can be avoided: if consumption is reduced in time.

Action must be taken quickly. But beyond a certain point, it is almost impossible to stop deforestation.

Source: GTZ – GATE, 1984

Figure 1.9: The unexpected shock, or how the forest disappears

Consequently, the degree and timeliness of the intervention determines the avoidance of the crisis. Sustainability requires that the Improved Cookstove Stove dissemination (ICS) endeavors are primarily regarded a transition phase towards alternative modern cooking energy, rather than the end goal. Yet a smooth transition is necessary. Without this smooth shift, a forced reactive change due to severe crisis of fuel gap is likely to subject many lives to disaster. So, the path of this necessary transition requires a clear mapping through research and analytical planning, otherwise. A sudden response due to resource extinction will most likely create severe social, economic and ecological damage.

Consequently, sustainability cannot be achieved amidst ambiguity in the execution of practical actions. It must be clear to what extent and for how long improved wood stove is a solution to the biomass scarcity and which category of consumers it is appropriate. Furthermore, an inventory of alternative cooking energy options needs to be clearly identified and the contexts in which each of them can be adopted. In other words, sustainable provision of modern cooking energy demands a careful inquiry into the barriers and drivers to the adoption of the alternatives by the different categories of consumers.

However, the inquiry should not be just related to prices of biomass or cooking alternatives alone. The influence of non-cost factors, including the socio-cultural context needs careful scrutiny. For example, for many centuries back the African cuisine has been generally designed and adapted to the traditional biomass cooking energy. This allegedly implies that both the cooking process and the product quality (flavor, taste, etc.) are sometimes dependent on the traditional cooking system so that a change in the cooking device or fuel could alter the flavor or taste of the food.

The research hypothesis in this study will be rejected if the research findings indicate that the existence of realistic solutions or coping mechanisms and compelling evidence that these actions will be effectively adopted in time to avert the forthcoming cooking crunch. It will be rejected if the fuel gap does not actually exist because of alternative biomass sources or if these are a growing emergence of technically sound, socially acceptable and economically feasible alternatives that are capable of substituting the lost wood fuel or if the research findings indicate that wood fuel supply mechanisms could actually sustainably meet the cooking needs of the Ugandan population.

In other words, if sustainable forestry management practices can be implemented throughout the country, the environmental system is capable of maintaining the woodfuel resource. This in turn is essential for the absorption of CO_2, slowing water evaporation, filtration of water, slowing the wind speed, absorption of odor and pollutants, provision of oxygen, temperature regulation, prevention of soil erosion, maintaining biodiversity and provision of fruits. Above all the woodfuel resource is the main source for woodfuel for cooking. Dealing with the challenge of increasing wood scarcity requires either the change to alternative fuel or the alternative technology, both aimed at cutting down the fuel consumption. But in the long run both technology and fuel need alternatives, yet the most important determinant is development, which can uplift the welfare or living standards. To enable the improvement of living standards there is need to control the population growth. This concept is illustrated in the schematic diagram (**Figure 1.10**).

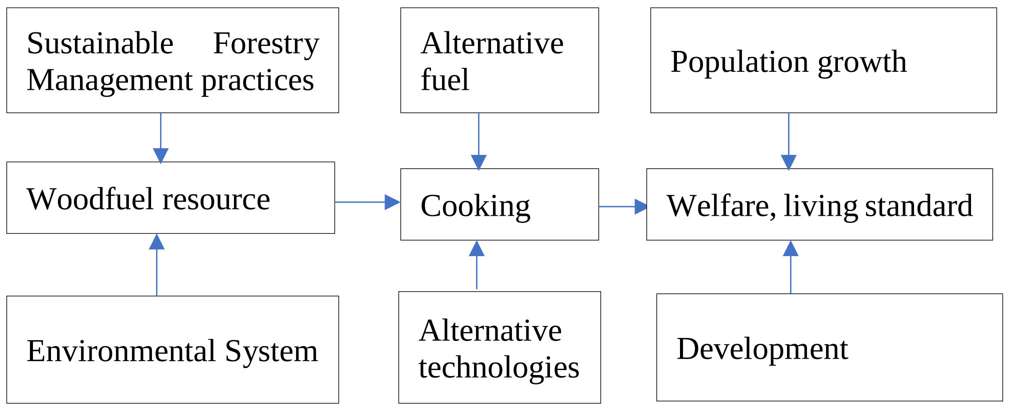
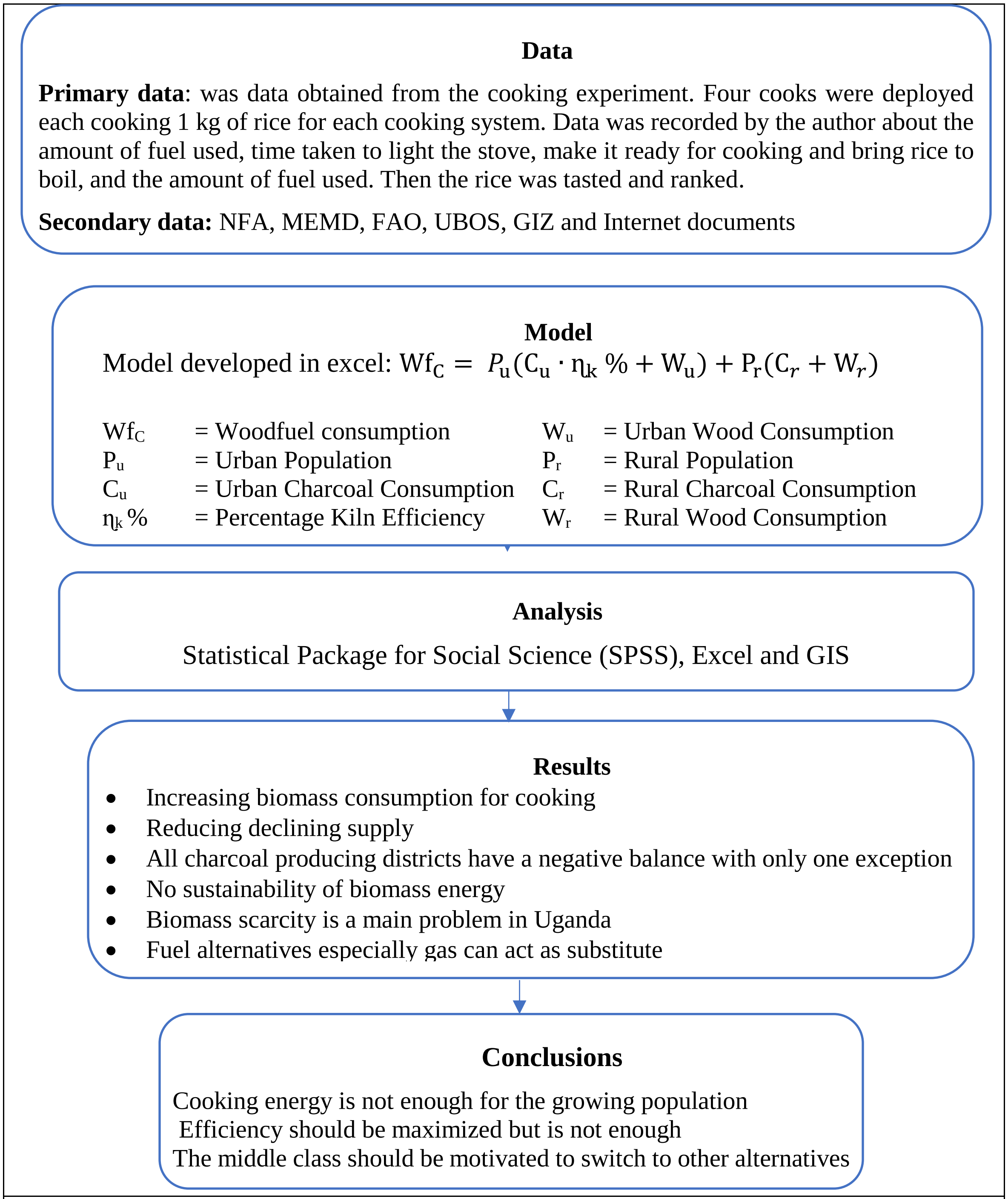


Figure 1.10: Interlinkage Connected with Cooking Fuel

1.4. Research sequence

The flow of this research can be represented by the following sequence: data – refers to the individual facts, statistics, and item which will be analyzed to obtain information: data will be both primary and secondary. Then data will be fed into the Model, which is a representation of a system or process created on a computer, to assist calculations, manipulation and predictions. The model then will be used for the analysis – a process of separation of any academic material or abstract entity into its constituent elements. The analysis gives the results as the outcome. Based on results will be made conclusion. This process is illustrated in the diagram in **Figure 1.11**



Data

Primary data: was data obtained from the cooking experiment. Four cooks were deployed each cooking 1 kg of rice for each cooking system. Data was recorded by the author about the amount of fuel used, time taken to light the stove, make it ready for cooking and bring rice to boil, and the amount of fuel used. Then the rice was tasted and ranked.

Secondary data: NFA, MEMD, FAO, UBOS, GIZ and Internet documents

Model

Model developed in excel: $Wf_C = P_u(C_u \cdot \eta_k\,\% + W_u) + P_r(C_r + W_r)$

Wf_C = Woodfuel consumption
P_u = Urban Population
C_u = Urban Charcoal Consumption
$\eta_k\,\%$ = Percentage Kiln Efficiency
W_u = Urban Wood Consumption
P_r = Rural Population
C_r = Rural Charcoal Consumption
W_r = Rural Wood Consumption

Analysis

Statistical Package for Social Science (SPSS), Excel and GIS

Results

- Increasing biomass consumption for cooking
- Reducing declining supply
- All charcoal producing districts have a negative balance with only one exception
- No sustainability of biomass energy
- Biomass scarcity is a main problem in Uganda
- Fuel alternatives especially gas can act as substitute

Conclusions

Cooking energy is not enough for the growing population
Efficiency should be maximized but is not enough
The middle class should be motivated to switch to other alternatives

Figure 1.11: Research flow Chart

1.5. Scope and Limit of the Thesis

This thesis seeks to investigate whether the woodfuel supply in Uganda is sufficient, given the growing demand (due to population growth and poverty) and the diminishing supply resource base (also related to reduction in space due to increase in population density); consequently it aims at presenting the case for fuel alternatives. On the demand side, two sets of data will be used to address demand: data from National Forestry Authority (NFA) and estimated data from Ministry of Energy and Mineral Development (MEMD).

To begin with, the entire wood demand subsector will be analyzed, including the quantity of non-energy wood. Then woodfuel will be analyzed in detail with a particular focus on the fuelwood and charcoal used for cooking purpose. Though some reference will be made to the energy used in institutions, commercial and industrial sectors to capture the total woodfuel, the core focus of analysis will be on fuelwood and charcoal used for cooking with particular emphasis on households.

On the wood supply side, two technical reports will be used: National Biomass Study (NBS) – Technical Reports: 1990 (Drichi, 2003) and 2005 (Diisi, 2009) detailing the biomass stock changes at national and district levels. In this study the estimated wood demand will be compared with the annual increment of stock. Accordingly, the rates of increase and decline per district will be projected to be the indicative volume and weight of the stock. The first major constraint is to do with the increasing districts which were 34 (Green, 2008) and they increased to 121 (MOLG, 2017). The rapid increase in districts is beyond the scope of this thesis.

The second constraints relate to data scarcity: two datasets may not be sufficient or reliable to make a valid conclusion; nevertheless, there is some scanty data to support or confirm that the decline is a reality. Using Statistical Package for Social Sciences (SPSS), several arithmetical outputs will be generated to ascertain the scientific significance of different parameters. A schematic diagram showing the scope and limits of this research is given in **Figure 1.12**.

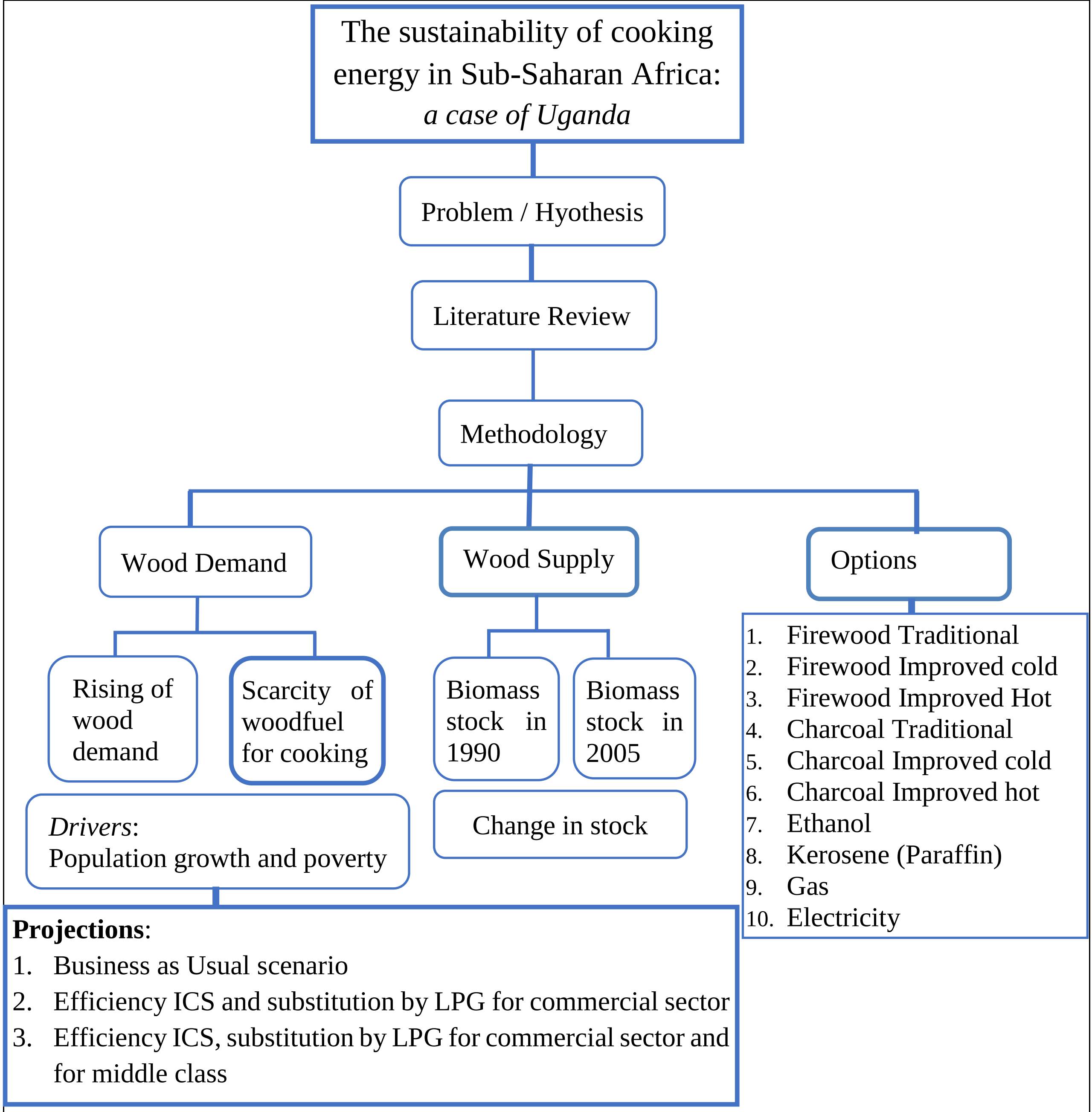


Figure 1.12: The Scope and Limit of the Thesis

Then the assessment of the alternative technology (stoves and fuels) will be carried out. Four cooks will be assigned the task of conducting the cooking operation in which each cook has to bring 1 kg of rice to boil on each of the ten cookstove: Firewood

Traditional, Firewood Improved (cold), Firewood Improved (hot), Charcoal Traditional, Charcoal Improved (cold), Charcoal Improved (hot), Ethanol, Kerosene, Gas and Electricity. The cooking environment will be the same, so the effect of temperature, humidity and wind will be minimized. Then the author will make the choice by comparing the cooking systems in terms of price, cooking time, power, energy, quantity of fuel or mass used per kg of rice, food taste and cooking costs. Analysis to determine the statitstical significance using SPSS, will be carried out.

Lastly, three scenarios will be analyzed using a model created in excel: Business as Usual scenario (what happens under the current policy action), Efficiency – Improved Cook Stove (ICS) and substitution by gas for commercial sector and Efficiency ICS, and substitution by gas for commercial sector and for middle class. These actions will be effective in reducing the demand of woodfuel.

1.6. Objectives

The main objective of this study is to analyze the highway to sustainability of the cooking energy in Uganda.

The specific objectives are:

- To analyze the cooking energy needs for the different categories of consumers in Uganda.
- To investigate the socio-economic consequences of fuelwood scarcity.
- To analyze the biomass resource base, evaluating the production and outtake: hence determining demand and supply.
- To explore the business potential of the cooking energy alternatives in relation to demand and supply regimes and assess the feasible extent of switching.
- To compare biomass demand and supply and forecast the business-as-usual scenario and the alternative scenarios for addressing cooking energy.

CHAPTER 2

LITERATURE REVIEW

This chapter addresses the literature that is related to this research. Accordingly, it is divided into 7 divisions: introduction (addressing general aspects), determinants of household fuel use (education, income, household size and composition and gender of the household head), tastes and preferences of cooking fuels, preference for wood (due to cultural setting), wood saving by improved cookstoves, balance for demand and supply and the woodfuel gap theory (how it works). The key words for this chapter are cultural system, cooking traditions, stoves, poverty, and rural and urban identity.

2.1. General Background

Energy poverty cannot be captured in single definition; similarly, there is no definition for poverty itself. The characteristics distinguishing the condition of energy poverty are diverse, including nutrition, life expectancy, living conditions, literacy and access to energy. Considering the UNDP's multidimensional idea of poverty, non-income dimensions of poverty are as essential as the employment or wages, and therefore critical aspects that are essential for survival include energy (UN, 2010).

One of the measures of poverty is the income outlook: to be “poor” is to earn less than $2 per day (adjusting for the purchasing power parity of countries) – implying that 40% of the global population is poor (Sovacool, 2012). Globally the population living on less than US$1/day is two billion people which is almost the same population lacking modern energy (FAO COFO, 2005).

Nearly 80% of the population without electricity reside in rural areas mainly in developing countries, primarily South Asia and SSA. The challenge of grid extension in rural areas is threefold: first, the households are few; secondly, they are scattered thirdly their ability to pay is low. As a result, the costs of rural electrification can go up to sevenfold compared to the amount required to electrify the urban area. Consequently, woody biomass in Africa, Asia and Latin America accounts for 89%, 81%, and 66%, respectively, of total wood consumption (IEA, 2006).

A critical feature distinguishing the SSA from other countries is the use woodfuel. “Woodfuel” is a broad term covering both the direct use of wood for cooking and heating, the use of charcoal (both for households and for industrial use) and also recovered wastes in wood-using industries” (Donald J. Mead, 2001). The use of woodfuel is expected to grow given the current driving forces especially rapid population growth rate, which has no comparison with the slow economic growth. In the 47 SSA countries, people in rural and urban areas use woodfuel to meet their energy needs especially cooking. On the other hand, woodfuel peaked in China and India and is expected to decline as the economies grow. But in case of SSA, 81% of households still depend on woodfuel: a proportion which compares to no other region in the world. The informal sector is boosted by a big number of actors participating in the buying, transporting, and selling woodfuel, in an effort to add value to the informal sector (THE WORLD BANK , 2011).

Global energy demand is estimated to increase in the future, with population growth and lifestyle changes in the developing countries, particularly Africa, where economic growth goes in tandem with energy consumption: a 1% growth in GDP requires 0.55% of GDP (Kebede E, 2010). Africa has about 13% of the global population, yet it consumes only 5.6% of the global energy supply as of 2001 (latest data available), meaning that with the increase in trade, improved standard of living and advanced infrastructure Africa’s energy per capita will increase (Cerutti, 2015). On the other hand, if Africa is to expand its economy, it needs a lot of investment in modern energy. Currently, its wood fuel that plays a central role.

However, the increase in energy may not significantly imply a transition in the energy, given the fact that the cost of rural electrification is prohibitive and the socio-cultural setting still favors woodfuel. So in relation to the source of energy, woodfuel (mainly firewood and charcoal) is the main fuel for cooking in the Sub-Saharan Africa, catering for an estimate of 93% of the households. With the exception of South Africa where coal plays a major role for cooking, the largest proportion of the population of SSA rely on the traditional biomass for cooking. SSA is the region with the highest per capita average wood energy consumption of 0.69 m^3, compared with the global average consumption of 0.27 m^3, in 2011. Firewood is the main fuel for rural area, while charcoal is prefered choice for urban markets due to higher energy density, ease of storage and transport, and lower smoke production. Nevertheless it emits a lot of carbonmonoxide.

The Sub-Saharan Africa had a rural population of 477 and an urban of 176 making a total of 653 in 2009, which increased slightly to 741 in 2015 and is projected to be 918 in 2030. But the population using biomass in Africa in 2015 is 65% and is projected to be 61% by 2030; in SSA it is estimated at 77% and is projected at 70% by 2030; all other figure relating to the consumption of biomass are much lower (Cerutti, 2015). However, new estimates project the African population to be nearly 1.3 billion (Worldometers, 2018).

Wealthy household have both the ability and the willingness to pay for higher quality of energy; hence the higher the income of the household the more likely it is to switch from primitive energy such as firewood to modern fuels. A study conducted in India indicates that there is a positive correlation between per capita total household expenditure and per capita total energy requirement, meaning that the poor households remain in energy poverty and cannot afford modern energy services (Pachauri S., 2004).

2.2. Determinants of household fuel use

Determinants of household use of fuel for cooking as shown by emperical evidence from SSA, using data from the World Bank Living Standard Measurement Study (LSMS), throws more light on pattern of cooking for East and Southern Africa. These LSMS include: (1) Ethiopia Socioeconomic Survey (2013) with a sample of 5262; (2) Malawi Integrated Household Panel Survey (2013) with a sample of 4000; (3) and Tanzania National Panel Survey (2012 – 13) with a sample of 3924 (Dil Bahadur Rahut, 2016).

According to this research and several others it is clearly revealed that the determinants of choice of fuel are income, household size and composition, education and the gender of the household heads. The distribution pattern of the households by cooking fuel indicates that solid fuels are still predominant in Eastern and Southern Africa. The research indicates that 93% of the household were using solid fuel for cooking and only 3.5% use electricity and 1.9% cook with gas and kerosene. If an analysis is done to separate the individual countries the results would be 90.1% of the Ethiopian, 95.6% of the Malawian and 94.6% of the Tanzanian households depend on solid fuels for cooking.

This study reveals four of the essential determinants of choice of cooking fuel in the household. First, is the education level of the household head. An increase in standard raises the percentage the households using electricity from 0.8%, 3.2%, 5.2%, 17% and 43.6%, for uneducated, primary school, senior, senior secondary, and university heads respectively. Moreover, 7.8% of household heads with university qualification use gas and kerosene, whereas only 0.8% of the household of eneducated heads use gas and kerosene. So the level of education of the household head influences the cooking fuel choice. Education has a positive influence on income, and a negative effect on family size and time availability for cooking.

Second, the wealth of a household as measured by the type of toilet influences the choice of cooking fuel: 1.9% of the households with open ground toilets, 5.2% with a pit toilet and 36.5% of flush toilets respectively use electricity. However, if car ownership is taken as a measure of wealth, only 3% of the households with no car use electricity for cooking compared to the 28.7% with a car ownership use electricity.

Third, the households closer to the market within a distance of 11 km use electricity for cooking, while those within a distance of 23.6 km use gas and kerosene and household beyond 52.5 km use solid fuels. The average road distance for the households using electricity, gas and kerosene, and solid fuels for cooking, is 2.1 km, 4.4 km and 13.4 km respectively. The average distance to the location for households using electricity, gas and kerosene, and solid fuels, is 7.8 km, 15.7 km and 36.6 km respectively.

Fourth, the study further shows that female-headed households are more likely to choose electricity for cooking than the male-headed households. This is because the application of electricity provides comfort to the female members of the household, who take on the responsibility for the cooking task.

Another study carried out in SSA was conducted in West Africa in Nigeria whose population is the highest in the region. About 70% of Nigeria´s population is primarily rural, and depends mainly on woodfuel for their cooking needs. Using data from Demographic and Health Survey (DHS) of 2013, which nationally represents 38,495 households, and by application of SPSS, percentages, chi-square and logistic were used to address the research questions. Results show that 55% of the households have electricity, while 44% do not. Moreover the main cooking fuel is firewood used by 66.3% or 81% (if charcoal is included), followed by kerosene used by 23.6% of the households for cooking purposes. Furthermore, the main proportion of the households in the urban areas used modern fuels such as electricity, LPG, natural gas, biogas, and kerosene, whereas those of the rural areas depended on the primitive forms of fuel such as firewood, straw, agricultural residue, and animal dung.

This study highlights that nearly 76% and 24.5% of the urban and rural households respectively, used electricity for cooking; whereas LPG is mainly used in 89.1% and 10.9% of urban and rural households respectively; and, 76.1% and 23.9% of the urban and rural households, respectively used kerosene for cooking. This data showed that 76% and 26% of the rural and urban households used firewood for cooking respectively; whereas LPG and natural gas are only affordable by a small section of urban dwellers because they are very costly. Even when there is price subsidy for kerosene, LPG and natural gas these fuels are less affordable to the urban community who are the richer section of the population.

Further, the analysis shows a relationship between access to electricity and type of cooking fuel used by the household. Only 1.2% of the urban households having access to electricity use it for cooking; likewise, natural gas and LPG are used only by 3.2% and 2.0% of the urban household with electricity access, respectively. 49% of the urban households with access to electricity use kerosene for cooking. The availability and cheap cost of wood lead to its dependence, whereas factors like poverty, lack of access and irregular nature of power supply, minimize electricity as an alternative for cooking.

Results also show that electricity is used by 2.4% of households with no education, 10.7% with primary school, 40.8% with secondary and 46.1% with higher education. About 49% of households with no education heavily rely on the fuelwood for cooking; whereas 21.6% and 26.6%, of those with primary and secondary education respectively depend on firewood for cooking. Only 2.8% of the household with tertiary education use firewood for cooking. Nigeria is divided into 6 geo-political regions and the proportion of firewood consumed varies from as high as 25.9% northwest to as low as 13.6% south-south yet some southwest region consume 9.0%. This pattern is a result of the low cost of fuelwood and scarcity of the alternatives.

There is a relationship between the wealth of a household and its cooking fuel. LPG is consumed by 99.7%, natural gas by 90.0% and biogas by 93.0% of the richest households. Therefore modern energy access, including electricity, LPG, natural gas, biogas and solar are all fuels for the rich. Kerosene is consumed by the poorer (0.2%), middle (5.3%), richer (30%) and the richest (63.6%) households. Results showed that 20.4%, 26.6% and 29.3% of the poorest, poorer and middle income households respectively used wood. So there was a statistically significant difference between rural and urban dwellers in relation to the type fuel used for cooking.

There was also a study of energy consumption pattern in Tanzania household. In this survey determinants of fuel choice were investigated. Data was obtained from Morogoro and Ruvuma region, using several methods: household questionnaire, focus group discussion, key informants interview, and researchers' direct observation. A sample was obtained composed of 568 respondents. The respondents were divided into 3 categories based on their wealth status: low, medium and high categories, depending on the household assets as proxy indicator for their wealth. Data analysis was done using SPSS and Excel statistical computer programs (Lusambo LP, 2016).

Results showed that the types of fuel found in the study area are kerosene, firewood and charcoal accounting for 83%, 81%, and 58% respectively; only 14.5% of the households are electrified. Crop residues, solar and natural gas account for 17%, 0.2% and 0.2% respectively. About 51.4% of the households gather firewood mainly from natural forest (73.6%), plantation forest (19.5%), private farm (1.4%) and 5.5% from other places.

A round trip may take 2 to 20 km and a mean of 3.3 km; and time spent gathering firewood ranges from 2 to 12 hours with a mean of 3 hours. Time spent to move firewood from the forest to home depends on the speed of the transport means used: 86% of the households carry it on their heads; 7.7% of the households transport it on bicycles; and 5.7% of the household use animal transport. The transported load depends also on the means of transport ranging from a minimum of 15 kg and a maximum of 300 kg with a mean of 20 kg.

Statistically significant determinants influencing fuel choice were found to be:

Education level of the household head (0.05): influences the cooking fuel choice – the more educated the household head the higher is the preference for charcoal. Residence ownership (0.001): residential rented households prefer charcoal to firewood. Dwelling category (0.001): households with modern dwellings are likely to go for charcoal rather than firewood. Household income (0.01): households with higher income have a have the ability choose charcoal rather than firewood. Location ($p < 0.001$): urban household are likely to opt for charcoal rather than firewood, unlike their peers in the village who would choose firewood. Residents in the study area had a statistically significant preference for wood in Miombo woodland as the woodfuel source ($\chi^2_{(2,\ n = 520)} = 43.76$, $p < 0.05$).

Still another study conducted in Abuja, Federal Capital of Nigeria, explored whether there are preference among the fuels and access to them; and whether there is a difference among the zone preference and access. A multistage sampling was done for this survey as the best method, while the questionnaire was used as a tool for data collection. The independent variables were type of fuel used for cooking and household location, and dependent variables were access and preference to the fuel. Household locations were introduced to inquire whether there is a spot difference in preference and access among the households. Cooking fuels are in different levels according to the energy ladder hypothesis: “firewood, electricity, charcoal, kerosene and cooking gas”, while the four zones were: “Abuja central, eastern, northern and western”. The fuels were coded with numbers: very highly accessible (4) accessible (3) fairly accessible (2) low access (1) not accessible at all (0), whereas the level of preference were coded as very highly preferred (3), highly preferred (2) fairly preferred (1) not preferred (0) (Ajah, 2013)

Using SPSS 15.0, an ANOVA for household cooking fuel results was perfomed. First, the ANOVA calculation can be given as $F(4,848) = 324$, $p = 0.00$, meaning that there is a statistical difference in access of certain cooking fuel irrespective of the place of residence. Second, results show that: $F(12,848) = 15.10$, $p =0.00$ meaning, that there is an interractive statistical different between households based on cooking fuel and residence. Third results, $F(3, 212) = 26.65$, $p = 0.00$, indicates that the results for the cooking fuels based on the location of the households had a statistically significant difference. Computing the means separately reveals that the most accessible cooking fuel would be firewood (3.25), kerosene (2.20), charcoal (1.94), electricity (1.14) and gas (0.22) respectively (Ayodeji, 2016). **Table 2-1** shows ANOVA results of households access to cooking fuel and **Table 2-2** is the mean separation of households access cooking fuel – type of cooking fuel.

Table 2-1 ANOVA results of households access to cooking fuels

Source of variation	**Df**	**SS**	**MS**	**F**	**p-value**
Cooking fuel	4	1125.71	281.43	324.67	0.00
Cooking fuel location	12	157.65	13.14	15.10	0.00
Error (cooking fuel)	848	735.04	0.87		
Locations	3	15.98	5.33	26.65	0.00
Error (Location)	212	42.34	0.20		
Total		1079	2076.72		

Source: Survey data 2011

Table 2-2 Mean separation of households' access to cooking fuel types

Agric zones	**Firewood**	**Charcoal**	**Kerosene**	**Cooking Gas**	**Electricity**	**Zonal**
Central	3.70	2.91	2.57	0.17	1.07	2.09^{a}
East	3.04	2.28	2.57	0.30	1.57	1.95^{a}
North	3.69	0.69	1.93	0.13	0.93	1.47^{b}
West	2.59	1.89	1.74	0.30	0.98	1.50^{b}
Total	3.25^{a}	1.94^{c}	2.20^{b}	0.22^{c}	1.14^{d}	1.75

Means with the same alphabet did not significantly differ from each other. Source: Survey data (2011)

The results show further that: F(4, 848) =273, p = 0.00, which implies that there is a statistically significant difference among households regarding the cooking fuels used in different places of residence. Similarly, the depiction that: F(4, 848) = 13.76 , p = 0.00, represents a signicant difference resulting from the combination of cooking fuel and the location. Additionally, F(3, 212) = 24.50, p = 0.00, there was a significant difference based on the location of households regarding the cooking fuels. Following the ANOVA, the distinction of the means based on the highest was firewood (2.69), charcoal (1.66), kerosene (1.65), electricity (1.07), and gas (0.23). Table 2-3 shows ANOVA results of households' preference to cooking fuels and Table 2-4 the mean separation of household preference to cooking fuels – types of cooking fuels. In any case the main fuel that is preferable and accessible to households is fuelwood.

Table 2-3 ANOVA results of households' preference to cooking fuels

Source of variation	Df	SS	MS	F	p-value
Cooking fuel	4	699.25	174.81	273.00	0.00
Cooking fuel location	12	105.76	8.81	13.76	0.00
Error (cooking fuel)	848	542.99	0.64		
Locations	3	13.24	4.41	24.50	0.00
Error (Location)	212	37.63	0.18		
Total	1079	1398.87			

Source: Survey data (2011)

Table 2-4 Mean separation of household preference to cooking fuels – Types

Agric zones	Firewood	Charcoal	Kerosene	Cooking gas	Electricity	Zonal total
Central	2.70	2.17	1.80	0.20	1.13	1.60^{a}
East	2.44	2.00	2.02	0.39	1.61	1.69^{a}
North	2.65	0.39	1.22	0.93	0.89	1.89^{b}
West	2.94	2.09	1.57	0.24	0.67	1.67^{a}
Total	2.69^{a}	1.66^{b}	1.65^{b}	0.23^{d}	1.07^{c}	1.46

Means with the same alphabet did not significantly differ from each other. Source: Survey data 2011

2.3. Tastes and Preferences

The data was obtained from Ghana Living Standards Fourth Round (GLSS4): gathered by Ghana Statistical service between 1998 and 1999. Although the data is too old it is most reliable and the pattern of cooking fuel has not changed much. The households were totalling up to 65,222 and were bundled into 1208 groups, for analysis. This data related to fuel type and cost; population and total expenditures was gathered. Ghana was divided into 3 ecological zones: coastal, forest and savannah (Akpalu, 2011).

The standard deviations are lower than the mean values for LPG and for firewood, which indicates that there is not much variation in the data values. On the other hand the standard deviations are higher than the mean values for kerosene and charcoal, meaning that there is much variation in the data. The mean values for household expenditure, level of eduction, age, and marital stutus per cluster are higher than their respective standard deviation; whereas, the mean values for energy usage, prices of all fuels, and ecological zones are lower than their standard deviations.

With respect to the main hypothesis, there is a significant (1%) difference among the cooking different fuels, indicating there is a significant difference among the preference for fuels used for cooking. From the elasticity coefficient the hierachy of preference is LPG, charcoal, firewood and kerosene. These results agree with (Masera, 2000) that households don't forgo solid fuels for liquid just because of clean burning. First, kerosene stove produce much less fire compared to firewood, hence taking a long time to cook. Secondly, with a kerosene stove, one cannot use a round bottomed pot. Third, a kerosene stove by its make is weak and cannot support heavy pots.

The price elasticity of demand for each fuel is inelastic, except for kerosene. In other words, no matter how much the price varies among other fuels the quantity demanded remains almost the same. This explains why quantity demanded of biomass is almost stable and unaffected by price changes. Furthermore it explains why the policy in Ghana that aim at promoting LPG have been almost a failure. The changes in price cause the quantity demanded of kerosene to easily fluctuate, whereas the quantity of wood demanded remains the same. Whenever the price of charcoal increases, household use kerosene as the alternative. Moverover, while kerosene serves as a substitute for LPG, the latter is a complement for firewood.

2.4. Preference for Wood

A study conducted in Kiambu, Thika and Maragwa districts of central Kenya were purposevely sampled on the basis of their diverse wood production systems, ecological conditions, and population densities (Githiomi J.K., 2012). Choice of households was made using multistage stratified sampling, which ascertains that every one of the three districts was divided according to the socio-economic and climatic characteristics, hence ensuring both homogeinity and heterogenity of the sample. Then households were selected by random sampling from the household list. Data was recorded using a questionaire and was analyzed using MS-Excel and SPSS.

Firewood is the most common woodfuel meeting energy demand in most residential places: 87%, 80% and 96% consumed by households in Kiambu, Thika and Maragwa respectively. The most rarely used fuel were crop residue, gas and kerosene. The data shows there was a significant difference ($p=0.01$) among the cooking devices within the districts, in which it is clearly revealed that the traditional three stone fire dominates the cooking devices with shares of 76%, 59% and 64%, next is the charcoal stoves with 18%, 30% and 24% in Kiambu, Thika and Maragwa districts respectively. A very tiny proportion of households uses kerosene and gas.

The population having the awareness about the improved stoves was over 70%. The adoption of improved charcoal and firewood stoves is 19%, 24.5% and 28% for Kiambu, Thika and Maragwa districts respectively. The main cause for the low adoption for the improved stoves is the high cost, followed by non availability and the lack of awareness of their benefits. One of the prominent improved charcoal stoves used in Kenya and in the neigbouring countries is the Kenya Ceramic Jiko (KCJ). It is like a traditional charcoal stove but has a ceramic lining which reduces heat loss by minimizing radiation.

Regarding the supply, 57% of the respondents in Kiambu and Thika districts were using purchased wood; the rest gathered it on the farm. Maragwa district had the biggest proportion of household collecting wood on the farm. The household response to question regarding the future supply of wood indicated that all the districts will face a crisis of wood scarcity. While there is a decline in all districts the severity is more intense in some than others. The decreasing supply of wood in three district is a result of land scarcity, deforestation of reserve and private land area, and slow growth rate of the local trees. These challenges can be solved by planting of fast growing trees using better planting technology. Motivating farmers to invest in tree planting could increase the supply of wood; the only limitation is that valuable wood (like timber) is normally a priority compared to woodfuel.

In order to assess nations by region another study was selected that compares well with SSA countries namely, Guatemala. Guatemala has 45% urbanization and the urbanization rate of 3.4% per year; and a population growth rate of 2.8%. Furthermore, biomass is the main fuel, making up to 52% of the national budget, and meeting 75% of the household energy needs. In addition 88% of the rural household rely on it for cooking and heating. In this survey the international migration as a cause of switching to cleaner fuel is studied (Taylor, 2011). The population studied involved those who never migrated, return migrants and migrated in search of better jobs especially in the US. in 2001, 2006, and 2010. Selection of households for interviews was done based on condition that the family has at least one member who is abroad or returns after a year.

The results of the study show that 98% of the migrant and 31% of the non-migrant households have LPG. Migrants possess LPG that is three times that of non-migrants. In fact a consideration of the percentage shows that nearly every one of the migrants possess LPG. Despite the fact that LPG is possessed by almost all the migrants still 77% continue using firewood for cooking most of the time. Furthermore, 94% of migrant and 88% of nonmigrant households purchase wood (rather than gathering their own). Two reasons may explain this strange reality: an economic reason and a cultural one.

First, the economic reason is that although LPG is cheaper than firewood as regards to its unit cost, it becomes more expensive when one considers the cost of the stove and the cylinder (US$2005 112), which makes most rural and 46% of urban households, continue to use firewood for cooking. Secondly, the cultural background requires that some foods are better cooked using firewood because of various factors including economy, time and cooking preference. It is not really a difficult thing to buy LPG or to use it, but the question remains: why do the households still use biomass? This is a question that goes beyond the cost implication and perhaps it points towards the direction of cultural setting.

For instance the remark that: “The food tastes better when cooked on firewood and for longer periods slowly” or “You can always keep hot water boiling/warm”. But sometimes, even what seems like an irrational decision, when analyzed from a different perspective it might turn out to be rational. For example the analysis of cost per calorie might turn out to be cheaper for firewood or different for various cooking fuels. Gwatamala two staples, beans and corn, need first of all boiling then milling. This process would be too costly if gas were used for cooking, hence the preference for fuelwood. Furthermore, the burners on the gas stove cannot accommodate the big pots and the necessary large amount of fire to cook the quantity of beans, corn and tortillas. Lastly, the increasing LPG price makes fuelwood a very attractive option.

Because of these reasons the concept boils down to “fuel starking” or “mixing” rather than clear cut fuel transition. Besides, the survey indicated that 81% of the migrants were using improved cookstove, which has the advantage of superior combustion that reduces smoke and ensure that the residual smoke is channeled outside through a chimmney.

Another study was conducted in the northern forested township called Labagoumen in Beijing, China. The survey was conducted in 10 villages of the township of Labagoumen in 2001, with an aim of research on the impact of local population on the biodiversity by selecting specific socio-economic characteristics (Demurger Sylvie, 2011). Research villages were purposively selected putting into accout their diverse characteristics. Within each village, 30 households were randomly selected and interviewed. Within this sample 5% stated bought firewood while others stated having received firewood it as a gift.

According to the results, household head is reported in 89% of the cases as the one who is responsible for collecting wood. The average collection distance is 2 km and it takes nearly 1 hour, and in most cases it is practically accessible. Most of the population is involved in subsistence agriculture, being the main source of income. The number of livestock is on average 2.4 and mean farm size is 0.5 ha with a maximum of 1.7 ha. Although the households located along the road have small farm sizes, their incomes and wealth are significantly higher.

The population attribute is nearly the same and average household size is 3.3 and maximum is 6 and average life expectancy is 41 years. The education standards are quite low, with grade 5 as an average and less than 6 for the household heads; none was reported to have gone beyond primary education.

Theoretically, it can be urged first, that the substitute of firewood is coal at market price. Second, that the shadow price may be used to capture the price for firewood which is collected using labor. In poor regions of the world even when the income increases still the households use firewood. There are two categories of effects stimulated by an increase in income: first, an increase in fuelwood consumption as a result of a rise in income; second, there is a reduction in fuelwood due to the increased substitution. The overall trend depends on other influencing factors, like time, type of food and the income itself.

Moreover, using household assets that indicate wealth (color TV, radio, a refrigerator or a washing machine) the wealth index was generated. The sample was split into two categories – above and below the mean and then each of the two subcategories is further split into two which makes a total of four depicting the four levels of wealth (poorest, poor, middle, wealthiest), to which each individual household is assigned.

The relationship between household assets and firewood consumption in Labagoumen shows that the poorest household consume significantly more firewood than the wealthiest. To some extent these results provide evidence for support for the theory of the energy ladder, which states that as incomes increase the households move up the energy ladder because fuelwood is an inferior good. The relationship is in form of a covex curve. The convex shape of the association demonstrates it has some “floor effect”, which denotes that the weathier households abandon fuelwood through fuel substitution as incomes rise yet the effect is slow.

Specifically, there is a level below which increasing income cannot cause fuelwood to be subsituted. In other words all households use wood, irrespective of the level of wealth they possess. One of the ways of explaining this is that households tend to use coal as a replacement for fuelwood for heating as they get richer but they don’t substitute fuelwood for cooking their traditional meal.

There are a few research findings pointing towards the association between poverty and fuelwood consumption. For example, the size of the house per capita has a significant negative relationship to the consumption of fuelwood, indicating that the wealthier households don’t consume much firewood as compared to the poorer. Keeping other factor constant a 10% increase in per capita size of the house leads to a 1.7% decrease in fuelwood consumption.

Another example is livestock. An increase in livestock is associated with a significant reduction in small amount of fuelwood. A 10% increase in the farmland owned by a household leads to a 1.8% consumption in fuelwood. Own price elasiticity of demand in relation to firewood is the percentage measure of the quantity demanded of firewood “caused” by a percentage change in price of firewood. The time spent for firewood collection (in hours per kg) in relation with the wealth category of the household is “proxy” for price of firewood. There is no connection between time used for the firewood collection if it is assessed in relation to the poorest households (inelastic). But there is a significant negative relationship (elastic) between collection time and the rich households. This means that an increase in standard of living results into own price effect being effective. In other words, the opportunity cost of firewood collection by a wealthy household increases with scarcity of wood and is able to cause substitution.

Other significant variables obtained in this study were household size, household average age and the average education level of adult member. Household size is positively correlated with fuelwood consumption and with availability of labour to collect it. The positive and significant average age for the young as compared to the old indicates that the older people are not willing to adopt new heating and cooking methods. It is also more probable that the elderly are more likely to spend a lot of time at home which leads to the utilization of much wood for heating during winter. On the other hand, there is a negative relationship between the education level of the adults and the use of firewood.

Looking at determinants of fuelwood one appreciates that wealth may play an essential role to influence the options and diminish the firewood consumed. All the estimates show that coal is a substitute for fuelwood. When the opportunity cost relating to time increase the household switches to another energy option. Lastly, the use of coal is dependent on the level of education and whether the family has relatives in another village.

A study on domestic use of firewood in rural communities of the Caatinga was conducted. Two rural communities – Cachoeira (common areas) and Barrocas (private area) – located in the municipality of Soledad, in the state of Paraiba, Northern Brazil. The total respondents were 41. A Kruskal-Wallis analysis was done to ascertain whether the volumes of wood present in the study area kept in the homes of respondent differ and whether the frequences of wood collection were the same throught the year . Spearman correlation run to establish the species most used in the area. Chi-square was applied to establish whether there are difference in the data (Marcelo Alves Ramos, 2012).

The larger part (88%) of respondents use fuelwood in their houses; while 18.2% solely depended on it for cooking; and 81.8% used firewood and LPG for cooking. The combination of these two fuels was pointed out as a strategy for saving energy and money, in that the choice of the fuel depends on the meal cooked. For example, to cook a combination of meat and beans one requires to use fuelwood, given the fact that the meal takes long to cook. Though there are so many gas stoves, their use is very limited. This was reported indirectly by the high frequency of cookstoves use by respondents. The overwhelming majority (97%) of residents were lighting their stoves at least once a day, and continued to add wood until the end of the cooking process. In soledad, reason for perpetuating the use of fuelwood were economic (88.2%), followed by cultural (8.82%) and preferential (2.94%). This means the justification for the continued use of firewood was socio-economic. Households cannot cope up with costs to buy gas, stoves and canisters; whereas fuelwood and its stove cost nothing.

The frequency of firewood collection varied from household to household depending on the diversity of activities done in their homes. There were also seasonal variations depending whether it was a dry season (16.27±1.85 days) or rainy season 21.45± 5.76 days). There are three ways of moving firewood from the forest, first: 45.5% carried it on their head (singulary women) – moving with 20 – 30 kg; second, 41% used a cart pulled by an animal (donkey or horse) transport to huge amount of wood (150 – 200 kg); and thirdly, 13.5% used human pulled wagon to carry a load of approximately 50 kg.

The influence of seasonality on firewood collection was different in the dry season the average volume was 39.29 m^3±(10.58) in Barrocas and Cachoeira; whereas in the wet season it was 19.13 m^3± (9.93). It was a statistically significant difference $\chi^2 = 6.96$; $p = 0.008$, indicating that there is a variation in Caatinga regarding firewood collection based on the season. During the rain season the average volumes of firewood reduce because the firewood is economized – less wood is consumed. This is done through cooking practices, for example, the frequency of lighting the stove is reduced, while the frequency of gas stove increases. Those who do not have gas stoves also adjust the frequency of firewood stoves.

2.5. Wood Saving by Improved Cookstove (ICS)

Two locations were selected for the study in Malawi: Zomba (Domasi) and Chiladzulu (Milepa). Malawi was chosen for this study owing to its primarily rural community with a high population density, intense poverty and reliance on firewood. About 90% of the Malawian population are rural and depend on small scale agriculture for their livelihood. First a two day workshop was organized to train residents how to build a Chitetzo improved clay stove. Chitetzo can be made using local tools and material hence boosting local business capacity. Second, data was gathered using a questionnaire regarding the stove performance after about a year. Data was gathered before (78) and after

(72) introduction of the stove. Microsoft Excel and NVIVO 8 were used for analysis of quantitative and qualitative data respectively (Timko, 2016).

All the respondents perceived that firewood had reduced over a period of past 5 years. To deal with the crisis residents tried to plant trees near their houses, at their boundries and the common lands; at the same time substituting inferior fuels, including plastics and agricultural residues. The use of firewood had reduced in the past 5 years in 59% of the household even before the introduction of Chitetzo.

The first reason for fuelwood scarcity is due to deforestation and forest degradation. The second reason was the decline of household size because of divorce or grown up children leaving the home. Nearly 29% of the household stated that their firewood consumption increased in the 5 past years. The justification for this rise was the children were growing up and their consumption too increased, in terms of food and firewood. The remaining people stated that they did not realize a change in consumption of fuelwood.

There was saving of firewood resulting from the launching of Improved Cookstove (ICS) as reported 89% of users. But the method of firewood collection did not change. Before the introduction of ICS, 88% of interviewee said they gathered firewood, whereas only 9% both combined gathering and purchasing it; after stove launching 83% interviewee gathered, whereas 16% of the interviewee gathered and purchased firewood. While farmlands were the main source of firewood prior to the introduction of the ICS, there were an increase in respondents who said that their main source of firewood was the forest.

Chitetzo successfully replaced the traditional 3 stone fire as may be appreciated from the length of time of stove lighting, which slightly increased from 4.02 hr to 4.83 hr in changing from 3 stone fire to Chitetzo. Before the introduction of Chitetzo all households were using the three-stone fire; and after the lauching the Chitetzo stove almost all changed to the new stove. Nevertheless, a few respondents said that they use Chitetzo along with the 3 stone fire. The condition which causes them to use each stove were not made clear.

It is a common practice for people of Malawi to plant tree in their homes to provide shade, fruit, shelter and against the wind. As these trees grow they are pruned and thinned to provide firewood. Nevertheless, all these activities cannot provide enough firewood – it remains scarce. Almost 96% of the respondents showed motivation in planting trees on their land and 97% had thought about planting trees to accompany Chitetzo stoves.

Another study was conducted in Ethiopia – a country having 92% of its residents relying on traditional biomass for cooking. Ethiopia is one of the 4 countries with the highest fuelwood consumption (rural consumption is 0.70 tons per capita per year), collected by women and children. A Controlled Cooking Test (CCT) methodology was applied to measure the fuelwood consumption, time taken and convinience, for the Mirt (an Improved Cookstove) in comparison with the traditional three stone fire, to cook 1 kg of Enjera (staple Ethiopian food), in 3 regions. 110 sites were identified, from which 15 villages covered during the pilot survey and 14 villages, which do not use three stone fire were removed. From the remaining (81 villages), 36 sites were selected using proportionate random sampling based on regional state area. Then a random sample of 14 households was selected from each site giving a total of 504 household. Out of 14 households 10 received a Mirt stove (360) and 4 did not receive (meaning they used the 3 stone fire) (Gebreegziabher, 2017).

The CCT fuelwood reduction by the Mirt stove was 22% to 31% (291 grams of firewood) at statistical significance greater than 1%. This implies that a household can save 1 metric ton of firewood per year. But according to the pooled sample mean of CCT, cooking time was greater for Mirt than for the 3 stone fire by 7.13 minutes, which was statistically significant at 1%.

Generally, from a social point of view 100% ranked the Mirt stove as good, and 85% as very good; in relation to smoke reduction it was ranked at 85% (very good) and convenience in comparison to the 3 stone fire, 83% (ranked it as very good). There is an interesting discussion about Mirt stove because over 90% owners say they have advised their neighbours to get a new stove and 42% have accepted the advice.

In order to test and compare the performance of the most popular stoves in the various parts of the world, an experiment was conducted: traditional and improved charcoal stoves. The traditional charcoal stoves were 3 and the improved were 11 (from Haiti, Cambodia, Mali, USA, India, Zambia and several other African countries). Modified Water Boiling Test (WBT) 4.1.2 was used while operating in high and low power, and a lid covered the pot. Starting temperature was 20^{o}C and each stove was maintained at simmering temperature (3 – 6^{o} C below full boil) for 45 minutes without adding or removing fuel, and had to bring 5 L of water to boil in less than 60 minutes.

Ensuring that there is no variation in properties the same bag of charcoal was used. Particle size was between 23 to 43 cm^3: minimum particle size of 23 cm^3 was avoid the possibility of air flow blockage and the maximum of 43 cm^3 was chosen because large particles too are strenuous to fit in the stove. Fuel to cook = 5*SC;   SC = fd/Vw . Where SC = Specific fuel consumption, g/L is derived from, fd = the Equivalent of Dry Fuel Consumed Over Whole Test (g) (Bentson, 2013). Figure 2.1 shows the results of stove performances in terms of minimum and maximum.

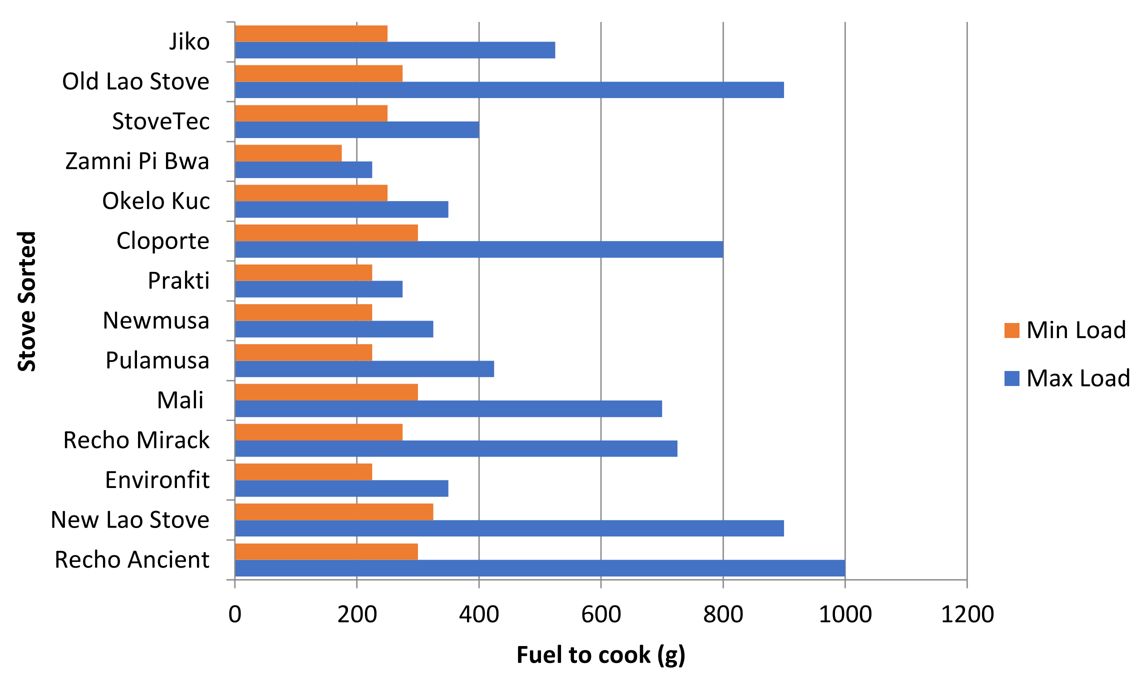


Figure 2.1 Stove performances in terms of maximum and minimum fuel

Source: (Bentson, 2013)

Fuel load needed for cooking is a maximum of 225 – 1000 g and a minimum of 175 – 350 g. According to the data, the stoves exhibit a wide range of performance resulting from full loading, but much less with a minimum loading. The charcoal consumption range is

200 – 1600 g for stoves tested at maximum consumption; nevertheless, if the 3 stoves with the highest consumption of more than 5 standard deviation are eliminated, the range reduces to 200 – 600 g. The minimum range of consumption is 150 – 300 g. Experiments should be held with an awareness that the choice of initial charcoal loaded in the combustion chambers exerts an influence on the quantity of fuel that is used. From these results, it clear that stoves from different regions have different performances.

2.6. Demand and Supply balance

In order to have a clear picture or overview of demand and supply, and balance, another study was taken from Kamfor in the Ministry of Energy (MOE) in Kenya. This research projected the biomass decline in 2002 – 2020, as the population suffers from scarcity of wood (Githiomi, 2012). Using average annual increment, a calculation of sustainable supply minus demand is made and when the supply is greater than the demand the balance is positive and when the demand is greater than the sustainable supply a negative balance is encountered. Table 2-5 is a projection of biomass demand and supply in Kenya.

Table 2-5 Projections of Biomass Consumption/Supply

Years	**2000**	**2005**	**2010**	**2015**	**2020**
Population	28,686,607	32,494,444	36,810,671	40,941,673	44,981,767
Consumption tonnes/yr	35,119,615	39,896,632	44,599,347	49,164,960	44,981,767
Sustainable supply/yr	15,024,510	15,488,936	16,634,550	17,984,406	53,416,327
Deficit/yr	(20,095,105)	(24,407,696)	(27,964,797)	(31,180,555)	(33,856,589)
Deficit (%)	-57.2	-61.7	-62.7	-63.4	-63.4
Deficit (tonnes/person)	-0.701	-0.747	0.760	-0.762	-0.753

Source: MOE, (2002)

Without a strong policy action, the deficit would be 33.9 tons by the year 2020 given the population growth of those who depend on woodfuel. The state of unsustainable biomass threatens to subject the poor population to absolute lack of woodfuel, having robbed the environment of forests. The result is land degradation and soil erosion.

Githomi suggests the following policy actions which can bring back the deficit into supplus: land for production of woodfuel made available as a priority; increase of woodlots in farmlands; efficient management of woodlands and range lands; increase the adoption of efficient devices; increase the adoption of substitute cooking fuel (LPG, kerosene and electricity); apply biomass energy technology alternative (e.g. gasification, biodiesel and briquette); framework of wood energy institution strengthened; wood energy policy and planning enablement (to ensure self-sufficiency); and wood energy database improvement.

2.7. The Woodfuel Gap Theory

The woodfuel crisis (also termed as the gap theory) was formulated in 1970s. Based on the imbalance between demand and supply of wood as projected in the future (Leach, 1988; Donald J. Mead, 2001). Basing on the annual forest growth rate (supply) with the consumption (demand) of woodfuel, it was estimated that demand was exceeding supply and the result would generate a woodfuel gap. The remedy was to plant trees, adopt ICS and control population rate (Leach, 1988).

Nevertheless, the woodfuel crisis never happened: the terrifying situation of complete depletion that was anticipated did not occur. Leach and Maerus (1988), have helped us to identify the gaps in the gap theory: (1) the calculation inacuracies of demand and supply tend to be erroneously amplified, making the situation extremely disastrous, (2) trees outside the forest were not considered (yet these constitute 13 – 73%) (3) the re-growth of the trees was ignored, and (4) the switching to the alternative was ignored (Donald J. Mead, 2001).

According to Asia - Pacific Forestry Sector Outlook (FAO, 1997) misconceptions about wood can be summarized as follows: Wood energy is no longer relevant, it is of little value, used by the rural poor and is phasing out. Woodfuel is a traditional product being substituted by modern fuels and research and development should focus on solar, wind and hydro. Burning wood adds CO_2 to atmosphere and is responsible for deforestation since it originates from the forests. Wood energy cannot be planned, fuelwood is a free natural gift and wood production is an insignificant subsector.

But reality refutes all those assertions as follows: wood meets 30% of the demand in Regional Wood Energy Development Programme in Asia (RWEDP) member country. In all the the RWEDP member countries the consumption of wood is rising, totalling up to US$30 billion per year. Research findings indicate that wood is utilized by all socio-economic classes. Currently, modern technologies utilizing biomass are invented and modern applications are typical. In reality 2/3 of wood come from non-forested land and deforestation is not due to woodfuel. Furthermore, not all wood is free, some is harvested as a crop; contributing 10% rural household income; generating about 40% of the earning for businesses; and yielding 20 times more energy compared to oil. Indicative data is enough for policy planning of wood energy. Sustainable regrowth makes CO_2 to be neutral and of all the sources of energy wood provides the greatest share in RWEDP (FAO, 1997). In otherwords there are good urguments for and against wood as modern fuel.

The calculations may sometimes be misleading when it comes to the estimation of the reality of what is going on in regards to biomass. Firewood is gathered from a variety of sources: natural and degraded forests, savanah and shrub lands, and trees planted in the plantations, farms, in villages and along roads (Donald J. Mead, 2001). FAO estimates the biggest proportion (42%) of woodfuel to be obtained from scattered trees (Trossero). The trees from forest and farm supply contribute only 28%. **Figure 2.2** shows the breakdown of wood supply from different sources from Vietnam.

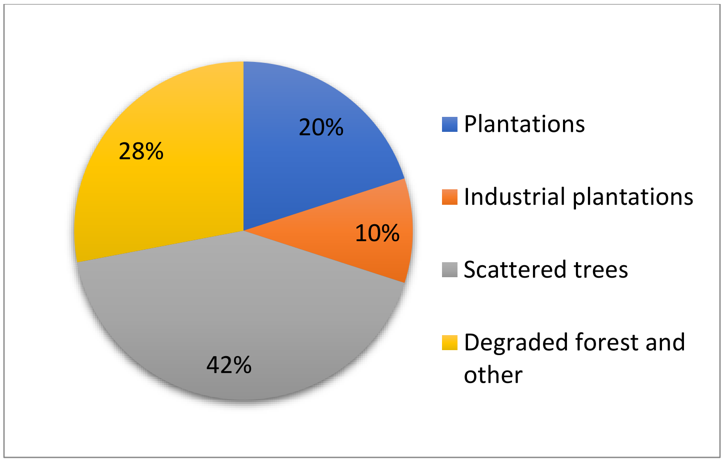


Figure 2.2: Wood supply by type of land, Viet Nam
Source: Data from FAO’s regional Wood Energy Development for Asia

There has been an evolution regarding the perception of woodfuel demand/supply within the past four decades. It has evolved from alarmist (1970), through indifference (1990) to awakening (2000), and approaches are varied. From large-scale plantation of wood and protection of the indiginous forest to a mix of small-scale tree growing and protection (Zulu C, 2013).

Nevertheless, the case of Uganda presents unique situation that needs to be assessed as far as woodfuels are concerned. Rapid population growth, reduction in land size per capita, use of traditional firewood and charcoal stoves, rapid urbanization (leading to increased charcoal production), the economic development (which stimulates building of many houses, leading to production baked bricks), and low supply of modern energy is a cause of great concern.

Because urbanization goes in tandem with use of charcoal, and the use of charcoal entails two types of conversion: carbonization and combustion, the situation will become worse, given the rural urban migration. This migration is driven by scarcity of land due to overpopulation and lack of jobs in the rural areas whereas there are many job opportunities in urban areas. Taking the total national biomass can be misleading due to local scarcity in some places and abandance in others; beyond a certain distance the abandant supply is not helpful to the area where there is scarcity. Consequently, there is need to have a spatial analysis of demand and supply at different localities.

In general different methods were used to obtain results, but non of them generated contradicting results. The main results indicate that whether the analysis used is parametric (like the mean and standard deviation or ANOVA) or non-parametric (like Chi-square or Kruskal-Wallis) still you get similar results. Even if only qualitative methods like focus group discussions were used one conclusion would stand. All studies from the sub-saharan Africa indicate a scarcity of woodfuel due to population growth and economic expansion.

CHAPTER 3

METHODOLOGY

Data for demand has been obtained from National Forestry Authority and Ministry of Energy Mineral Development. Regression models were used to analyze the trend in biomass consumption over time. Supply data was obtained from the Forestry Department of 1990 which was compared with that of 2005. To establish the sustainability of biomass supply, the sustainable yield (annual increase in biomass in a given area for a specific period) was estimated from private area (minus the reserve areas). In order to investigate the demand and supply in each district, the district population and its growth rate were considered in order to establish the current and projected demand. Then an analysis was done to compare 10 cooking options or systems each using 1 litre of water to cook 1 kg of rice. Using Statistical Package for Social Science (SPSS), several statistical operations have been conducted to manipulate data to obtain the mean, median, mode, standard deviation, Coefficient of Variation and ANOVA. The model which was used was developed by the author to capture the consumption in rural and urban for charcoal and firewood demand.

3.1. Biomass Demand

3.1.1. Data for Demand

Data used for this study was obtained from different sources. The Uganda Bureau of Statistics (UBOS) is the agency that has the mandate to collect and disseminate data in all sectors. However, there are some ministries, departments and agencies that complement UBOS effort (UBOS, 2009, p. 13). For example, biomass consumption data is collected by the Ministry of Water and Environment (MWE), National Forestry Authority (NFA) and Ministry of Energy and Mineral Development (MEMD). Though this data can be contradictory due to collection and methodological differences one thing that is common is that consumption of biomass is related to the population growth and for that matter biomass consumption is increasing with time.

Initially, the population censuses in Uganda were only administrative, conducted in 1911, 1921, 1931 and coming up with the population in millions of 2.5, 2.9, and 3.5 respectively. However, the first scientific census was conducted in 1948 and the second one was done in 1959. The post-independence censuses were conducted in 1969 followed by those of 1980, 1991, 2002 and 2014 respectively (Uganda Population, 2017, p. 13).

Generally, every approximately 10 years there was a National Population and Housing Census (NHPC), though the last census was delayed due to lack of budget funding. Every 2 – 3 years UBOS carries out a demographic survey primarily assessing social service delivery which includes agriculture, health service, road infrastructure, education and security (UBOS, 2007).

Data that will be used in the graphs will be obtained from NFA, through UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90) and in tables, it be based on the Uganda Population and Housing Census (UPHC) (UBOS, 2006a) and Uganda National Household Surveys (UNHS) for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12). The purpose of these graphs and tables will be to analyze the trend in consumption compared to the production of biomass. These trends will answer the question whether biomass consumption is on the rise. If it is on the rise, it is necessary to investigate whether the production too is on the rise or constant or falling.

Contrastingly, wood consumption data from MEMD segregates the consumption of charcoal and wood for rural and urban areas, for the total population for the whole year. It is based on the assumption given in section 3.1.2. The reason why the above formula is appropriate is that it captures both rural and urban consumption for firewood and charcoal. This formula will be used to calculate the consumption and to make projections about the consumption of woodfuel. The two equations are adopted from the formulas used to compute compound interest. The difference between the projections is that the geometric projection has a less steep curve than the exponential one. This means that the geometric projection is more conservative than the exponential. Nevertheless, the two projections give nearly the same results in case of slower growth rate, while the difference increases as the growth becomes more rapid. The population size was based on the census of 2014, and thereby making a projection basing on the previous population and the population growth rate of 3.03% (indicating a slight reduction from 3.2% in 2002). The urban population growth rate was estimated by the United Nations (United Nations, 2014). The three equations are used to calculate the demand and the projection in section 3.1.3.

3.1.2. Rural and Urban consumption for Firewood and Charcoal

$$\mathrm{Wf_C} = P_\mathrm{u}(\mathrm{C_u} \cdot \eta_k\,\% + \mathrm{W_u}) + \mathrm{P_r}(\mathrm{C}_r + \mathrm{W}_r) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$\mathrm{Wf_C}$ = Woodfuel consumption
P_u = Urban Population
C_u = Urban Charcoal Consumption
$\eta_k\,\%$ = Percentage Kiln Efficiency
W_u = Urban Wood Consumption
P_r = Rural Population
C_r = Rural Charcoal Consumption
W_r = Rural Wood Consumption

3.1.3. Population or Biomass Growth

Geometrical Formula: $P_t = P_o\,(1 + r)^t$ ……………………………………………… (2)

Exponential Formula: $P_t = P_o \cdot e^{r\,t}$ ……………………………………………………(3)

P_t = Total population or biomass after time t
P_o = Starting population or biomass
r = Percentage rate of growth
t = Time lapse
e = Euler number = 2.71828…

3.2. Biomass Supply

3.2.1. Data for Supply

On the wood supply side, two main reports will be used: National Biomass Study-(NBS) Technical Reports: 1990 (Drichi, 2003) and 2005 (Diisi, 2009) detailing the biomass stock changes at national and district levels for a period of 15 years. Accordingly, the rates of increase and decline per district will be projected to be the indicative volume and weight of the stock. Of course, two datasets may not be sufficient or reliable to make a valid conclusion; nevertheless, there is some scanty data to confirm that the decline is consistent.

This study estimates wood demand and compares it with the wood supply (in terms of annual increment of stock). Accordingly, the rates of increase and decline per district will be projected to be the indicative volume and weight of the stock. However, there are two major constraint: one is the increasing districts which were 34 by 1991 (Green, 2008) and they increased to 121 by 2017 (MOLG, 2017). The second constraints relate to data scarcity. Due to budget constraint, it is not easy to collect data extensively. Otherwise, two datasets may not be sufficient or reliable to make a valid conclusion; nevertheless, there is some scanty data to confirm that the decline is a reality.

3.2.2. Growth and Yield

Growth is defined as the rate of biomass accumulation per unit of time expressed in tons per hectare per year (Drichi, 2003, p. 53), while yield has different meanings. The Florida Forestry Stewardship indicates that the term "yield" has two meanings. It could either refer to the amount of crop (grain, fruit, vegetable or fiber) that can be harvested per period, or the total amount that could be removed at any time (University of Florida , 2010). In this study, yield is the annual increase in biomass in a given area for a specific period. So, the product of the growth rate in tons per hectare with land cover areas provided the gross yield for each land cover.

The growth rate was obtained from the biomass NBS in which approximately 300 plots were established for periodic measurement in order to establish the growth and yield per land cover/use. The report notes that in some cases the number of sample plots was not representative for reliable statistical inferences. For example, the tropical high forests, degraded tropical high forest and built up areas had two sample plots each which are not sufficient for generalization for the entire land cover strata across the country. Nevertheless, it gives a clue for estimations.

There are land cover classes with almost no biomass, for example open water and impediments. Others have negligible biomass, such as wetland. Figures for biomass growth in terms of Current Annual Increment – CAI (tons per hectare airdry) indicate that the highest growth rate is within the well-stocked tropical high forests (15), followed by hardwood plantations (13), THF low degraded (11), woodland (5), and built up areas (3). The bush, grassland and subsistence farming have each a growth rate of only 1 ton per hectare. However, without the agroecological zoning, the CV is higher than the expected 25% except for the THF low stocked (20%), meaning that there was a lot of variability. However, these estimates are taken to be "reasonably good and fairly representative at national level" (Drichi, 2003, pp. 54-55).

Table 3-1 presents results of biomass growth for selected land cover without agro-ecological zoning. These results are based on undisturbed area, though in practical reality most of the area gets disturbed at varying extents.

Table 3-1 National biomass growth and sustainable yield

Land Cover/Use	Duration in Decimal Years	Current Annual Increment, CAI, (tons /Ha air-dry)	No. of Plots	Coefficient of Variation (CV%) 1st Visit	CV% 2nd Visit
Plantations (Hardwoods)	0.99	13	66	85%	81%
Tropical High Forest (THF)	0.95	15	22	52%	48%
THF degraded	1.83	11	22	28%	20%
Woodland	1.97	5	30	64%	63%
Bush	2.61	1	13	79%	81%
Grassland	2.45	1	50	83%	76%
Subsistence Farmland	2.43	1	195	200%	184%
Built up Areas	2.55	3	22	123%	124%

Source: (Drichi, 2003, p. 54)

The CAI has been applied as the growth rate. For Kampala, which is a built up area with no part undisturbed, the idea of assuming a non-disturbed area is most unrealistic, so the factor applied of 0.1 (Drichi, 2003, p. 57) which is based on the biomass dynamics under the influence of human activities is applied in this case.

Total biomass yield in a given area (country, district or parish) is the sum of the biomass yields from different land cover types within the specific area. However, these figures represent growth rate for undisturbed situation. The product of these growth rates and the land cover area gives yield estimates per land cover area.

3.2.3. Meeting Demand with Supply

The accessible biomass has been regarded as that which is in private areas. This means that despite the usual exceptions and violations, the accessible biomass has been assumed to exclude the one in reserve areas, like national parks and game reserves. In reality reserve areas can be encroached especially when there is a crisis of biomass supply. The accessible biomass was estimated by multiplying the area of private land by the mean stock of the land cover class.

$AB_p = A_p * MSt$ ……………………………………………………………………..(4)

AB_p = Accessible Biomass

A_p = Private Area

MSt = Mean Stock

3.2.4. Forecasting the district population and biomass

The districts of Uganda have been split continually and therefore increasing in number with time. For example, there were only 38 by the beginning of the National Biomass Study (1991), yet the Technical Report published in 2003 recorded 56 districts, and the next technical report (2005) published in 2009 documented 80 districts. By 2010, districts had risen to 112. Moreover, even the lower administrative units have undergone a similar fragmentation. This inconsistency makes it very difficult to make concrete comparison of the variables like population and land cover between two periods.

To facilitate this comparison number of districts for the whole country has been maintained at 80. Therefore, the 56 districts by the time of the first study (2003) has been adjusted to 80 by scrutinizing those that have undergone a splitting and considering new ones formed up to when they became 80. In considering the latest population data, the number of districts, which had increased to 112, was reduced to 80 by tracing the new ones back to their origin when they were still 80.

Taking the district percentage biomass increment between 1990 and 2004/2005 as the rate for estimating future biomass dynamics, the stock is forecast for the 80 districts.

The yield, based on the CAI, as a percentage[1] of the stock is used for the projection of the yield based on the forecast stock. The urban population projection is based on the estimates of the United Nations (UN, 2014). However, some districts primarily use firewood, and less charcoal, while Kampala district, with no rural vicinity predominantly uses charcoal. This was done in order to project biomass supply from the period of 2006 to 2040. The Gross stock and gross yield were projected and then the demand was compared with the sustainable yield (supply). Then the balance on stock (Bal_Stock) was calculated.

Two extreme scenarios are set: the most optimistic and an extensively pessimistic. In the optimistic scenario, demand is estimated using a conservative figure of per capita rural firewood consumption of 0.68 tons per capita for all districts, except Kampala. This is based on the assumption that charcoal consumed at local level by most districts, apart from Kampala, is negligible. See **Figure 3.1**.

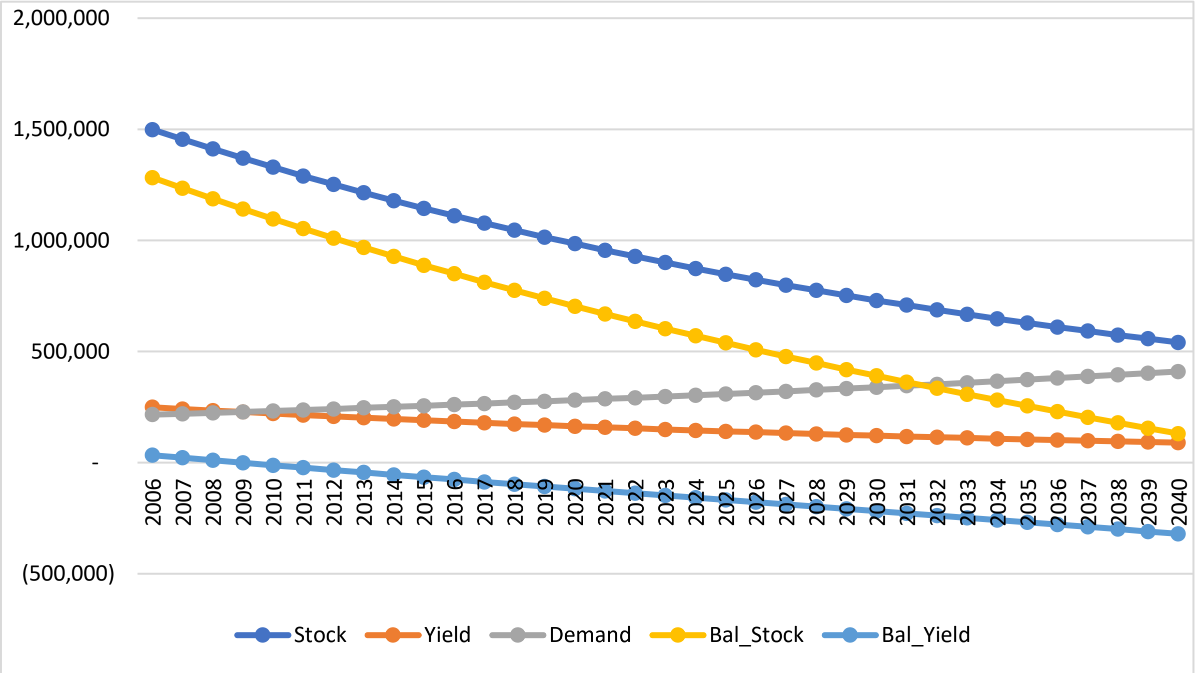


Figure 3.1: Projection of Biomass Stock, Yield, Demand and Balance in Kayunga District (This same methodology was applied in all the districts in Uganda)

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[1] This proportion varies depending on the age and type of biomass. So this ratio cannot be guaranteed to remain constant.

Practically, many charcoal producing districts sell most of their charcoal to the capital city, Kampala, but for the starting scenario, this quantity is ignored. Further, this scenario considers all the biomass, including the one in the reserve forest. This is based on assumption that there is still some access to the biomass in the reserve forest. Though this is true, this access is regulated. However, for the sake of the optimistic scenario, this restriction is overlooked. So, the availability all the biomass in the district along with a minimum consumption gives the most optimistic picture of the highest available biomass per capita and lowest rate of depletion.

The second scenario assumes that each district has both urban and rural areas and so respective per capita consumption for firewood and charcoal in the rural and urban areas are applied as stated in the REP. Due to absence of specific population data for urban and rural areas in each district, the proportions for national population for rural and urban are applied as proxy estimators for each district[2]. The exception is Kampala city, a district whose rural environment is negligible. Furthermore, the biomass in the reserve forests is deducted. This would give a less generous or severer scenario. The strictest scenario would be obtained if biomass in the national parks too could be deducted, but because this biomass was not segregated by district, it was not possible to allocate the quantities to the respective districts. Nevertheless, the second scenario gives an appreciably critical picture.

Then the third scenario considers this charcoal that is primarily consumed in Kampala. This gives an impression of the extent to which a depleted district can affect those around it as it strives to meet its biomass demand. A study commissioned by Energy Advisory Project supported GIZ which was based in the MEMD identified 10 districts as the main suppliers of charcoal consumed in Kampala (Kisakye, 2004). In this study, the charcoal supply was established by conducting a one-week (7 days) survey in which the enumerators were stationed at each road entering Kampala city in order to record every truck carrying charcoal into the city.

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[2] In reality, each district has its own proportion of rural and urban population. Moreover, some districts are more dominated by the rural setting than others and in this case the use of charcoal in some of these districts is rare.

The district of origin of the charcoal and the number of bags on the truck were recorded. The total quantity of charcoal in terms of estimated weight was obtained by multiplying the number of bags by the mean weight of 60 kg per bag. To estimate the round wood equivalent in tons of dry matter, used to produce the quantity of charcoal the latter was multiplied by ten, based on the assumption that the mean conversion efficiency is 10%. The weakness in this study is that it was conducted for a period of only 7 days and extrapolated for the year, whereas there might be season variation in the charcoal production. Nevertheless, this was the only study that gave this kind of data.

To consider the lowest consumption scenario, the charcoal source districts are considered to consume only firewood at the rate of rural consumption, that is, 0.68 tons per capita. Demand for firewood in those charcoal producing districts is established by multiplying the forecast population based on 2002-2014 population growth rate (UBOS, 2014, pp. 22-23) by the rural firewood consumption. All charcoal generated from these districts is considered to meet the demand in Kampala. Definitely some charcoal is consumed locally and some wood from some districts is transported to Kampala, but this is ignored in this scenario. The demand for charcoal is calculated by applying the Uganda urbanization growth rate figures of the UN is estimates (UN, 2014).

In this case the current annual increments (CAI) put into account all the protected areas (Kisakye, 2004, p. 26) and in this scenario these values are assumed to vary with the stock biomass based on the change in the period 1990 – 2005 (A.10). The annual estimate of wood demand is the ten times the quantity of charcoal plus the quantity of firewood consumed (based on assumed efficiency). A sustainable balance is obtained by subtracting the demand from the yield (CAI). A balance on stock is obtained by subtracting demand from the stock. The ten charcoal producing districts were all computed using the same methodology. For example, the Firewood and Charcoal converted in terms of Wood Equivalent, for Kamuli District is given in **Figure 3.2**. But there are several assumptions.

Assumption 1: Wood Equivalent=52weeks/year*60kg/bag*1000kg/ton*10 (Charcoal Conversion Efficiency=10%). A study was carried out to determine the charcoal consumed in Kampala. Firstly, the limitation of this study was that it was carried out only in one week. This misses the trend of charcoal transported in low and high season. So the quantity was projected from one week to 52 weeks. Secondly, the bag of charcoal was not standard: charcoal was always sold in varying weights and volumes. According to ESD 1995, a bag of charcoal was estimated to be in the range of 40 – 50 kg with an average of 50 kg (ESD, 1995). But it looks like a bag of charcoal changes with time because in 1990 – 2000 bags were joined in a way that made them to appear to be two in one. Such bags were estimated to weigh up to 78 kg. But in this survey the bags were not exactly too big or too small; they weighed on average about 60 kg (Kisakye, 2004) Thirdly, the charcoal kiln efficiency also varies depending of the management of kiln. 10% is only an average.

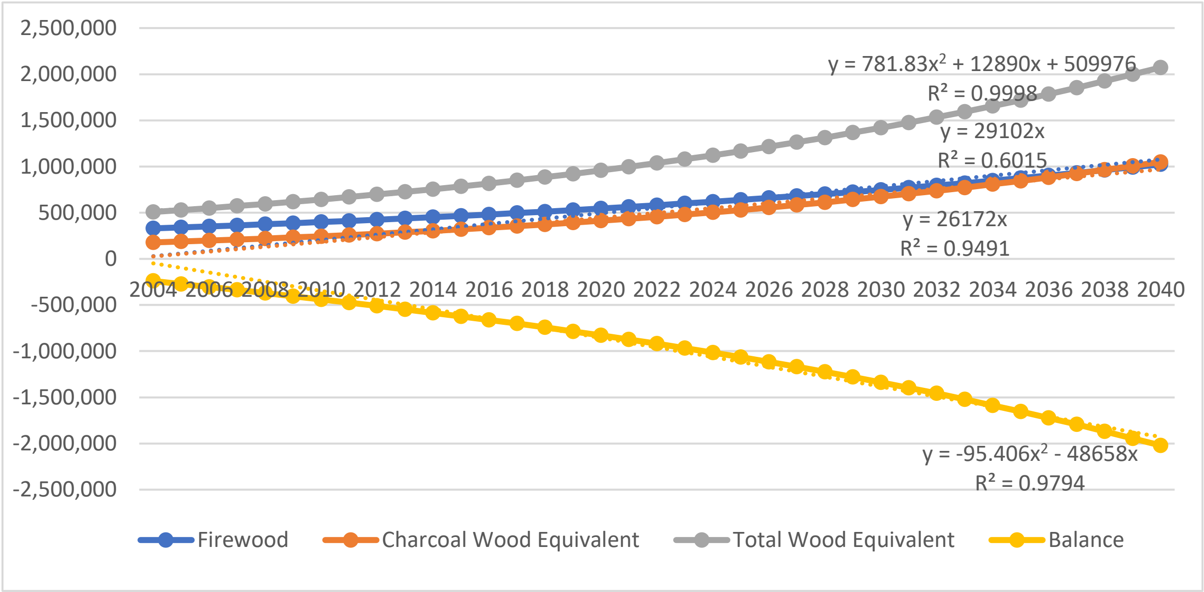

Figure 3.2: Firewood and Charcoal Wood Equivalent for Kamuli District
(The same methodology was applied in all the 10 charcoal producing districts in Uganda)

Assumption 2: All firewood is consumed locally, and wood equivalent is of charcoal supplied to Kampala.

Reality: Some firewood crosses beyond the local districts depending on the district which may or may not be on the way to Kampala and has a strong wood demand, such wood may not be accounted for. Annual firewood consumption (tons/year) = 0.680 ton/capita. This is just the average consumption for firewood. The projection assumes that the percentage land use change per year is constant. In reality it can be slowed down or increased. The UN data for urbanization rate for Uganda was used for projection (United Nations, 2014).

The National Biomass Study (NBS) conducted in 1990 conducted an assessment to determine the area and extent of land cover. This was accompanied with the biomass survey data enabled the quantification of biomass standing stock in Uganda. One of the remarkable challenges was the choice of the stratification system, which did not have to focus only on biomass but for multiuse. There was a land cover map of Uganda which was published in 1996 which had 13 land cover classes with several classifiers which indicate soil water seasonality, woody biomass stock, bush type and bush percentage.

Then later on land cover mapping was generated using the FAO LCCS classification. Comparing the two data sets is necessary to establish the trend of biomass evolution. There are several similarities which make the two categories of data sets comparable. However, there are also differences regarding classification which make comparison difficult. Because the existing land cover classification schemes were based on forestry practices and were economically oriented, they were regarded inappropriate for multipurpose application and therefore, NBS project developed its own classification system, based on a combination of land cover and land use (Drichi, 2003, p. 13)

Land cover mapping and stratification that was used to produce the 2005 was conducted using Landsat imagery; image interpretation using GeoVIS and the FAO classification system called Land Cover Classification System (LCCS) (Diisi, 2009, p. 7). It is also important to note that the land cover mapping has greatly improved, and this also becomes a challenge. Different names were used to refer to same land cover classes during the 1990 and in some cases, the 2005 gives different naming. These names referring to the same land cover class will be used interchangeably (Table 3-1).

3.2.5. National share/ district distribution

In analysis of distribution of land cover types, two proportions have been computed: National share of the land cover type which specifies the total area of a particular land cover type as a percentage of the total country area and the district distribution which specifies the frequency of districts with the particular land cover as a percentage of the total number of districts:

3.2.6. National share/ district distribution

In analysis of distribution of land cover types, two proportions have been computed: National share of the land cover type which specifies the total area of a particular land cover type as a percentage of the total country area and the district distribution which specifies the frequency of districts with the particular land cover as a percentage of the total number of districts:

Table 3-2: Generalized NBS-LCCS classification translation

NBS Class	**NBS Code**	**LCCS Classes**
1	Broad leaved plantations/ deciduous trees (“hardwood”)	Broad leaved trees
2	Coniferous plantation/softwoods	Needle leaved trees
3	Tropical High Forest well stocked/ normally Stocked	Closed multi-storied high trees
4	Tropical high forest low stock/ depleted/encroached	Open high trees
5	Woodland	Closed trees, Open trees, generally open trees, very open trees, woody areas
6	Bush	Closed, Open or very open shrubs
7	Grassland	Graminoids and herbaceous areas
8	Wetland	Permanently wet Graminoids and herbaceous areas
9	Small scale farmland/ Subsistence farmland	Shrub and herbaceous crops on small fields
10	Commercial farmland	Shrub or herbaceous crops on Medium or large size fields
11	Built up area	Artificial surfaces- urban, airport, refugee camp
12	Open Water	Standing and flowing water and water dams
13	Impediments	Bare soil and bare rocks, quarry, snow

Source: modified from Table 2-1 (Diisi, 2009, p. 11)

- National share or Size

$$S_n = \frac{C_1}{C_t} \cdot 100\% \quad \ldots\ldots\ldots\ldots (5)$$

S_n = National share or Size
C_l = Sum of land area for the land cover type in all districts
C_t = Total Land Area of Uganda

- District distribution

$$C_d = \frac{D_C}{D_t} \cdot 100\% \quad \ldots\ldots\ldots\ldots (6)$$

C_d = District distribution
D_c = Number of districts with a particular land cover type
D_t = Total number of districts in Uganda

The mean of the sample and population

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \ldots\ldots\ldots\ldots (7)$$

$\bar{x}$ = Sample mean

n = Sample size

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N} \quad \ldots\ldots\ldots\ldots (8)$$

μ = Population mean

x_i = value of element i of the sample

N = Population size

Coefficient of Variation of a population.

It allows meaningful comparison between two or more magnitudes of variation even if they have different means or different scales of measurements e.g. land cover types.

$$CV = \frac{\sigma}{\mu} \times 100\% \quad \ldots\ldots\ldots\ldots (9)$$

CV = Coefficent of Variation for a population
σ = Standard deviation for population

μ = Mean value for population

Coefficient of Variation of a of a sample

$CV = \frac{s}{\bar{x}} \cdot 100\%$ ….…………………………………………………..……...(10)

CV = Coefficient of Variation for a sample

s = standard error of the mean

$\bar{x}$ = sample size

The difference between the mean and mode, or mean and median, will tell you how far the distribution departs from symmetry. A symmetric distribution (for example, the normal distribution) has a skewness of zero.

PMS = $= \frac{3(\bar{x} - M_d)}{\sigma}$ ………………………………………………………...(11)

PMS = Pearson Mode Skewness
M_d = Median
σ = Standard deviation for population
$\bar{x}$ = Mean value

SES = 2√6/n …………………………………………………..…………...(12)

SES = The standard error of skewness
n = Sample size

***If the value of skewedness is greater than twice the standard error of skewness, then the distribution is significantly skewed* (Tabachnick, 1996). *Therefore, it is not normally distributed.*

3.3. Method Used to Assess Cooking Fuels

Then the energy alternatives include traditional firewood stove (three stone fire, which is the main cooking device in Uganda), firewood improved mud stove (cold and hot start) – operating on the rocket principle, traditional metal charcoal stove (with no ceramic liner), improved charcoal stove with ceramic lining (cold and hot), ethanol (butane), kerosene (paraffin), LPG, electricity four tests were carried out by 4 cooks. The cooking systems were all used to boil the same amount of water and to cook the same quantity of rice. The time it takes from preparation to the cooking of each stove was recorded. The author was responsible for supervision and making all the calculations.

- Fire preparation
- Pot warming
- Putting oil in the cooking pot along with onion, tomatoes and spices mixing them until they are ready
- Pour in 1 litre of water 20^oC and bring to to boil almost 98^oC
- Put 1 kg of rice and cook it.

The initial mass and the final mass of fuel in each case was recorded except for electricity. After combustion, the charcoal leftover cannot be considered since the charcoal residue is normally not useful, hence only the wood left is weighed. Also, in regard to wood, the remaining wood was recorded but not the residue charcoal which is normally wasted. MCwb was measured and in each case, it was 25% and gross calorific value of charcoal was taken to be 29.6 MJ. Remaining wood and charcoal were measured after the cooking test.

SPSS was used to analyze the following aspects: Time (minutes), used fuel mass per kg of rice per appliance, fuel consumption per kg of rice, taste of food ranking, heat energy use by cooking devices and annual cooking costs (US $). In normal life it is not rice alone that is cooked; several other foods are cooked along with sauce. Moreover the cooking frequencies are also important as well as the habits.

3.4. The Analysis Of Variance (ANOVA)

This will be applied to analyze the cooking fuels and technologies.

3.4.1. Hypothesis

H_0: The population means of all groups under consideration are equal.

H_a: The population means are not all equal.

3.4.2. Assumption

(i) Subjects are chosen via a simple random sample.

(ii) Within each group/population, the response variable is normally distributed.

(iii) While the population means may be different from one group to the next, the population standard deviation is the same for all groups.

3.4.3. Components of the One Way Analysis of Variance (ANOVA)

Source	DF	SS	MS	F	P
Factor	**m-1**	**SS (Between)**	**MSB**	**MSB/MSE**	
Error	**n-m**	**SS (Error)**	**MSE**		
Total	**n-1**	**SS (Total)**			

From F–distribution with m–1 numerator and n – m denominator d.f.

MSB = SS (Between / m – 1)
MSE = (Error)/(n – m)

n – 1 = (m – 1) + (n – m)

SS (Total) = SS (Between) + SS (Error)

3.4.4. Column headings of the ANOVA are as follows:

(1) **Factor** = characteristic that defines the populations being compared.

(2) **DF** = degrees of freedom in the source.

(3) **SS** = sum of squares due to the source.

(4) **MS** = mean sum of squares due to the source."

(5) **F** = *F*-statistic.

(6) **P** = *P*-value.

(7) **n** = variation within the group

(8) **m** = variation between the group

3.4.5. Raw heading of ANOVA are as follows:

(1) **Factor** means "the variability due to the factor of interest." At times the factor is the treatment and therefore the heading of the row is known as the as **Treatment**. Sometimes the row is designated as the as **Between** to make it clear that the row concerns the variation *between* the group mean and the grand mean. It quantifies the variability between groups of interest.

(2) **Error** means "the variability within the groups" or "unexplained random error." Sometimes, the row heading is labeled as **Within** to make it clear that the row concerns the variation *within* the groups.

(3) **Total** means "the total variation in the data from the grand mean" (that is, ignoring the factor of interest).

3.4.6. The Sums of Squares (SS)

SST = SSG + SSE…………………………………………………………(13)

SST = Total Sum of squares
SSG = Sum of squares between the groups
SSE = Sum of squares (error) within the groups

X_{ij} denote the j^{th} observation in the i^{th} group, where $i = 1, 2, ..., m$ and $j = 1, 2, ..., n_i$. Important thing to note here... note that j goes from 1 to n_i, not to n. That is, the number of the data points in a group depends on the group i. That means that the number of data points in each group need not be the same.

$$\mathrm{SST} = \sum_{i=1}^{k} \sum_{j=1}^{ni} (x_{ij} - \bar{x})^2 \text{……………………………………………………….(14)}$$

SST = Sum of squares total
k = The number of groups/populations/values of the explanatory variable
ni = The sample size taken from group i
xij = The jth response sampled from the ith group/population
xi = The sample mean of responses from the ith group
$\overline{x}$ = The mean of all responses, irrespective of groups

$$\mathrm{SSG} := \sum_{i=1}^{k} n_i \, (\bar{x}_i - \bar{x})^2 \text{………………………………………………………. (15)}$$

SSG = Variability between group means (variation around the overall mean $\bar{x}$)

k = The number of groups/populations/values of the explanatory variable

n_i = The sample size taken from group *i*

$\bar{x}_i$ = The sample mean of responses from the *i*th group

$\overline{x}$ = The mean of all responses, irrespective of groups

$$\text{SSE} = \sum_{i=1}^{k}\sum_{j=1}^{ni}(x_{ij} - \bar{x}_{i})^2 = \sum_{i=1}^{k}(n_i - 1)\, s_i^2 \text{ ……..……………………………(16)}$$

SSE = Variability within groups means (variation of scores about their group mean $\overline{xi}$)

k = The number of groups/populations/values of the explanatory variable

ni = The sample size taken from group *i*

xij = The *j*th response sampled from the *i*th group/population

xi = The sample mean of responses from the *i*th group

$\overline{x}$ = The mean of all responses, irrespective of groups

s_i = The the sample standard deviation from the *i*th group

The mean squares (MS) column, has the "average" sum of squares for the Factor and the Error:

$$\textbf{MSB} = \frac{\textbf{SS (Between)}}{\boldsymbol{m-1}} \text{ ……………………………………………..…………(17)}$$

MSB = Mean Square Between the groups

SS ($_{\text{Between}}$) = Sum of Squares Between the groups

m – 1 = The between group degrees of freedom

$$\textbf{MSB} = \frac{\textbf{SS (Error)}}{\boldsymbol{n-m}} \text{ …………………………………………...…………..…(18)}$$

MSE = Error Mean Sum of Squares

SS ($_{\text{Error}}$) = Sum of Squares within the groups

$n – m$ = The error degrees of freedom

$$F = \frac{Variability\ between\ groups}{Variability\ within\ groups}$$

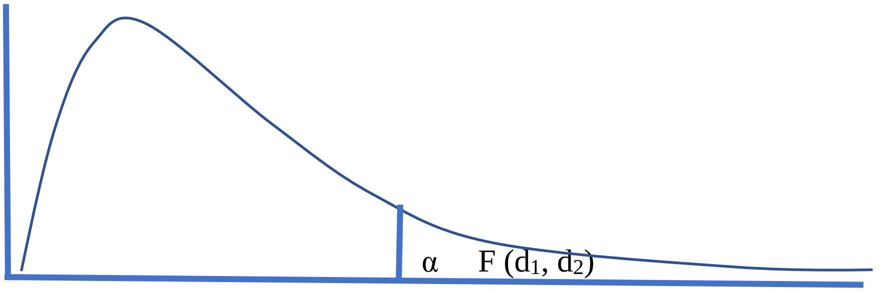

Figure 3.3: Schematic Diagram of F-Distribution: with α and degrees of freedom for the numerator and denominator.

Critical value is obtained from the reference Table of degrees of freedom.

3.4.7. Tukey's Test

Is a single post-hoc step of multiple comparison to ascertain if there is of statistical significance between any pair of means. After the ANOVA, which specifies that is a statistical difference between at least one pair of means, it helps to determines and indicates which pair of means are significant. The statistically significant pair of means are marked by an asterix.

1. The observations being tested are independent within and among the groups.
2. The groups associated with each mean in the test are normally distributed.
3. There is equal within-group variance across the groups associated with each mean in the test (homogeneity of variance).

$$HSD = \sqrt[q]{\frac{MS_w}{n_k}} \quad \text{..}(19)$$

HSD = Tukey's Honestly Statistical Difference

q = Constant from studentized range q Table

S_w = Mean Square within

n_k = Number in each category (n for one condition)

Purpose: Grouping the means into various subsets
Why it is used: To separate the groups according to their statistical signifance.

$$ES = \frac{\bar{x}_i - \bar{x}_j}{\sqrt{MS_w}} \text{ ....(20)}$$

$\bar{x}_i - \bar{x}_j$ = Mean difference between two groups two groups under consideration
MSw = Mean square within or Error

3.4.8. Levene's Test for Equality of Variances

(Levene's Test for Homogeneity of Variances*)*

A homogeneity-of-variance test doesn't depend on the normality than most tests. For each case, it computes the absolute difference between the value of that case and its cell mean and performs a one-way analysis of variance on those differences.

The value of critical region is determined by Classical Approach or the P-value Approach:

	Classical Approach	**P-value Approach**
Critical Value:	$F\alpha(df_1 = t - 1), df_{2 = N - t}$	N/A
Rejection Region:	$F_{Levene} \geq F\alpha(df_{1 = t - 1}), df_2 = N - t$	p-value ≤ α

$$F_{Levene} = \frac{\dfrac{\sum_{i=1}^{t} ni(\bar{D}i - \bar{D})^2}{t-1}}{\dfrac{\sum_{i=1}^{t} \sum_{j=1}^{n_i} (Dij - \overline{Di})^2}{N-t}} \text{ ....(21)}$$

t = number of treatments [t = k for one-way ANOVA]
yij = sample observation j from treatment i (j = 1, 2,…, ni and i = 1, 2,…, t)
ni = number of observations from treatment i (at least one ni must be 3 or more)
N = n1 + n2 +…. + nt = total number of pieces of data (overall size of combined samples)
$\overline{yi}$ mean of sample data from treatment i
Dij $= |yij - \overline{yi}|$ = absolute deviation of observation j from treatment i mean

Di = average of the ni absolute deviations from treatment i

D = average of all N absolute deviations

- **Make your decision**

If the value of the test statistic, F_{Levene}, falls in the rejection region or if p-value $\leq \alpha$, then reject H_0; otherwise, fail to reject H_0 .

- **State the conclusion in words**

Reject H_0 : "At the $\alpha = 5\%$ level of significance, there is enough evidence to conclude that the variances are equal."

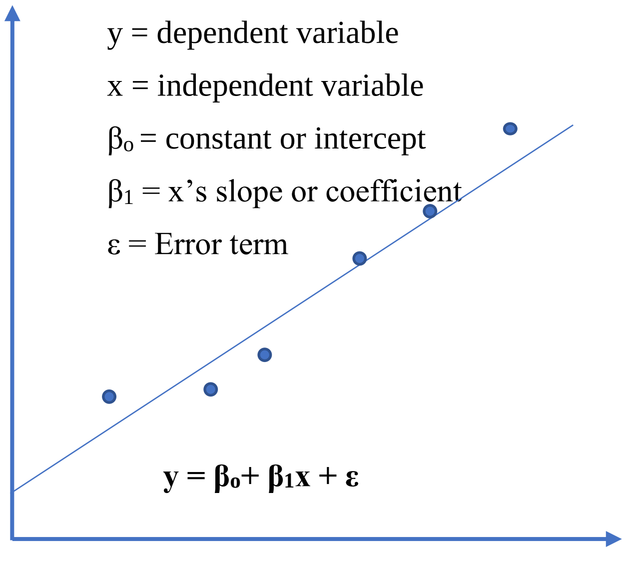

Figure 3.4: Regression model

$$R^2 = \frac{SS_{Res}}{SS_{Tot}} \quad \text{……………………………………………………………………………..(22)}$$

SS_{Res} = Residuals

SS_{Tot} = Total sums of squares

In regard to forecast, three scenarios were considered. First was the business as usual, which stipulates the impact of current policies related to biomass and cooking energy. The second scenario is related to the maximization of efficiency of charcoal and firewood stoves, and the charcoal kiln. In addition, the commercial sector is undergoing substitution by LPG. In the third scenario, the LPG substitution is not only done for commercial sector but also the middle-income group. Consequently, the biomass demand curves go down as the substitution goes up.

Statistical Package for Social Science (SPSS) and Excel were the main computer software applied. Several statistical outputs have been generated and the commentary is given within the text in the related context.

CHAPTER 4

TRENDS IN BIOMASS COOKING ENERGY CONSUMPTION IN UGANDA

In the previous chapter the methodology is described in detail. In this chapter the past the consumption of wood is addressed. Data used in this chapter was obtained from the National Forestry Authority (NFA) and Ministry of Energy and Mineral Development (MEMD). Using graphs and tables each subsector is analyzed separately. The evolution of biomass consumption shows that demand increases tandem with with population growth. Wood energy includes fuelwood-household, fuelwood-commercial and fuelwood-industrial and household-charcoal; non-energy wood includes pole and sawn timber. The analysis shows that the biggest share is that of household wood energy, of which the nonmonetary wood is the dominant one. By 2011, the total demand of wood had already exceeded the sustainable supply, based on the accessible yield. Yet this is at national level. The main objective is to investigate the sustainability of cooking biomass in Uganda. Let us now look at the demand or consumption of the biomass.

4.1. Uganda

Uganda, being in the heart of the SSA (**Figure 4.1**) is among the poorest countries in the world that heavily rely on biomass for cooking. Though the country had a strong poverty reduction accomplishment in the past two decades with the poverty headcount rate declining from 56.4% in 1992/93 to 24.5% in 2009/10, no corresponding decline from biomass consumption is attained. Moreover, the Uganda Bureau of Statistics (UBOS) raises two critical concerns that are likely to neutralize the poverty reduction achievements. First, the observed growth between the two recent surveys seems to have benefited more the affluent than average Ugandans.

Second, while the proportion of people living in poverty significantly declined, the reduction in the number of poor persons – in absolute terms – was not significant; and inequality of income worsened. In other words, while Uganda seems to have met the MDG target of halving income poverty target earlier than 2015, worsening distribution of income and high population growth, if not addressed, are likely to reverse the trends (UBOS, 2012, p. 28). Consequently, the high population increase of the largely poor people depending on biomass continues to exert high pressure on the diminishing resource supply.

Figure 4.1: Political Map of Uganda and its relative location in Africa (small)
(One World - Nations Online, 1998-2017)

Uganda is a land locked country with a terrain of mostly semiarid mostly plateau with a rim of mountains. The currency is Uganda Shilling (UGX), and the capital is Kampala. The environment is generally warm with minimum and maximum temperature of 7.7^{o} C and 27.8^{o}C respectively (World Statistics Pocket, 2014).

4.2. Biomass Supply Trend

According to the National Biomass Study 1996-2002, Uganda had a total standing stock of 468 million tons of biomass by 1990, out of which 155 million tons (about 30%) is found in protected areas and 312 million tons in private lands. This could ideally be expected to give a total yield of 50 million tons of biomass per year out of which 15 million tons is in protected areas and the balance of about 35 million tons in private lands. Hence the accessible biomass yield (in private areas) is only 7.48% of the total standing stock.

However, these estimates are based on growths from undisturbed plots. In reality, all the land cover in Uganda is subject to human interference such as charcoal burning, land clearing for Agriculture and infrastructure, and firewood collection. An assessment of the net biomass (growth and removals) indicated that nearly 26 million tons of biomass is lost per year, of which 12 million tons is lost from private lands. The sustainable balance (3 million tons) has not survived the strong power of the depleting factors, including the woodfuel demand for cooking.

The National Biomass Study Technical Report 2005 gives a total standing stock of 390 million tons by 2005 (Diisi, 2009, p. 57), which is a reduction of over 74 million tons from the 1990 stock, or -1.07% per year. This average annual decline would reduce the stock to 365 million tons by 2010. If the same proportions for private areas are applied, the accessible yield would reduce to 27 million tons. However, FAO indicate a total growing stock of 131 m^3 in the forest and 24 m^3 in other wooded lands, (FAO, 2010, p. 266) making a total of 155 m^3or 112.4 million tons of wood[3] by 2010.

The National Environment Management Authority (NEMA) observes that the energy subsector relies on wild services of biomass since little if not zero funding has been invested to develop biomass stocks in the recent past. NEMA also observes that the sector has also not benefited from research and development funding and technology (NEMA, 2008, p. 256).

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[3] Wood Density = 0.725 tons

4.3. Biomass Demand Trend

Biomass provides the largest share (almost 90%) of the total national energy mix **Figure 4.3**

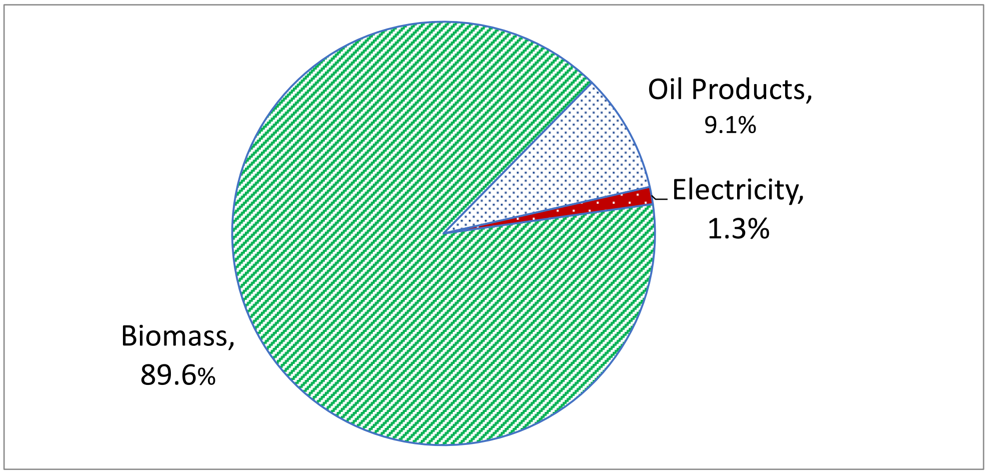

Figure 4.2: Uganda Energy Mix Based on the Energy Balance for 2011

Source: Based on data from Uganda Government Estimates (MEMD, 2012)

Biomass is followed by petroleum products that provide nearly 10 times less supply (9.1%), while electricity provides a very minor portion of 1.3%. The national Energy Balance indicates that renewable energy technologies such as solar and biogas are not included because their contribution estimated to sum up to a negligible amount.

A track of the evolution of the biomass consumption indicates that demand increases with population growth and economic activities. **Figure 4.3** exposes several facts regarding woodfuel consumption[4] between 1980 and 1998. First, fuelwood is the dominant type of woodfuel consumed. Charcoal consumption seems negligible if viewed in terms of final energy but if considered with respect to primary energy (wood converted into charcoal), the proportions turn into more noticeable levels. Accordingly, the total primary woodfuel consumption becomes amplified. This substantial amplification is because of low carbonization efficiency.

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[4] To convert from volume to mass, FAO wood density of 0.725 tons/CUM of wood was used.

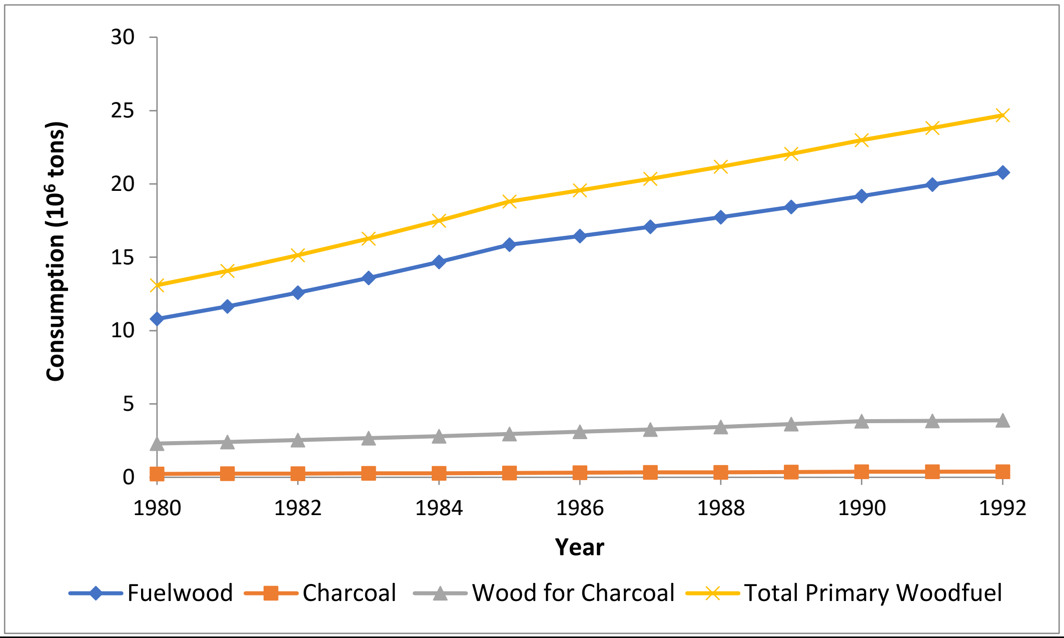

Figure 4.3 Woodfuel Demand Trend 1980 – 1992

Source: Data based from regional studies (Amous, 1999)

Though FAO applies a theoretical carbonization ratio of 6.6 Tons of wood per ton of charcoal for Uganda studies (Amous, 1999), the Uganda's national data applies a lower efficiency of 10% by mass of the air-dried wood, based on a survey of the Earth Kiln Efficiency in 1986.

However, even the quantity of wood converted into charcoal with a very low efficiency still trails below the fuelwood consumption, being 3.8 – 5.4 times lower. In other words, the ratio of round wood for charcoal production to firewood lies between 0.19 and 0.27. This continuous lag is a result of the fact that fuelwood is primarily used by the rural poor households, while charcoal is a major fuel for the urban area which happens to have people with relatively higher incomes. The population census indicated that the rural population reduced from 83.6% to 75% from 2002 to 2014 (UBOS, 2006a, p. xiii). Since the rural poor constitute the majority of the population, fuelwood which they depend on for cooking becomes the dominant woodfuel for Uganda. Hence fuelwood makes the total primary woodfuel consumption curve its mirror image.

The overall trend shows an increasing consumption of woodfuel (shown by the trend line). The continued rising trend of woodfuel consumption is evidenced by the more detailed national data from the UBOS in the subsequent period. In 2000 the total consumption of round wood rose to 24.4 million tons, out of which 23.2 million tons (95%) was woodfuel (UBOS, 2001). **Figure 4.4** shows that the later years (2003 – 2011; A.1) have been characterized by a continuous increase in biomass consumption.

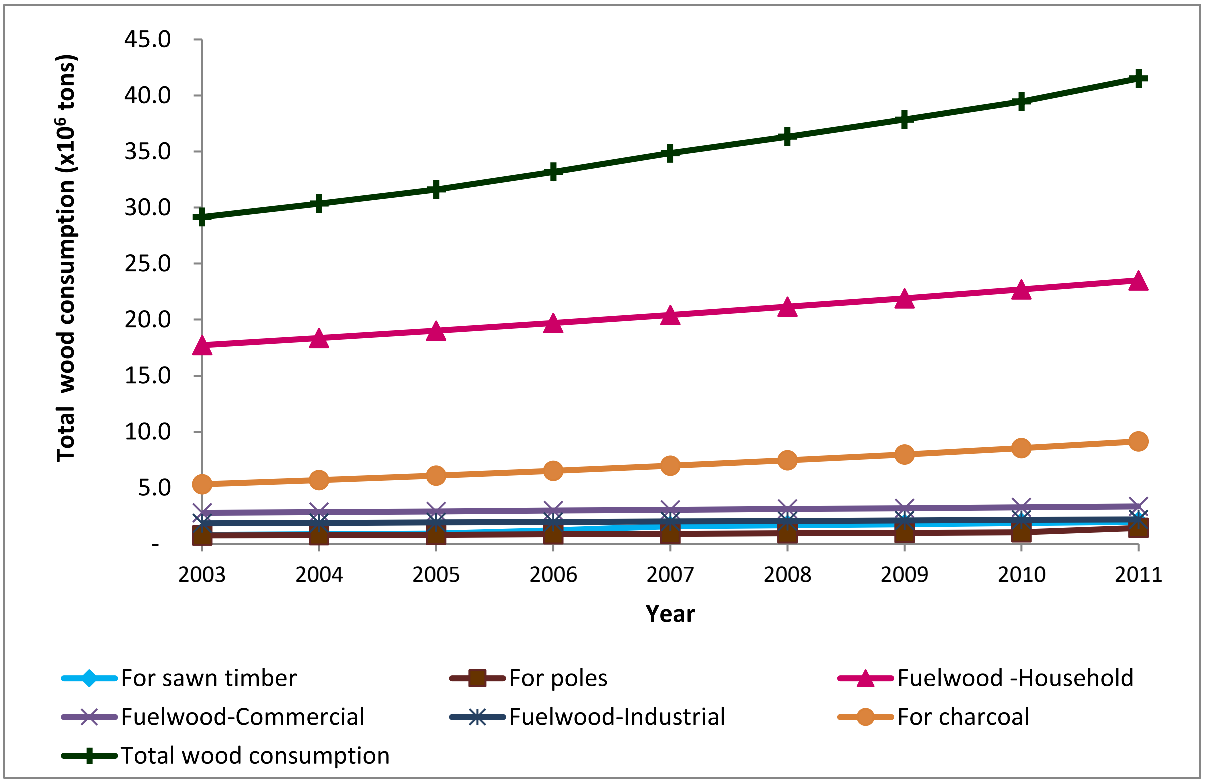

Figure 4.4 Total round wood consumption by purpose

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

The graph indicates that the total round wood demand (including non-energy use) from 2003 to 2011 rose from 29 million tons to 42 million tons – a consumption that is above the 1990 accessible yield of 35 million tons, yet the wood standing stock has been declining (meaning that the sustainable yield by 2011 is less than 35 million). So there is no question that the wood demand had already reached the unsustainable levels. Further, **Figure 4.4** indicates that the most prominent wood usage is woodfuel: firewood and charcoal. This is better exhibited in the **Figure 4.5** (data on page 210).

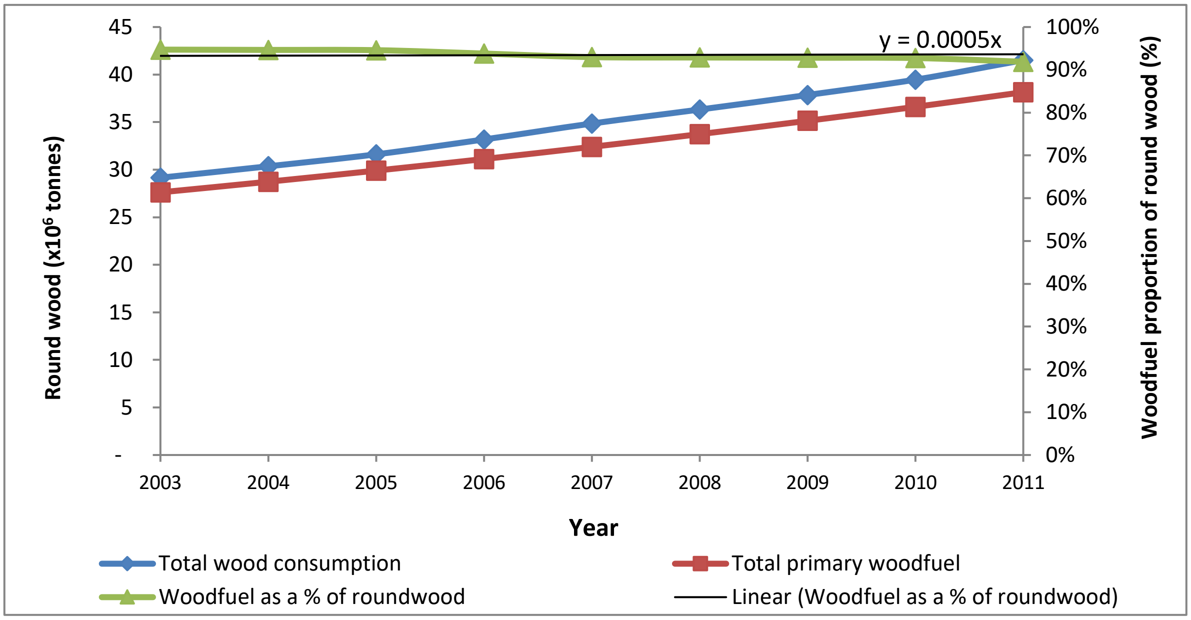

Figure 4.5: Primary woodfuel increasing jointly with total wood consumption

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

The graph reveals that the total wood consumption and total primary woodfuel increase in tandem, with a very slight divergence. This relationship is better exposed by the pattern of woodfuel as a percentage of the total round wood, whose trend line has a gradient that approximates to 0 (line is almost horizontal), denoting its near consistence over time. Specifically, it decreased marginally from 95% to 92% between 2003 and 2011. Since this proportion remains high, woodfuel continues to be the main end use purpose of round wood. In other words, the leading driver for wood demand is energy; consumption of round wood by other applications constitutes a minor share (5 – 8%).

In absolute figures, the graph indicates that the total primary woodfuel in 2003 is approximately 28 million tons and rose to about 38 million tons by 2011. This means that even woodfuel demand alone is higher than the sustainable supply (35 million tons) of

1990. Besides, this sustainable supply based on accessible yield could only hold for undisturbed areas. These facts give the very first signal that the current biomass demand in Uganda is no longer sustainable – even for energy purpose.

The main sectors consuming woodfuel are household, industry and commerce. However, most of the woodfuel, including firewood and charcoal, is for household use. The share of the household fuelwood is estimated to have risen from 79% to 80% in 2003–2008, and then to 81% in 2009 – 2011.

However, the Uganda Energy Balance obtained from the Ministry of Energy for 2011 (UEB_{2011}) indicates firewood consumption for the residential, commercial and industrial sectors of 6,544,259, 1,334,641 and 1,116,443 Tons of Oil Equivalent (TOE) respectively (MEMD, 2012). Though this allocates a lower share of fuelwood to the household sector (73%), there is no question that this proportion still remains the major one. The same UEB_{2011} indicates charcoal consumption for the residential and commercial sectors of 439,314 TOE and 215,501 TOE respectively, again giving the household the major share (67%) of charcoal consumption.

The Biomass Energy Strategy (BEST) Uganda estimates that the wood demand in million tons for charcoal production consumed was 13.2 and 2.6 for household and commercial sector respectively (MEMD, 2013, p. 22). If this proportion (84%) is used to assign the estimated wood equivalent for charcoal consumed during 2003 – 2011, plus the firewood consumed by household in the same period the residential sector would be consuming 80 – 82% of the woodfuel as indicated in the graph which overlaps with the one for the household share of firewood in **Figure 4.6** (data in Appendix A.1, page 210).

The household fuelwood constitutes the biggest share (averaging 63%) of the total woodfuel. Though this proportion drops gradually from 64% in 2003 – 2005 to 62% in 2009 – 2011 (A.1), this declining pattern does not change the big share of the household sector. Overall, the residential firewood consumption as a percentage of the total roundwood demand reduced from 61% to 57% during 2003 to 2011. However, this relatively small decline does not affect the actual quantities of household fuelwood consumption which increases at an annual rate of 3.6%.

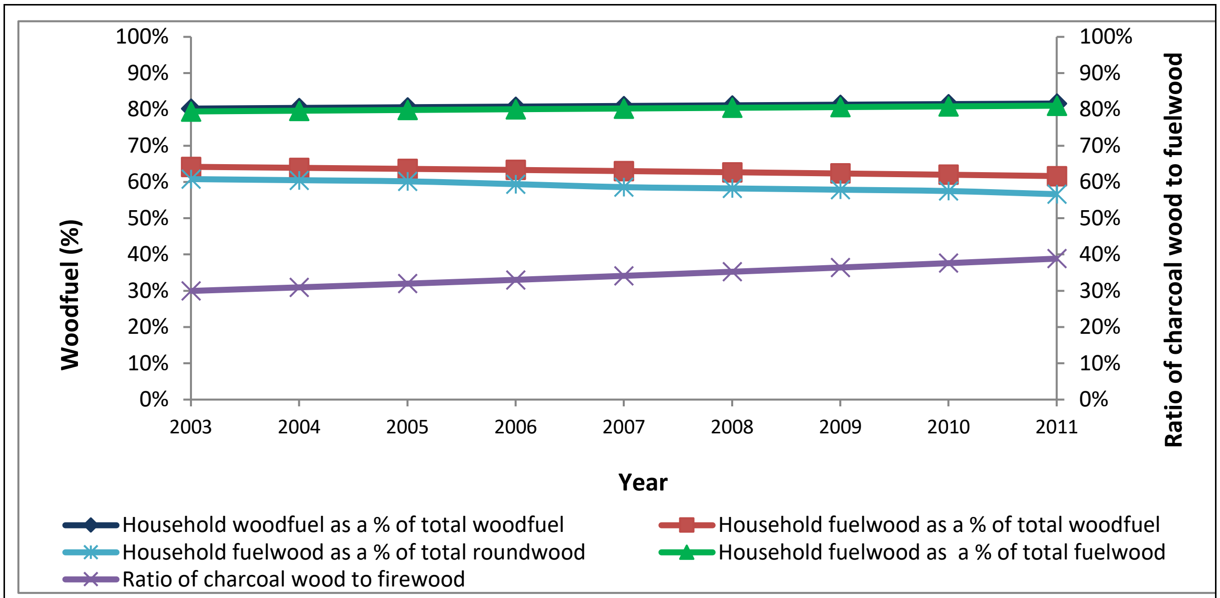

Figure 4.6: Household woodfuel proportions
Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

However, this slim but steady decline is also reflected by the increasing ratio of wood for charcoal equivalent to fuelwood whose maximum value was 0.27 in the period 1980 – 1999, but as shown in this graph, it had increased to 0.30 in 2003 and rose to 0.39 by 2011 (Figure 4.6; data in Appendix A.1, on page 210).

The increase in this ratio suggests that though demand for firewood is higher than that of wood for charcoal, the rate of increase in consumption for the latter is increasing more, despite the fact that consumption for both is rising. While fuelwood retains the larger share due to the greater rural population, charcoal consumption growth rate is relatively higher due to increasing urbanization.

However, taking the UEB_{2011} figures the ratio of total wood for charcoal to firewood shoots up to 0.73, in 2011 as opposed to the 0.39 which becomes a contradiction of the data of the MEMD and the NFA. However, it strengthens the deduction that while the firewood demand is growing very fast, the driving forces for charcoal consumption are intensifying more rapidly.

Nevertheless, it is indisputable that charcoal demand is growing very fast and so is its price. Since the major demand for charcoal is the residential sector, the rapid expansion of urban households with their wealth is propelling the demand for charcoal much stronger than in the past. Since urbanization tends to increase commercialization, it is no surprise that the charcoal for commercial and households are growing concurrently, though the former is only 1/3 of the total demand.

In terms of primary woodfuel consumption[5], based on UEB_{2011} figures, the residential, commercial and industrial sectors consume 33,183,000 tons, 10,587,000 tons and 3,387,000 tons respectively: again, assigning the household the major share (70%) of the woodfuel demand. This gives an overall net total primary wood consumption of 47,158,000 tons. However, apart from the charcoal production losses there are additional losses in the wood and charcoal supply of 450,000 TOE and 33,000 TOE respectively, whose consideration in terms of primary energy would give the total gross primary supply of 16,321,000 TOE or approximately 50 million tons of wood.

Precisely, while the NFA and UBOS estimates indicate that the Total Primary Woodfuel consumption for 2011 is 38 million tons; whereas the MEMD puts it at 47 million tons (or even 50 million tons if gross supply is considered) – an increase of about 24 – 32%. If this UEB_{2011} estimates are reliable, then the NFA and UBOS projections were probably underestimated. If the 2011 share of 8.1% for timber and pole is used for estimating the non-energy application, the gross demand for round wood would be almost 54 million tons, which is 54% above the 1990 accessible yield. This further emphasizes the unsustainable state of consumption of biomass in Uganda.

Ideally, once the negative balance is supplied by the stock, the capacity of the biomass resource is depleted, and its yields reduce accordingly. The population growth rate of 3.03% (which is likely to reduce slightly) will give an estimated population of 40 million

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[5] The author has converted the energy in TOE to tons of wood by multiplying with 41.868/13.8. For charcoal, the efficiency of 10% is used.

by 2018. Taking an average consumption of 1.06 tons per capita[6], the woodfuel demand for households will be about 42.4 million tons. Assuming an average growth rate of 6.5%[7] for commercial or service sector, the latter would consume almost 15.9 million tons of woodfuel. The industrial sector, whose growth has been on average 12.0%[8], would demand 7 million tons. If a non-energy proportion of 7.2% is added, the total demand becomes about 73 million tons. However, if an annual yield estimate equivalent to 5.3 – 14% of the total stock is applied consistently despite the decline in the total stock to meet the balance, the stock deficit would be a negative balance (–196 to – 255) million tons by 2018, either way it is a negative balance. With these assumptions, even the household demand alone may not be sustained beyond this period.

In practice, however, the wood supply mechanism is not similar to that of other energy carriers which could be distributed from a centralized place through market infrastructures across the country. Apart from charcoal and timber, wood extraction and consumption take place at localized levels. Therefore, despite the generalized national assessment of wood demand and supply, most of the real scenarios take place at local levels. Nevertheless, the estimation of demand and supply is an important indicator of the overall trend. The negative balance is an indicator of an emerging scarcity that is capable of spreading like an epidemic.

The household sector that absorbs the biggest share of the woodfuel still consumes an additional biomass form called "agricultural residues". The UEB for 2011 estimates a total of 537,000 TOE of residues (MEMD, 2012), which constitutes a supply of only 3% of the total primary biomass energy consumption. All these residues are used by the household sector, contributing a supply of 5% to the residential consumption. The main

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[6] The estimates based on the net supply for UEB 2011 indicate a 70% share of woodfuel for households. If this proportion is used to estimate the individual sector primary woodfuel energy supply (out of the 50 million tons of wood), the household consumption would be 34,842,000 tons of wood. Given the estimated population of 32,940,000 tons (UBOS, 2011) the consumption becomes 1.06 tons/capita.

[7] The services industry grew by a revised rate of 6.5 percent in FY 2012/13, compared to the 4.8 percent estimate in the June release.

[8] The construction industrial sub-sector: The dominant industrial subsector in Uganda is construction which generates between 10% and 16% towards GDP since 2000. In 2010/11, for example, the construction sub-sector contributed about 13% to industrial GDP. The construction industry includes all the companies involved in building renovation and maintenance of residential, commercial and industrial structures.

category of residues is that obtained from the crops, either during pruning or harvesting. Though this addition seems meager, residues can sometimes be an important biomass fuel during certain seasons and depending on locality. For example, the huge supply of crop residues following the harvest acts as a suitable substitution for woodfuel because the latter is either expensive or very far away.

4.4. The Economic Value of Woody Biomass

Due to a variety of socioeconomic factors, an inquiry into the financial value of wood reveals a much-distorted pattern, since most woodfuel consumption does not bear its true value. The total consumption of round-wood, 2003 – 2011 shown is disaggregated into two categories: monetary and nonmonetary. Monetary is the wood sold on the market; while the nonmonetary has no commercial value. Accordingly, the wood that classified as commercial bears the price of the production chain, while nonmonetary does not. In other words, the price is hidden in the commodity and any attempt to assign a value can only be arbitrary. **Figure 4.7** (data in Appendix A.2, page 211) gives the monetary value of output round-wood timber at contemporary prices.

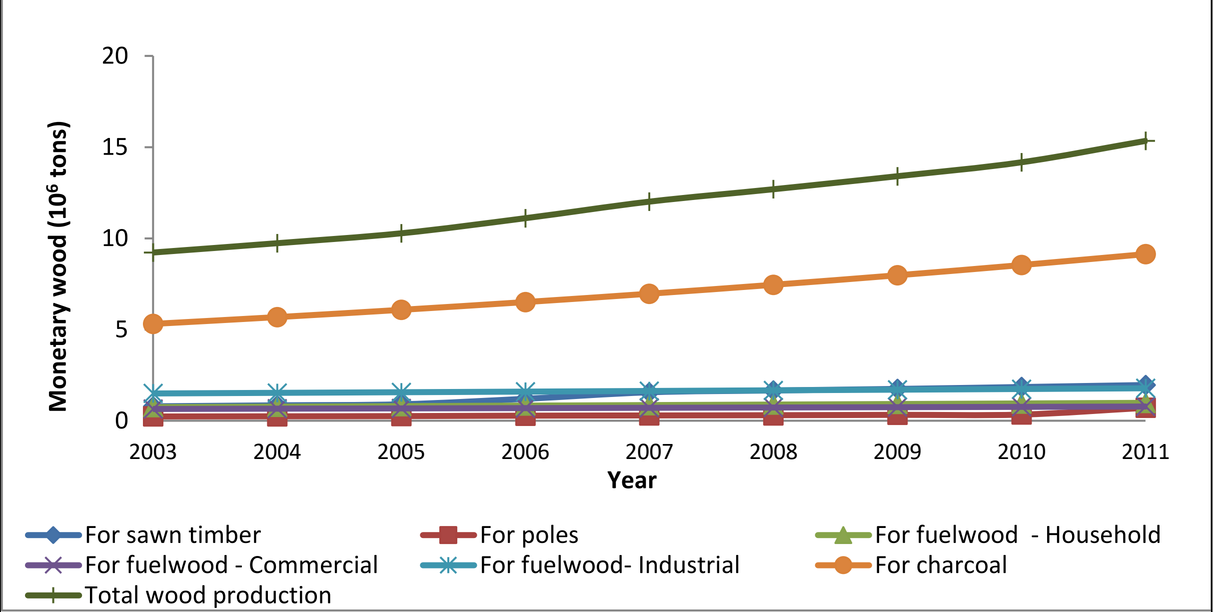

Figure 4.7: Commercial wood consumption

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

The total value rises from 9 to 15 million tons in 2003 to 2011 as a result of increased exploitation. As expected, the household woodfuel takes the biggest proportion in 2003 to 2011 of approximately 58.89 to 60.7%. It therefore looks like the bigger proportion is slightly rising due to increased charcoal consumption driven by urban expansion. It is clear (from the rise) that no other wood subsector is subject to rapid increase in value like charcoal. The rest of the monetary wood (including wood for sawn timber, for pole, fuelwood (commercial and industrial) is less than 40%.

On the other hand, non-commercial wood is for subsistence livelihood. From economic context, the majority of woodfuel consumers are the rural poor with very limited purchasing power. By 2010 the population of Ugandan living in rural areas was 85% (UBOS, 2012, p. 26) and by 2018 it was 84% (WORLD BANK, 2018). Most of them live by subsistence farming. In addition to growing most of the food they eat and eating most of the food they grow, they also collect most of the woodfuel they use. **Figure 4.8** shows the non-monetary wood consumption.

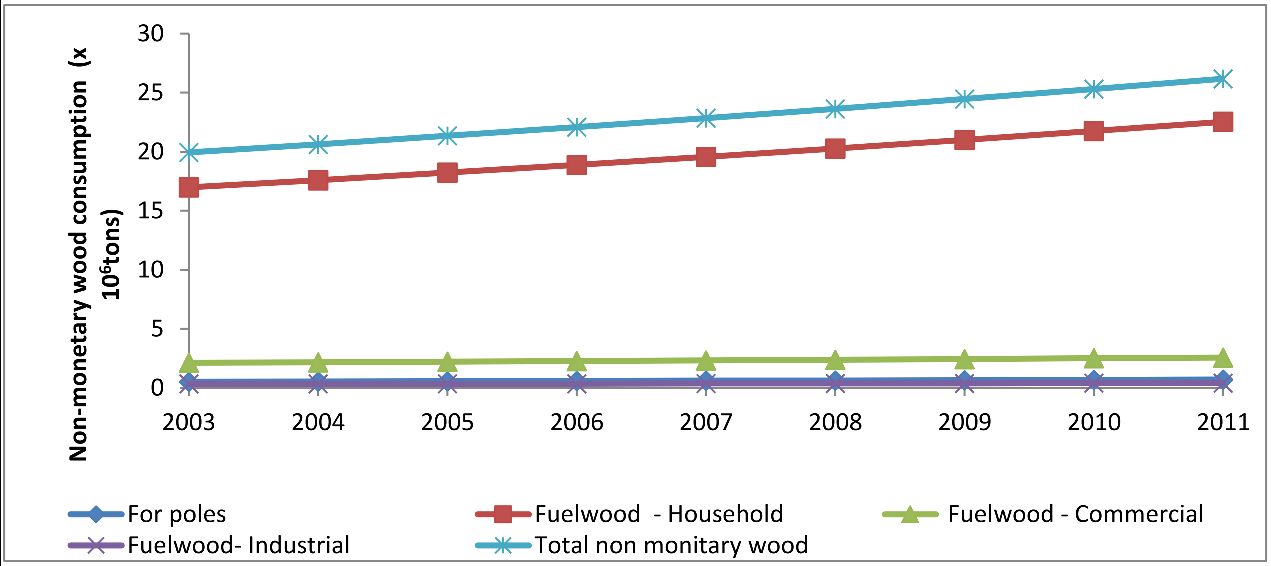

Figure 4.8: Non-commercial wood

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

It is not surprising that the wood that is non-commercial constitutes the big share of the wood consumption. On the other hand, it is noteworthy, that 84% of the population consumes 63.4% of the total woodfuel, which means as the percentage of the population in urban areas rises, the depletion of wood increases at an accelerating rate.

The State of Uganda Population Report (SUPRE), 2006, released by the Uganda Government Ministry of Finance, Planning and Economic Development (MFPED) makes the following remarks regarding economy of the rural poor: “Most households, especially the poor ones derive their livelihoods directly from natural resources. On a daily basis, they collect firewood, till the land, collect water and their sustenance is totally dependent on the status of the environment” (MFPED, 2006a, p. 6)

This means that the bigger the number of the poor the greater the pressure and dependence on natural resources, and the lower the monetary value of the latter. An economy relying on natural resources for its survival frustrates most of the business models or commercialized approaches for consumption. Attempts to introduce commercial fuel alternatives get hindered by the availability of what is perceived to be “free” fuel, provided by nature. Because of consumption of resources without price signals, such an economy is far from sustainability. The situation is aggravated by the increasing population growth and poverty, which together break down the capacity of the natural resources to sustain the community. In terms of money (million $US\$_{2010}$), the wood that is collected without payment (free wood of charge) is illustrated in **Figure 4.9**.

It is estimated to be in the range of 50 – 64 million US$ in 2003 – 2011, with the household woodfuel leading and creating the trend with 79% of the total wood obtained free. On the other hand, the monetary value of output round wood timber at current price is shown **Figure 4.10** (data is in Appendix A.2, page 211).

It is obvious that the value of sawn timber is the highest (55.6%) in compared to the rest. Consequently, if the value of wood is to be followed as a guide, then it logical to assert that sawn timber would be the most profitable. However, it must be born in mind that unlike firewood sawn timber leaves behind a lot of residues which may not be utilized. On other hand, the economic context for charcoal was quite different in this same period (2003 – 2010). While charcoal represents a relatively smaller portion (averaging almost to 20%) of the total wood consumption, it constitutes the highest quantity (averaging 60%) of the monetary wood, hence being the most lucrative in terms of woodfuel business.

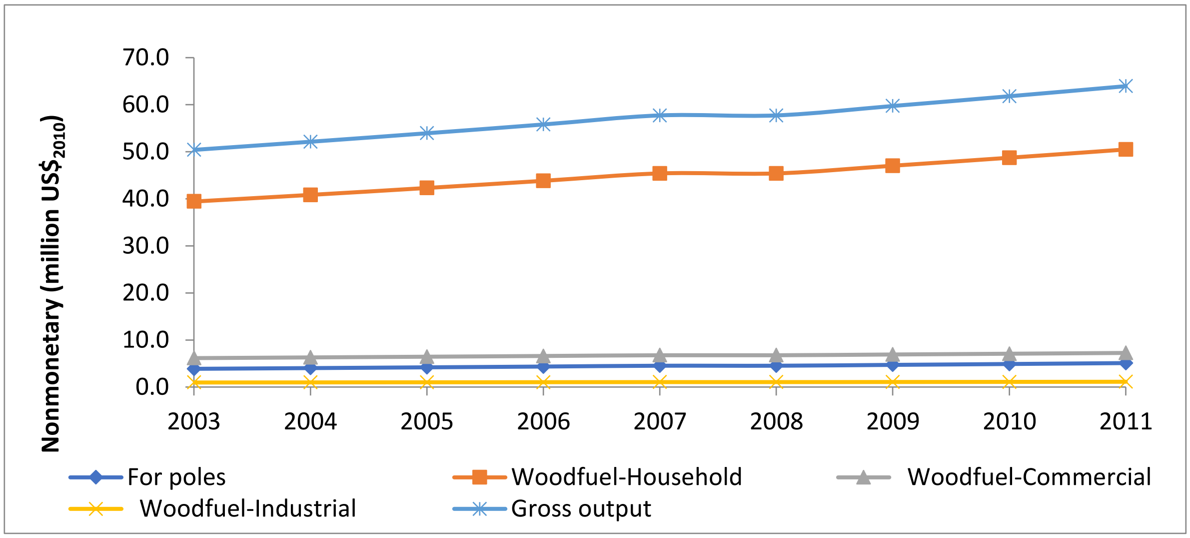

Figure 4.9: The value of output of round wood timber at current prices, 2003-2011

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

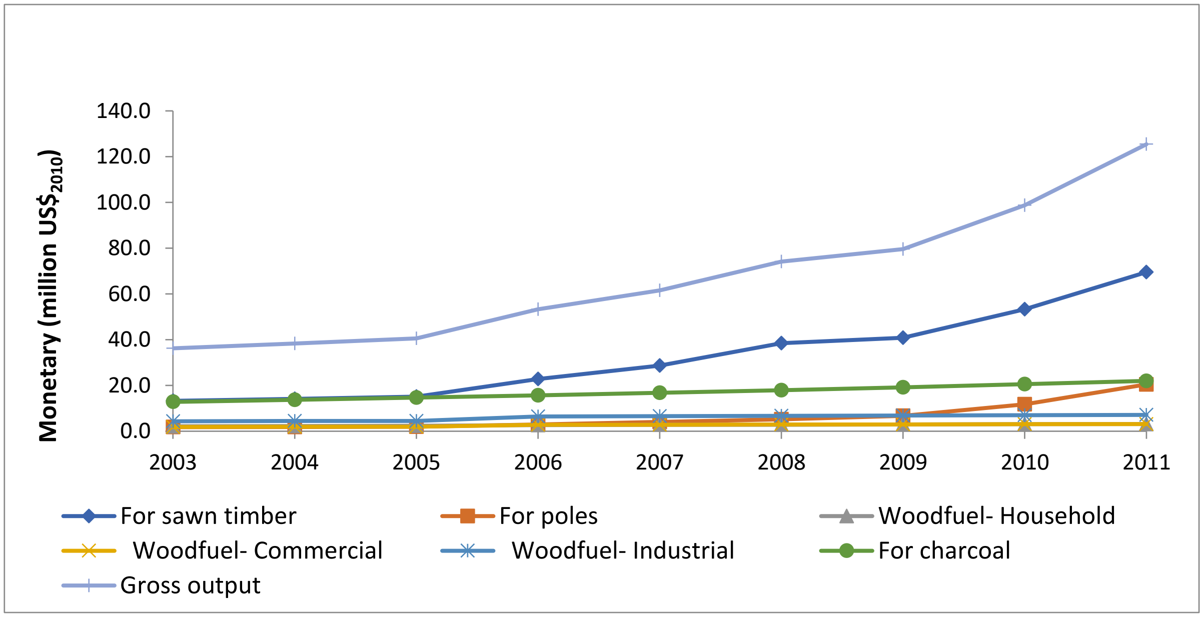

Figure 4.10: Monetary value of output round wood timber, 2003 – 2011

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

Charcoal is the woodfuel, for which there is no nonmonetary category: charcoal must be bought or sold. The simple conclusion is that while most of the firewood is collected for subsistence, nearly all the charcoal is made for commercial purpose. What is remarkable is that wood for sawn timber and for poles is taking first position in relation to the market. This is because most of the firewood is collected free of charge or sold very cheaply, unlike timber wood which is highly marketable. However, the puzzle can be resolved by noting that almost the whole wood can be used as a fuel in the stove, but not all the harvested wood can be sawn as timber.

An estimation of the fiscal value of all round-wood at contemporary prices is given in million Uganda shillings (Mill.UgX) in the corresponding two UBOS reports[9] (UBOS, 2009, p. 104; UBOS, 2011, p. 94). The estimates for monetary wood for the year 2010, for sawn timber and poles amounted to Mill.UgX 132,700 and 29,300 respectively; the firewood for households, commercial and industrial sectors added up to Mill.UgX 7,600, 7,600, and 17,400 respectively; and the wood for charcoal production was estimated at 51,200 Mill.UgX.

If comparison is made in terms of revenue per unit quantity, wood for poles has the highest worth of 86,540 UgX per ton, followed by sawn timber at 71,800 UgX per ton. The value per unit quantity of firewood for household, commercial and industrial sectors was estimated at UgX 8,000, 10,000 and 10,000 per ton respectively. Surprisingly, wood for charcoal production bears the lowest value of 6,000 UgX per ton. Two reasons could possibly explain this context: first, the labour for making charcoal is undervalued (since the charcoal producers can be satisfied with little payment); second, transporting wood is much bulkier and hence expensive compared to charcoal.

Definitely, the worth of wood is influenced by a number of factors, including its type, quality, size and density etc. But an outstanding fact exposed by these comparative

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[9] The estimates for the overlapping two years (2006 and 2007) show some variation, particularly for the monetary wood. Preference has been made to use the latest estimates of consumption data assuming it has been updated. But the question is, would this pattern of data match with the later one. So the leap between 2005 and 2006 should be taken cautiously.

figures is that the purpose (application) for wood is a major determinant for its specific quantitative value (value of wood per unit quantity). Most remarkably, the non-energy applications of wood generate the highest specific quantitative value. On average, the unit quantitative value for non-energy application of wood far exceeds the energy application by 8 ½ times. This would suggest that wood is too valuable for burning as a fuel, yet traditional practices exhibit the reverse. **Figure 4.11** (data on page 211) shows total gross output value of round wood timber.

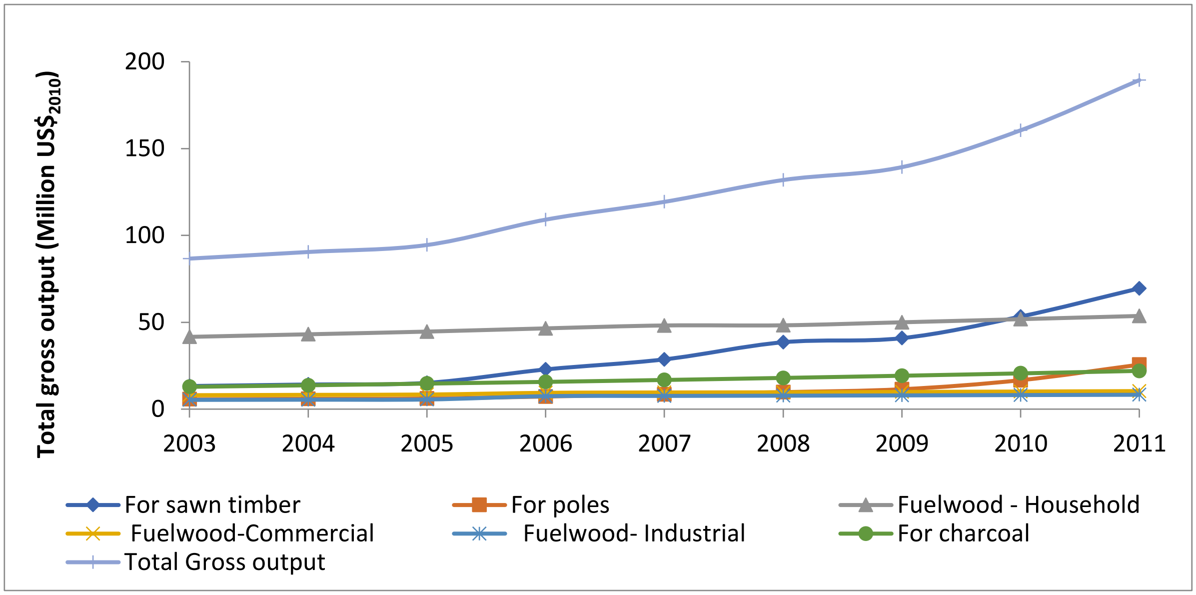

Figure 4.11: Total gross output value of round wood timber, for 2003 – 2011

Source: Based on data from UBOS (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

However, it only the case if wood is of good quality and if the processing plants are in the vicinity. Obtaining 1 unit of commercial wood one has to generate 1 unit of wood residues. In the year 2010, only 7% of the total wood consumption was used for non-energy purpose, meaning that the biggest share (93%) is assigned to the purpose where it generates the lowest financial benefit. Fuelwood for commercial and industrial sectors has almost the same value, while the one for household has slightly a lower value (20% less), possibly because the latter is not for productive use and is primarily used by the low-income population.

The possible reason for the low unit quantitative value of wood for charcoal is probably because the feedstock for charcoal production bears a minor cost or even a zero price. While the final price of a commodity normally reflects all the cumulative costs of the production chain, charcoal is exceptional. It is sold at a devalued price, because it does not normally bear the cost of raw material (wood). The commercial price of charcoal, therefore, begins from the phase of cutting rather than planting the wood. The reason for the absence of price for charcoal feedstock is that charcoal is generally produced from natural rather than planted forests. As such, the landowner never invests in the production of this wood and therefore he does not bear the value for it.

Sometimes the wood converted into charcoal is just a byproduct following or anticipating land clearing. Depending on the infrastructure and the distance or location, if such wood is not converted to charcoal it might be of no value; it could be burnt or simply left to decompose. In both cases, it has no inherent value since it is a waste. In contrast, many non-energy applications of wood, including sawn timber and poles tend to use either planted or highly valued wood. That explains the high price of the wood.

Though charcoal and sawn timber differ in their end use function (energy versus non-energy purpose), they have a remarkable technical and economic comparison. Technically, both require special processing; economically, both have no nonmonetary category: they are both produced exclusively for commercial purposes. Despite the estimated price of a unit quantity of wood for sawn timber being nearly 12 times that of charcoal in 2010, the quantity of wood for sawn timber as a percentage of the total monetary wood is only 13%. Therefore, with respect to commercialized wood, the feedstock for charcoal production (60% of the total monetary wood) was almost 5 times that of timber. Though both are commercialized products, charcoal becomes much more significant than sawn timber in terms of resource depletion and environmental impact. In these terms it is also the most significant of all commercialized wood.

4.5. Consequences of Woodfuel Scarcity

The consequences of fuelwood scarcity are terrible and sometimes dreadful. The State of Uganda Population Report 2006 states: “The distance travelled to collect firewood especially by women and children increased between 2002 and 2005. In Lira and Gulu districts, it has increased from 0.9 km to 7 km requiring 8 hours to collect a head load of approximately 0.25m^3 equivalent to 2000 UgX (MFPED, 2006b). This head load lasts a family of 4 for only 3 days of 2 meals per day. Low firewood availability results into poor quality food intake due to reduced energy for cooking. The districts in the North and North East have been the most affected by firewood scarcity" (MFPED, 2006a, p. 28).

This quantity of wood estimated at 2,000 UgX (about US$ 0.75) that is collected from a distance of 7 km is an indicator of a crisis. Spending 8 hours to obtain fuel worth less than US$ 1 reflects a play between poverty and energy. With high incomes, commercialized fuels would be preferred to firewood collection from long distances. In the framework of poverty, such as it is in rural areas, there is very limited choice apart from struggling to acquire firewood under hardest conditions.

Furthermore, the fact that the rural poor gather wood from 7 km distance and spend 8 hours in collection of the wood is in itself a crisis. This is what constitutes the woodfuel gap. It is a gap created when the poor lacks the fuelwood and cannot afford the alternatives to carry out cooking. Consequently, she or he walk a long distance in search for wood.

The woodfuel situation has changed for the worse, since 2006, and it has affected many pockets of areas who face severe consequences of woodfuel scarcity. For example, the south western Uganda in the district of Kisoro shows almost similar patterns of woodfuel scarcity ten years later. **Figure 4.12** shows the distance (A) and time (B) taken by the different sections of the rural communities in Kisoro district, to collect firewood.

Statistics shows that the major share of the population 38.8% walked a long distance (2-3 km) in search of firewood; and 5% of the population walk 4-5 km – the longest distance to collect wood. In terms of time, still the majority 37.8% take 3-4 hours and a small portion – 15% of the population takes more than 6 hours to collect wood for cooking. The wood, mainly Eucalyptus, is sometimes collected (often falling branches) and or bought from the woodlot owner. However, the alternative for wood are the inferior fuels, mainly sorghum and maize stalks. The majority of the people in Kisoro district don't have enough land to grow crops as well as fuelwood trees. The drivers for firewood scarcity are land shortage (90%), land use change with no forests (73%), rapid population growth

(60%), inefficient cooking methods (51.2%), brick and charcoal burning (41.2%) (Abigaba G., 2016).

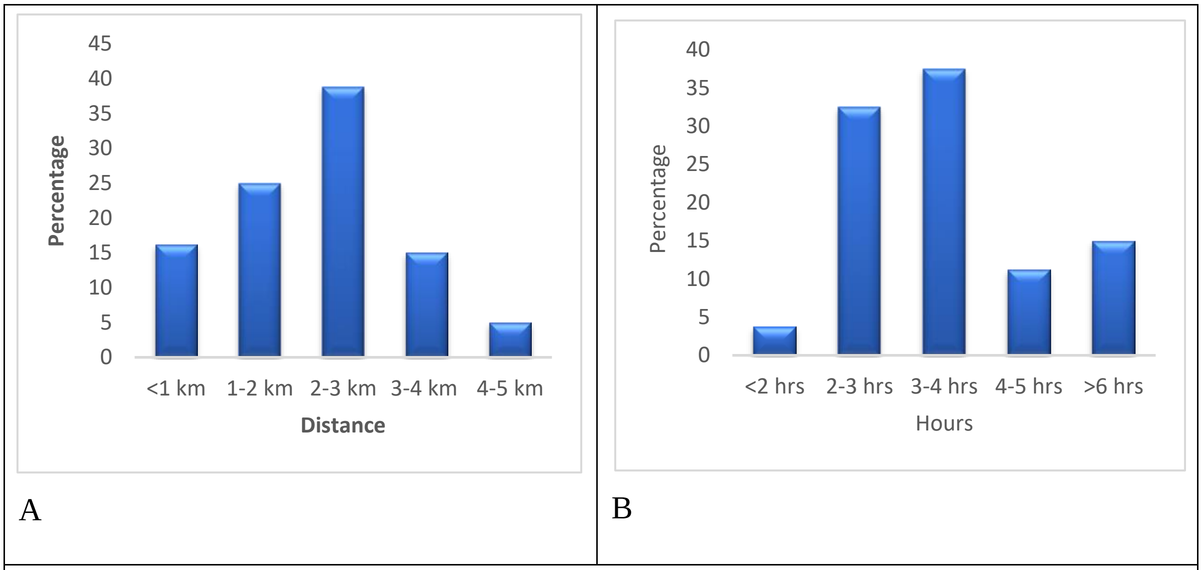

Figure 4.12: Distance (left) and Time (right) taken to collect firewood among rural communities in Kisoro district in south western Uganda.

Source: (Abigaba G., 2016, pp. 46-47)

Because of lack of wood for cooking the residents adapt to the situation by a number of adjustments. First, the cooking frequency can be reduced, for example cooking one meal per day or omitting extra cooking or boiling tasks, like water for bathing or drinking. Second, crop residues are used as alternatives, cause two difficulties: one, they burn very fast and need constant attendance, two, they emit a lot of smoke, which can be dangerous to the cook. Third, inferior biomass is used for cooking-including tiny sticks, leaves and grass, which generate the same results as those of the second. Fourth, non-biomass residues are used, including plastics, which is very dangerous for the environment and to the cook. Fifth, cooking becomes confined to the soft foods only, because these do not consume much fuel – beans and lentils with high protein are avoided. Sixth, along with the long distance is search for firewood, there is the risk of rape, snake and insect bites; and the compromise of the health of the woman by subjecting her to heavy loads that cause backache and headaches.

4.6. Rural and Urban Consumption

The main end use of woodfuels in households in developing countries is cooking, followed by heating and lighting (IEA, 2006, pp. 419-420). Uganda's heating needs are negligible because most parts of the country have a relatively warm climate almost throughout the year, and lighting is primarily done using kerosene.

So, cooking takes almost all the woodfuels, yet there are also other cooking alternatives in both the urban and rural communities, but these are negligible (like electricity, gas and kerosene). Two Uganda Population and Housing Censuses (UPHC), 2002 and 2014, and two subsequent National Household Survey by UBOS (2005/2006, 2009/2010 and 2012/2013) reveal more details on the pattern of consumption of cooking energy. The data shows details by percentage of households, both rural and urban using a particular fuel as the main cooking energy.

However, there are limitations with these figures. First, the data gives only proportions rather than absolute quantities of the fuels. Secondly, the data indicates the "main" fuel used for the household, which hides a lot of specific information regarding how much proportion "main" would be assumed to have. It could have nearly 100%, but depending on other fuels stacked in combination, this "main" could as well be less than 50% as long as it is the largest proportion. Nevertheless, the data throws light on the dynamics of the household main cooking fuel in Uganda.

Table 4-1 compares the main cooking fuels for both rural and urban areas of Uganda. The trend indicates that there is a gradual decline in the biomass consumption though it is indeed too slow. The record shows that by 1992/1993, 97% of the Ugandan population was using biomass as the main cooking fuel. However, UPHC report states that this proportion was 98% by 1991 and changed slightly to 97% a decade later (UBOS, 2006a, p. 25).

However, another possible perspective is that it was nearly the same (97%) for the entire decade and therefore the slight rise to 98% by 1999/2000 could have been a statistical error. Nevertheless, it reduced faster to 96% by 2005/2006 then to 94.5% in 2009/2010, and later on to 95.8% in 2012/2013 (perhaps this could be another sampling error or it could be that some people revert to biomass perhaps due to a fluctuating income) and it was 94.1% by the time of the census 2014. From optimistic perspective, the trend for biomass substitution exists and is growing slightly.

Table 4-1: Percentage distribution of households by type of fuel mainly used for cooking

Year	Residence	Firewood	Charcoal	Kerosene	Electricity	Other*	Gas	Woodfuel
1992/93	Rural	95	3	2				98.0
	Urban	27	62	5	5	1		89.0
	Uganda	85	12	2	1			97.0
1999/0	Rural	96	4					100.0
	Urban	20	70	5	3	2		90.0
	Uganda	84	14	1	1	0		98.0
2002	Rural	91.3	7	0.9	0.3	0.5		98.3
	Urban	22.1	66.8	4	4.3	2.7		88.9
	Uganda	81.6	15.4	1.3	0.8	0.8		97.0
2005/6	Rural	89.4	8.2	0.8	0.1	1.6		97.6
	Urban	22.9	66.1	3.5	0.8	6.8		89.0
	Uganda	77.8	18.2	1.2	0.2	2.5		96.0
2009/10	Rural	86.3	10.4	1.7	0.3	1.3		96.7
	Urban	15.4	69.8	4.9	1.6	8.2		85.2
	Uganda	73	21.5	2.3	0.6	2.6		94.5
2012/13	Rural	89.4	8.2	0.2	0.2	2		95.2
	Urban	36.4	54.4	2.8	1.4	5		90.8
	Uganda	75.3	20.5	0.9	0.5	2.8		95.8
2014	Rural	85.2	11.8		1.2	1.3	0.5	97.0
	Urban	31	58.2		4.4	4.1	2.3	89.2
	Uganda	71.2	22.9		1.9	3.1	0.9	94.1

Source: Author’s. Figures are based on the UPHC (UBOS, 2006a), UNHS for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and for 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12)

However, from pessimistic perspective, there are three concerns. First, the proportion of the households using biomass is still extremely high. Second, the population growth rate is exceedingly high, obscuring the gains from the substitution. Third, the substitution rate is too slow to make a substantial change.

Uganda's population which stood at 16,700,000 by 1990 increased to 21,424,590 by 1999/2000 (UBOS, 2001) and to 24,227,000 by 2002 (UBOS, 2006a). At a growth rate of 3.2% it grew to 27,049,310 by 2005/2006 and rose to 30,713,677 by 2010. Applying the percentages using woodfuels, the corresponding population using woodfuels was 16,199,000 by 1992/1993; it rose to 20,996,098 by 1999/2000 and was 23,500,190 in 2002. Then it increased to 25,967,337 by 2005/2006 and further to 29,024,425 by 2009/2010 and 34,634,650 by 2014 National Population Census (UBOS, 2013; UBOS, 2014a) . This is an annual average increase of 3% of the population depending on biomass.

So, despite the decline in the percentages, especially in the recent years, the absolute population depending on woodfuel is increasing at the tempo close to the total population growth rate. The impact on the resource depends on the scale and rate of exploitation, which in turn is subject to the actual number rather than proportion of the population consuming it. So, the biomass resource is subjected to depletion as determined by the population growth rate.

The quickest substitution rate from 96% to 94.5% between 2005/2006 and 2009/2010 is a drop of just 1.5 percentage points in 4 years. This is an annual average decline of 0.38 percentage points, which is just a tenth of the rate of increase in the population relying on woodfuel. **Figure 4.13** (data in Table 4-1) indicates the percentage of woodfuel in rural and urban residences.

The consumption of firewood in the rural households is the main determinant of wood that is consumed and the main driver because it carries the biggest proportion of the population. According to the gradient of the line (0.0015) the reduction is too slow (curve is almost flat). The x intercept determines the number of years if would take the whole household population to substitute the fuels that are currently used.

$$y = -0015x + 3.9503$$

$$0 = -0015x + 3.9503$$

$$x_{gross} = 2{,}633.5 - 1990.0$$

$$x_{net} = 643.5$$

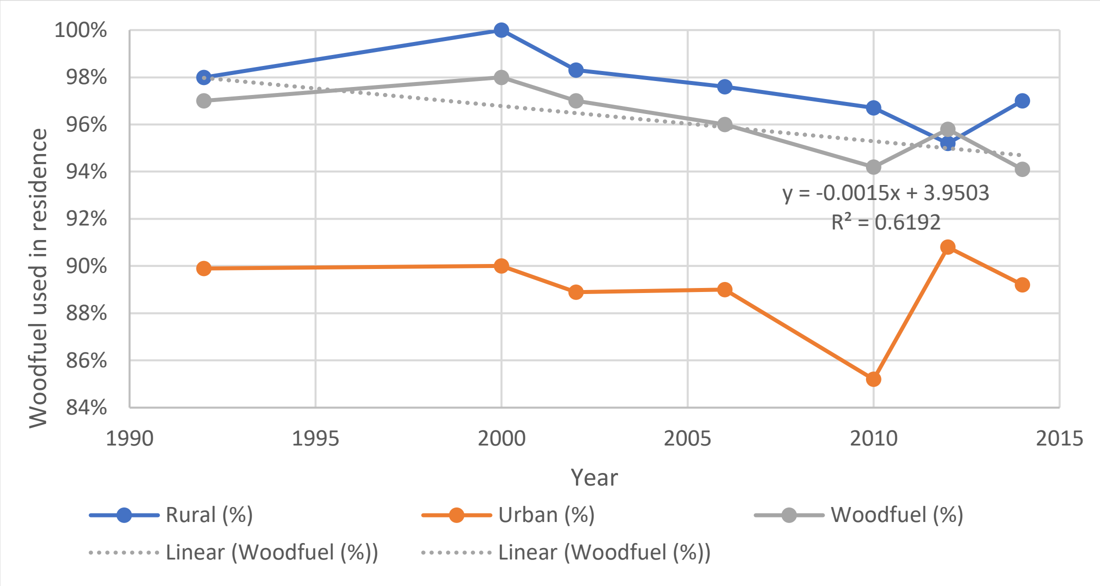

Figure 4.13 Woodfuel Percentage in Rural and Urban Residences

Source: Author’s. Figures are based on the UPHC (UBOS, 2006a), UNHS for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and for 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12)

It would take about 643.5 years for the whole household population to change from biomass as their main cooking fuel. If this rate were doubled, it would still take approximately 322 years for the entire population of household to use another alternative as the main cooking fuel. Even if the highest rate of change of 2006 – 2010 were taken, still it gives 96.0 – 94.2% = 1.8% in 4 years, which is a rate of 0.45%/year. This means that to have 94.2% households getting a substitute fuel, it would take not less than 209 years.

Otherwise, the disruption in 2010 – 2012 can be explained by the sampling error because in 2010 – 2012 a sample of 600 households was taken, whereas in 2014 it was the population census including all households in Uganda. It could also be due to the fluctuating incomes of the population or due to the expensive alternatives which makes the substitute cooking fuels less affordable. In any case the rate of switching from woodfuel to another alternative is too slow.

However according to the coefficient of determination, which assumes a linear relationship of $R^2 = 0.6192$ or 62%, there is another 38% part of the relationship, which is not predicted by the model. **Figure 4.14** indicates the total alternatives (non-biomass) fuel.

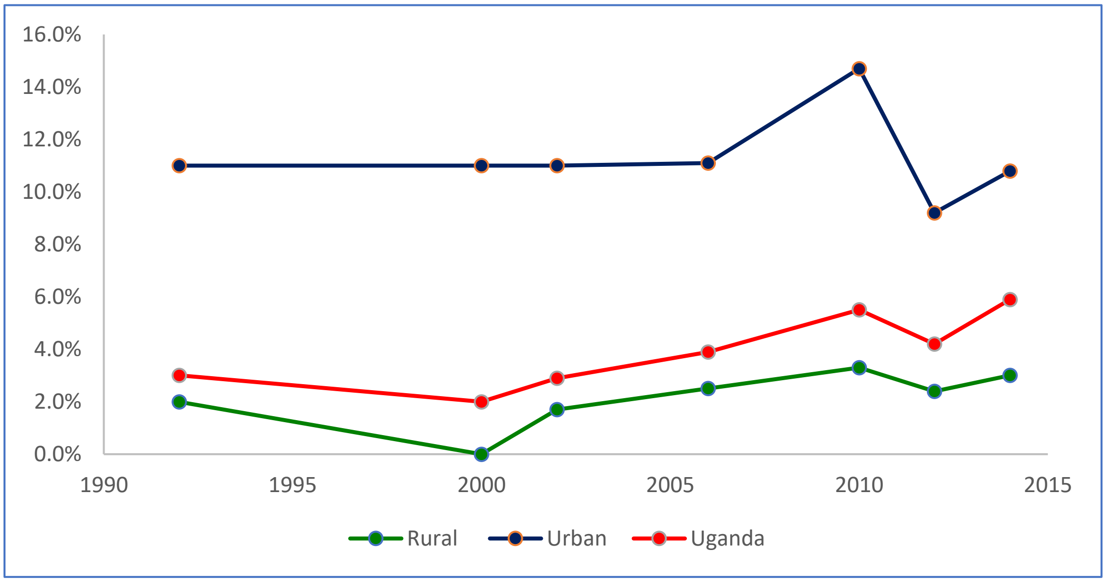

Figure 4.14: Total Fuel Alternatives (non-biomass)

Source: Author's. Figures are based on the UPHC (UBOS, 2006a), UNHS for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and for 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12)

The urban areas have a significantly higher fuel substitution. But still when one compares the figures it is very low. The rural fuel substitution does not exceed 3.3% and the minimum is 0. It is not technically 0 but the fact is that it is negligible.

Remarkably, the urban households are faster than the rural in the fuel transition. Urbanization is typically the major driver for transition to charcoal. Urbanization is the increase in population in cities and towns versus rural areas. In quantitative terms, charcoal consumption increases at a rate close to the urban growth rate of 6% per annum (MEMD, 2007, p. 24) and here the percentage of the urban households using charcoal is much higher than the one of the rural. In the same way, the rural household population using mainly firewood for cooking is proportionately higher than that of the urban counterpart. So this firewood to charcoal transition is ordinarily driven by urbanization. Nevertheless, the trend shows that there are other important drivers like income, prices and availability of the woodfuel are important influencing factors for the choice of the predominant cooking fuel.

However, this increasing biomass “intra-substitution” (from firewood to charcoal) tends to obscure the impact of charcoal on the woody biomass resource. The Renewable Energy Policy for Uganda (REPU) indicates that in 2006, Uganda had a per capita consumption of 680 kg/year and 240 kg/year for firewood, and 4 kg and 120 kg for charcoal, for rural and urban areas respectively (MEMD, 2007).

A simple addition would give a total per capita consumption of 684 kg for the rural and only 360 kg for the urban of woodfuel. The conclusion would be that the rural household resident consumes twice as much quantity of woodfuel as the urban counterpart. This gives more credit to the transition to charcoal. In terms of final energy, the rural and urban would consume 9.5 GJ and 7.0 GJ respectively. Though the two get closer, the urban seems to consume less because of the predominant use of charcoal.

There are also additional arguments in favor of charcoal. It is preferred to firewood because it has higher energy content than wood. Due to this high energy content per unit weight, it is easier to transport than wood and can be transported to markets far away from the forest, which is not possible with wood. The higher energy content compared to firewood makes it easier to burn in compact and portable stoves. Moreover, it is user friendly because it does not require pushing the fuel into the stove all the time unlike firewood. This makes it particularly suitable for urban areas where the dwelling spaces are small. When used for cooking, it is substantially more efficient than wood, does not burn with smoke and emits fewer polluting substances. Unlike firewood, no storage losses occur due to termites or rot. Because of this, many people consider charcoal a modern rather than a traditional fuel. When compared to fuels higher on the energy ladder, it is an inexpensive fuel capable of meeting the consumer needs (Kisakye, 2004, p. 2).

However, if the accounting is done with respect to the feedstock used for charcoal production, the picture gets reversed. Taking the Ugandan conversion factor of 10, the wood for charcoal would be 40 kg and 1200 kg for rural and urban household respectively. When firewood is added, the aggregate wood for the total primary energy consumption for rural and urban households would be 720 kg and 1,440 kg respectively[10]. So, the urban households that predominantly use charcoal for cooking require twice as much primary energy from wood as their rural counterpart. So, every Ugandan making a transition from using firewood to charcoal for cooking requires twice as much quantity of wood harvest. So, urbanization being a major driver for charcoal consumption is an important driver for rapid depletion of biomass resource.

4.7. Cooking Energy Consumption in the Household

Though the percentages of household using different fuels gives a lot of information, the real amounts would enable more detailed analysis. The Energy Sector Management Assistance Programme (ESMAP) had estimated that in 1990, the Primary Energy Supply from fuelwood, crop residues and coffee hulls was 5,023 mtoe, 686 mtoe and 7 mtoe respectively, giving a biomass total of 5,716 mtoe which 93 the Total Primary Energy Supply that is estimated at 6,129 mtoe. The Final Energy Consumption was 5,000 mtoe, out of which firewood, charcoal and crop residues (including bagasse) constituted 3,995 mtoe, 216 mtoe and 514 mtoe, giving biomass a total of 4,725mtoe (ESMAP, 1996), which is 95% of the total final energy consumption.

Out of the total household energy consumption in Uganda, biomass contributed 99.18% in 2007 and 98.8% in 2011. This indicates that the alternatives are not only negligible in distribution (**Table 4-2**), but also minor relation to the overall quantity. However, there is an increase in the consumption of all alternatives in the span of 4 years. Remarkably, kerosene increases at the highest annual average rate of 34%, followed by LPG and electricity which grow at 9%. But biomass consumption which grows at the lowest rate of 3% dominates and influences the overall increase (3%), which is nearly the population growth rate. Consequently, the biomass dominion constrains the growth in alternatives, keeping them at insignificant levels. Moreover, it is not clear whether the increase in kerosene consumption is really due to substitution for the cooking biomass. It

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[10] However, this does not put into account the non-conversion losses (harvest and transportation of charcoal and wood).

could as well be for lighting which would involve switching from the poor kerosene lamp to the lantern, which gives better illumination but consumes more kerosene. Related uncertainty pertains to electricity since it could be put to so many applications, and less likely to be applied for cooking. **Table 4-2** indicates the estimated quantities for the domestic final energy consumption for 2007 compared with 2011.

Table 4-2 Final Energy Consumption in the residential sector in 2007 and 2011

	2007		2011		Increase	
Energy source	Quantity (toe)	Share (%)	Quantity (toe)	Share (%)	Total Rise (%)	% Annual Growth
Fuelwood	5,774,591	86.24%	6,544,259	85.96%	13.3%	3%
Charcoal	396,504.50	5.92%	439,314	5.77%	10.8%	3%
Residues	472,925	7.06%	536,658	7.05%	13.5%	3%
Kerosene	23,010	0.34%	54,472	0.72%	136.7%	34%
LPG	3,485	0.05%	4,702	0.06%	34.9%	9%
Electricity	25,232	0.38%	34,142	0.45%	35.3%	9%
TOTAL	6,695,747.50	100.00%*	7,613,547	100.00%	13.7%	3%

*Total equals to: 99.95%. A mistake has been made in the rounding.
Source: Based on MEMD and GIZ data in (SE4ALL, 2012, p. 17; MEMD, 2012)

It is sometimes assumed that the unavailability of alternatives is one of the major hindrances of fuel switching. Definitely, there is no question about the logic that nothing unavailable can be adopted. But availability per se can play such an insignificant role that the extremely minor uptake of alternatives casts a doubt as to whether it is really available. Since some fuels are dual purpose, the distribution of households by type of lighting in Uganda throws more light on the availability of alternatives for cooking.

The UPHC, 2002, indicates that the majority (75.0%) of the Ugandan households used Tadooba (small kerosene lamp consuming little fuel), which reduced to 51.7% by 2014, next were the users of kerosene lantern with 10.8%, which slightly increased to 11.2% by 2014, and 20% used electricity by 2014. The total household population that used kerosene for lighting in 1991, 2002 and 2014 was 83.1%, 85.6% and 61.5% respectively for lighting; whereas for cooking it was 1.3%. Out of the total household, electricity was used for lighting by 5.6%, 7.8% and 20.4% in 1991, 2002 and 2014 respectively; but used only by 0.93, 0.8% and 1.9% of the population for cooking. The urban population, being the most electrified, had 33.6%, 39.3% and 51.4% respectively of its households using it for lighting; whereas only 6.31%, 4.3% and 4.4% used it for cooking (UBOS, 2006a, p. 23; UBOS, 2014a, pp. 31-32).

This underlines the reality that universal access to electricity is part but not the whole parcel of universal access to modern energy in developing countries. Though indispensable it is insufficient due to the diverse socio-economic context. Apart from the socio-cultural background, the rate of transition to modern energy depends on the economic environment. Accordingly, decision is influenced by the interaction between the relative prices of alternatives and the affordability that depends on the consumer income.

Consequently, there are four critical challenges. First, the majority of the poor cannot afford electricity, even if it is brought in the vicinity of their homes. There are so many poor non-electrified homes within the vicinity of the grid: they have the proximity but not the access. Second, many homes having access to electricity still cannot afford using it for the energy intensive processes of cooking – it is confined to the less energy consuming tasks like lighting, refrigeration, TV, phone charging and radio operations. Cooking is done using the cheapest energy which is wood fuel. Third, even those who can afford electricity prefer the cheaper alternatives (to save money) as long as it can effectively cook. Fourth, the socio-cultural perspective sometimes casts doubt on the suitability of electricity for cooking some of the local foods. When these factors are considered, it becomes less surprising that while the global population lacking access to electricity is 1.6 billion, the population using traditional biomass fuels for cooking is nearly 2.4 billion people (Modi, 2006), indicating that there is large population of those with electricity who use solid fuels like biomass for cooking.

Indeed, very few studies show any change in the use of fuelwood after the introduction of electricity especially in rural SSA. A longitudinal study of fuelwood use, using identical approaches, in five rural villages in the Bushbuckridge region of South Africa, spanning the period over which electricity became widely available indicated that a decade after the introduction of electricity, over 90% of households still used fuelwood for cooking purposes. The mean household consumption rates over the 11-year period had not changed, even with a policy of 6 kWh per month of free electricity. The proportion of households purchasing fuelwood had increased, probably in response to a number of factors, including increased fuelwood scarcity and increases in the price of fuelwood (Madubansi, 2003).

Expressly, regardless of significant increases in electrification, traditional cooking systems using biomass can still remain intact, frustrating the goal to reduce energy poverty. Uganda is one of the developing countries falling into the trap of regarding electricity as the one single solution to all its energy needs. It is putting almost all investment effort to increase electricity supply, mainly from Hydro-electric Power (HEP).

"Whereas the dependence on biomass by the majority of the population is likely to persist in the foreseeable future, there is no explicit policy on biomass development. Instead the current policy emphasis is mainly on developing HEP which includes the Rural Electrification Strategy. However, the economic viability of this strategy is still subject to debate in the face of worsening rural poverty and the high marginal costs of installing electricity network. With the reducing electricity supply and increasing tariffs, more people have resorted to using charcoal and firewood for cooking" (MFPED, 2006a).

Alternatively, it would appear that reduction of poverty levels would be the key driver for substitution. The energy ladder theory provides that as incomes increase, households adopt cleaner and more modern fuels for cooking, and discarding the traditional ones (Leach, 1988; Leach, 1992). However, there are alternatives to this theory of household energy transition. One argument holds that households "energy demand rises with income, but that energy preference is essentially unaffected by increasing income" (Foley, 1995). Another argument is that households do not move up the energy ladder replacing older fuels with more modern ones, but instead as household income increases and new sources of energy are adopted, the use of older ones is maintained to a significant degree in order to meet the increasing demand that follows increased income (Hiemstra-van der Horst, 2008; Peipert John, 2009). This is called fuel stacking.

These differences in conceptualization are indications that fuel substitution is a complex phenomenon, subject to interaction of multiple drivers. Poverty reduction is just one of them. **Figure 4.15** shows that despite the relatively high proportion of the high-income earners, the proportion of those using biomass as the main cooking fuel remains high. A comparison of two trend curves (percentage below poverty line and percentage using biomass for cooking) reveals several specifics. Though both curves show a declining sequence, the one for the percentage using biomass for cooking is more predictable as can be seen by the coefficient of determination ($R^2 = 81.8\%$) of its linear trend. The very small slope of the curve (-0.074) denotes that it is almost flat, indicating that the change in the percentage of those using biomass is minimal.

Conversely, the changes in poverty reduction have been faster during the same period. The period 1992/93 to 1999/10 had the sharpest rate of drop (22.6 percentage point) in the population below poverty line, from 56.4% to 33.8%. Along this sharp decline in poverty levels, there was the highest rate of increase (more than doubling) in the middle class, rising from 10.2% to 22.4% as seen in **Figure 4.15**.

Ironically, it was the period when there was no change in the proportion of the population using biomass (98%)[11]. Definitely, not all those who come out of poverty would attain a middle-class status – the transitional stage consists of those who are non-poor but insecure. These insecure non-poor are those with consumption below twice the poverty line. They are able to meet their basic needs but remain insecure and vulnerable to falling into absolute poverty (MFPED, 2012).

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[11] The UBOS 2001 report (p. 59) records a total woodfuel consumption of 97% for 1991/1992 and 98% for 1999/2000, which would indicate an increase in the percentage of those using woody biomass. However, this is likely to be a statistical error rather than practical change because there was evidently no remarkable shift from a certain fuel to woodfuel. Further, the analytical report following the 2002 census (UBOS 2006a, 25) indicates that the figure for the period 1991/1992 was 98%. In reality, the coverage change between 97% and 98% in 10 years is a minor one.

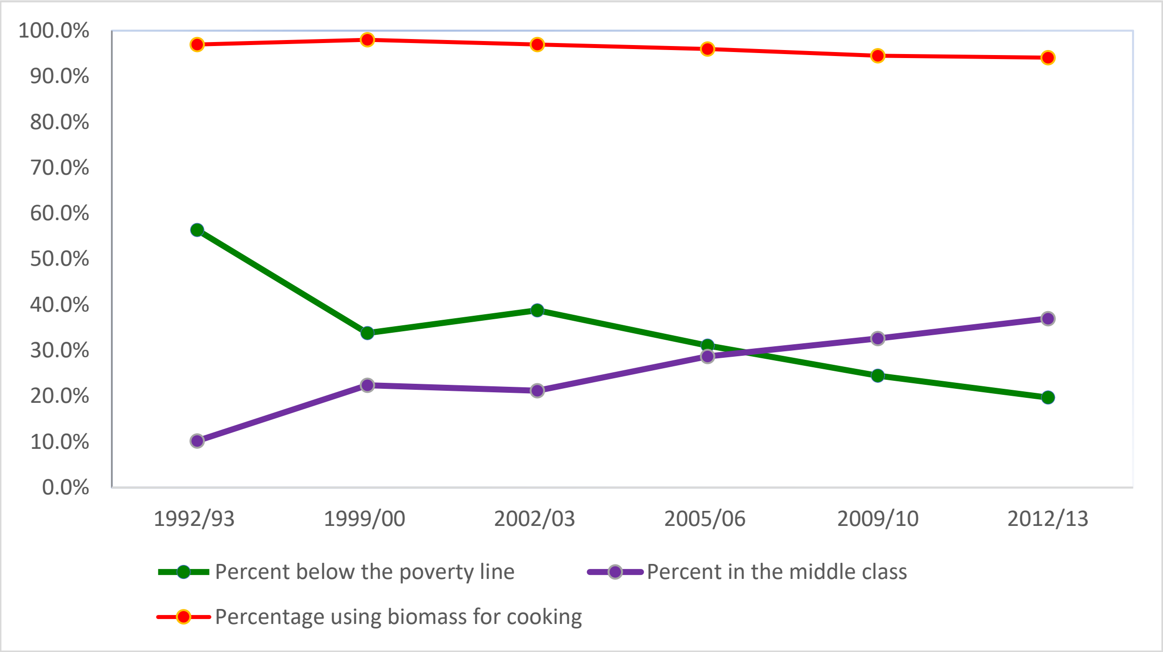


Figure 4.15: Percentage of high- and low-income groups and use of biomass for cooking

Source: Author's. Figures are based on the UPHC (UBOS, 2006a), UNHS for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and for 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12)

The graph in **Figure 4.16** displays a linear relationship between percent of population below poverty line and the percentage of the population using biomass energy for meeting their cooking needs. Though the graph shows a positive relationship between poverty levels and biomass use for cooking, the slope of the curve (0.1094) is very low. Precisely, the percentage of the population utilizing biomass for cooking is not very responsive to the reduction in proportion of number of people below poverty line. The intercept of 0.93 indicates 92.5% (the point where y = 0), meaning that even when the percent population below poverty line is brought down to zero, still there would be 92.5% cooking with biomass (of course this does not distinguish between wood and charcoal but it is still biomass). This income inelasticity of demand for substitutes indicates that cooking biomass may not be categorized exclusively as an inferior good. While the pattern could suggest that there are cases in which it is an inferior good, its resistance to substitution could indicate that it can predominantly be a necessity. However, there are also instances where it is a normal good because its consumption could increase with the incomes of people who cook more food varieties.

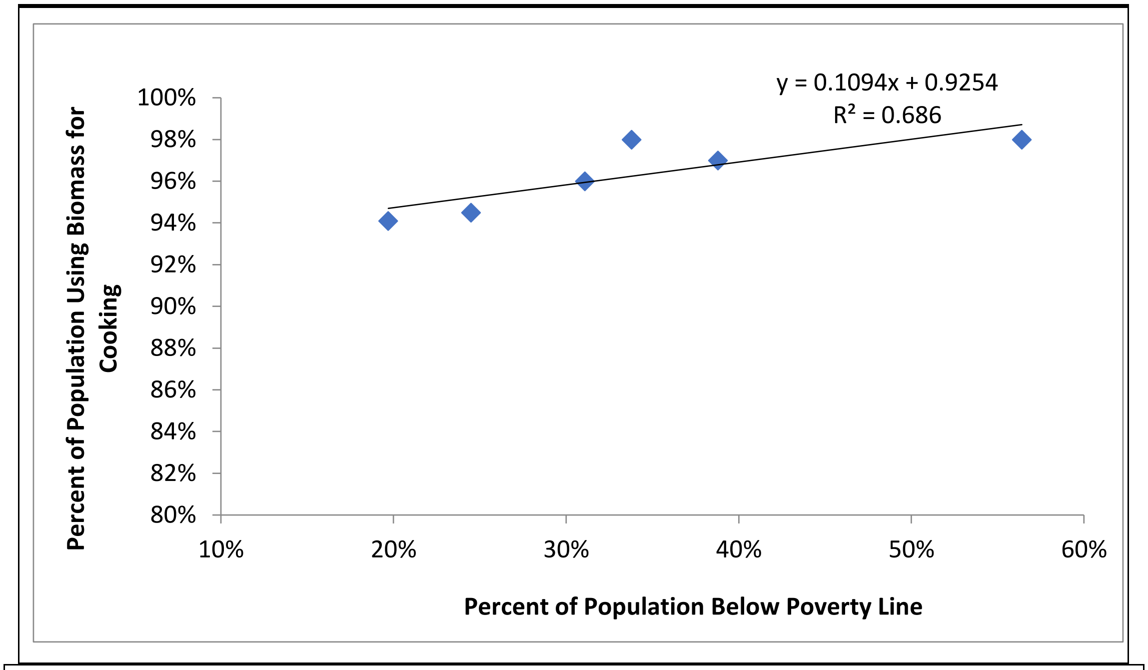


Figure 4.16: Population by Economic Category and Use of Cooking Biomass

Source: Author's. Figures are based on the UPHC (UBOS, 2006a), UNHS for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and for 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12)

There are several reasons why woodfuel is preferred for cooking. First the foods cooked in Uganda are conditioned to woodfuel and it is believed that it imparts an aroma which enhances the taste (but results obtained in chapter 6 seemed not to agree with this assertion). Secondly, woodfuel is inexpensive especially in rural area where it is collected for free and even in urban areas it is still the cheapest compared to other cooking fuels, which tend to be too much expensive. Third, wood is the most available fuel known to man and it was normally abundant for centuries.

The coefficient of determination (R^2 = 0.686), means that the model is able to predict (or explain) 68.6% of the relationship and the remaining (31.4%) is due to other factors and determinants influencing the affiliation. So perhaps, it is better to categorize these influencing factors as suppressor variables. Mugenda, et al, define a suppressor variable as an extraneous variable, which, when not controlled for removes, minimizes or conceals a relationship between the two variables (Mugenda Olive M., 2003). Perhaps it would therefore be unrealistic to count on the non-poor but insecure, as candidates for immediate switching from biomass for cooking because of their instability and the many other priorities they have to deal with. This means that unless there is a deliberate policy to make woodfuel either too expensive or the alternative cheaper, it is not possible to abandon woodfuel.

The reductions in poverty and creation of middle class have to do with income, which acts as the independent variable to influence substitution. There are two assumptions: one, income increases the ability to pay (ATP); two, willingness to pay (WTP) is inevitable. The relationship between ATP and WTP remains a matter of debate: some economists maintain that the two concepts should be highly distinguished (Mataria et al 2006). But the results being discussed here challenge these assumptions when income increases without strongly influencing substitution. Strangely, considering the absolute population rather than the proportions makes the picture even more remarkable. Despite the decline in the absolute population of the poor, the number of those using biomass for cooking increases at the same rate as the total population as indicated in **Figure 4.17** which shows the population of middle class and that of the absolute poor, and the population using biomass versus total population by 2013. Nevertheless, the middle class would be expected to switch to another fuel for cooking.

According to MFPED, 2012, the middle class has characteristics of that makes them distinctly resilient. They are much less vulnerable, facing lower risks because their incomes are higher and more stable, and they are better able to cope with risk because they have more assets and better access to savings instruments and insurance mechanisms. Perhaps there would not be an obvious reason for many of them to continue using biomass for cooking. By 2013, the middle class which was 12.6% of the population should ideally have corresponded to those using alternatives for cooking. This would leave 87.4% rather than the prevailing 92.54% depending on biomass. What is clear from the graphs is that the total population is growing in tadem with population utilizing biomass rather than increase the middle class.

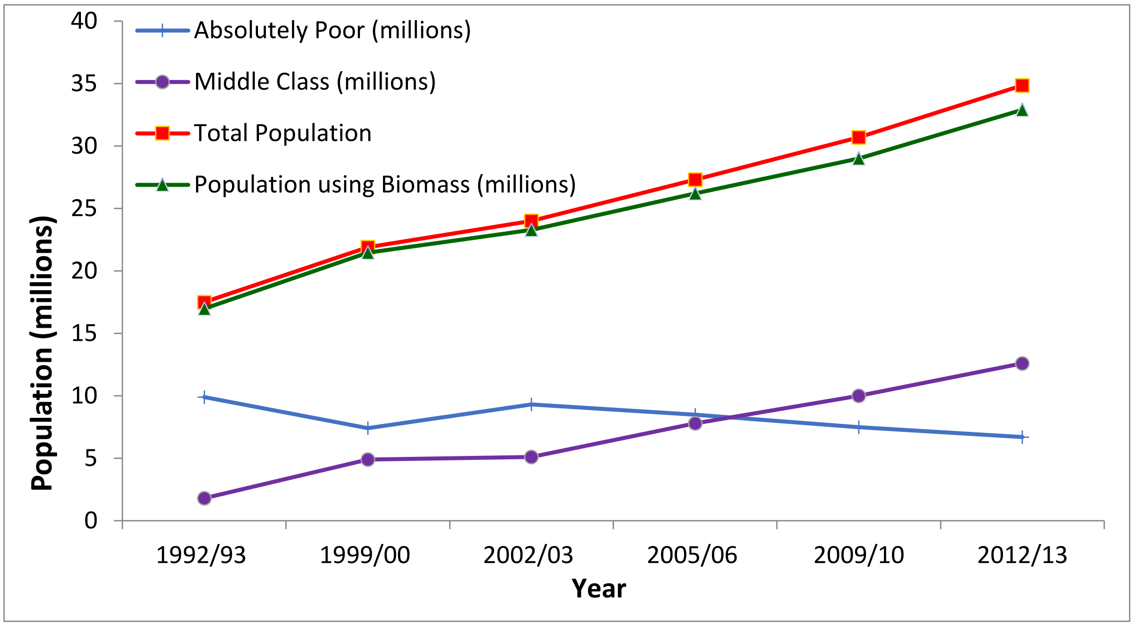
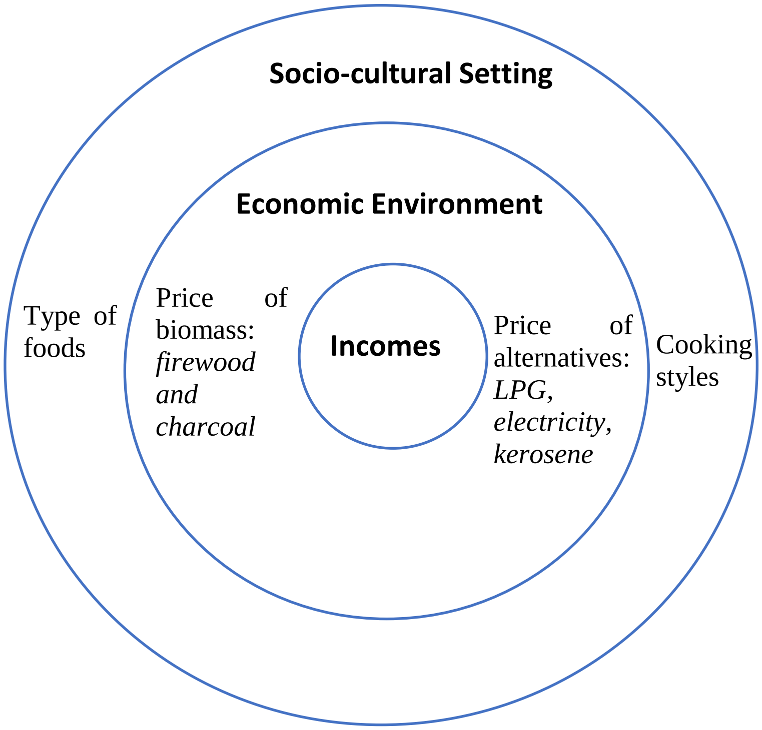


Figure 4.17: Population using biomass

Source: Author's. Figures are based on the UPHC (UBOS, 2006a), UNHS for 1999/2000 (UBOS, 2001, p. 59), 2005/2006 (UBOS, 2006b, p. 104) and for 2009/2010 (UBOS, 2010, p. 116; UBOS, 2013, p. 10; UBOS, 2014a, p. 12)

The conclusion is that though income is one of the primary enablers for fuel transition, it is not the exclusive determinant for switching. To a large extent these findings contradict the energy ladder that fronts income as the single factor influencing the switching of cooking fuels at household level. Time is a very crucial component in relation to switching. People's culture in relation to cooking certain meals may not be overcome in a short period of time. In the worst case, it might take an entire generation to get rid of a strong cooking culture. Therefore, the first step of policy should indeed be to reduce the population living below the poverty line, the second step should address the other critical issues relating to prohibition of wood and subsidizing of alternatives.

This is because the model that income absolutely influences switching is simplistic, disregarding the power of the economic environment and socio-cultural shaping. The economic environment, which among other things sets the price of the substitutes like LPG, electricity and kerosene is critically vital for the consumer's choice of cooking fuel. As long as biomass remains very cheap or even free while the alternatives retain their normal prices, the assumption that income enhancement will automatically influence substitution will always be invalidated. Furthermore, the influence of the socio-cultural orientation in determining the choice of food and the cooking method cannot be disregarded. Consequently, the price of substitutes relative to the one of biomass and the socio-cultural orientation can exert a strong suppressing effect, holding back the influence of income on the substitution of cooking energy. This relationship can be illustrated by the onion schematic diagram (**Source:** Author Figure 4.18).



Source: Author Figure 4.18: Income in Relation to the Economic and Social Context

The existence of a certain level of mismatch between energy and income poverty is observed by Shahidur R. et al, in the case of India. The authors rightly argue that "if the energy poor are income poor then reduction of income poverty is the condition for reduction of energy poverty; if they are not exactly the same, there are specific roles energy policies have to play in mitigating energy poverty". Their research observes that energy demand for end-use energy or energy expenditure in rural India does not respond to income until the 5th income decile or 50th percentile. Their most dramatic finding is for any given percentage of both rural and urban households that is income and energy non-poor, there is a probability of 41% and 16.6% for rural and urban households to be energy poor despite income non-poor. Their conclusion was that energy poverty and income poverty are not naturally the same therefore energy policies matter a lot in determining and eradicating energy poverty (Shahidur R. Khandker, 2012).

While the conclusion of Shahidur R. et al is more focused on quantity, the similarity with this analysis is the limitation of income in absolute determination of energy access. So the income improvement must be accompanied by the relevant practical actions to enable income to influence the proportion that does the fuel switching.

This is a controversy. The trend curve for the population in absolute poverty would be expected to correspond or at least roughly be paralleled by the one for the population using biomass. However, the reverse is true: the slight decline in the population in absolute poverty is partnered with a rapid increase in the population using biomass for cooking. Similarly, the increase in the middle-class population would have been expected to reverse the curve for the population using biomass. Ironically, the two curves are almost parallel: both increasing. This means that the increase in middle class population has no power to bring down the population depending on biomass. The only curve controlling the biomass population is that of the increase in the total population.

To a certain extent, this local pattern mirrors the general trend for the Sub-Saharan Africa and the overall trend in the developing countries depending on traditional biomass for cooking. It was projected in the reference scenario that the population using biomass would rise from 2.5 billion in 2005 to 2.6 billion in 2015 and to 2.7 billion by 2030. That is, one third of the world’s population will still be relying on these fuels (IEA, 2006, p. 47).

On the one hand, Uganda is highly acknowledged as a country that has already achieved the first UN’s MDG of halving, between 1990 and 2015, the proportion of people whose income is less than one dollar a day. The decline from 56% in 1992/1993 to 23% in 2009/2010 (even if the level of poverty increased somewhat in the middle) is more than a half (John Mary Matovu, 2011). However, the recommendation of the UN Millennium Project of halving the number of households using biomass (IEA, 2006, p. 47) is far from being achieved. Uganda is credited as being one of the countries on the path to achieve universal access for all. But the possibility of reaching the destination will depend on the relevance and inclusiveness of the strategic actions and the effectiveness of their implementation.

However, there is a strong positive correlation between the proportion of the people in the middle class and those using charcoal for cooking (**Figure 4.19A**), and it is greatly predictable ($R^2 = 0.9197$). It implies that 91.97% is explained by the model, leaving only 8% that is incognito. This suggests that charcoal is a normal necessity since its demand rises but less proportionately with incomes as confirmed by the gradient of the curve (0.4322). This slope implies that 4 out of 10 are able to switch to charcoal as a result of attaining the middle-class status. However, this relationship could also be caused by urbanization which can be a cause or a result of increased incomes. On the other hand, there is a negative correlation between the share of the population living below poverty line and the one using charcoal (**Figure 4.19B**).

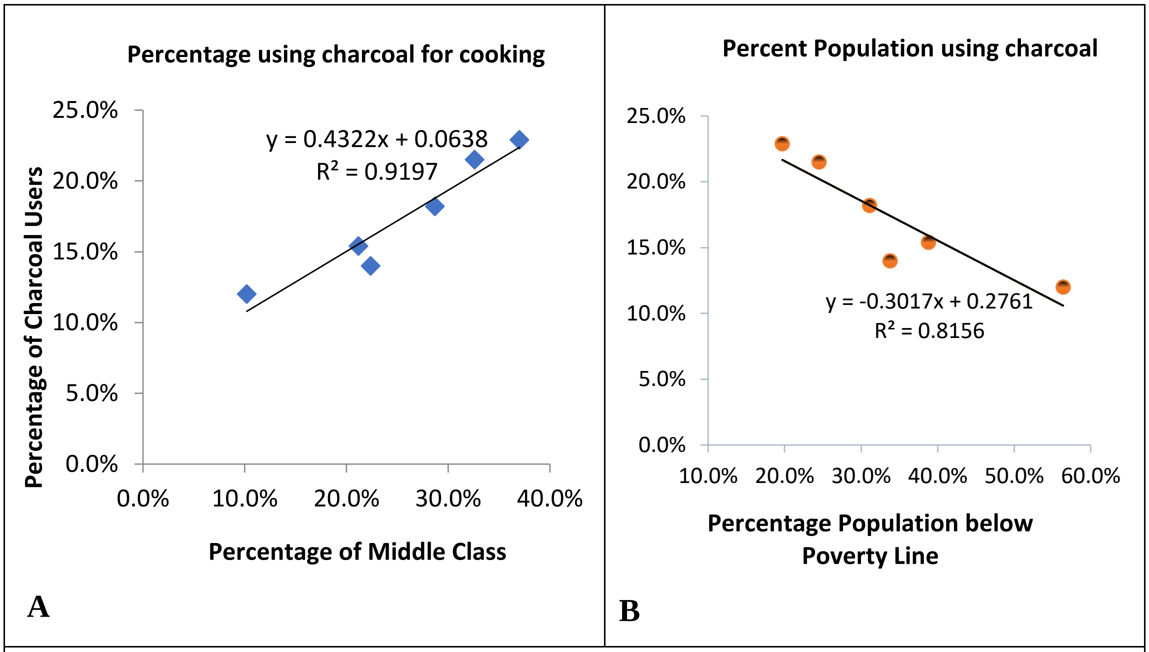


Figure 4.19: Charcoal Use Variation with Middle Class (A) and Poverty Levels (B)
Source: Author. Data based on UBOS reports (UBOS, 2001, p. 59; UBOS, 2006a, p. 25; UBOS, 2006b, p. 104; UBOS, 2010, p. 116) and poverty status report (MFPED, 2012, p. ix)

Though this relationship is less than that of the middle class it is still relatively strong, with $R^2 = 0.8156$, meaning that the model is able to determine 81.56% leaving only 18.44% unexplained. On the other hand, the gradient is also slightly lower than that of the middle class (-0.3017), meaning is less responsive to use of charcoal since every three out of ten people are able to switch to charcoal as a result of coming out of poverty. Nevertheless, these relationships are stronger than the ones relating to the substitution by other fuels.

The conclusion is that poverty reduction and the creation of the middle-income group in Sub-Saharan country like Uganda could influence, at best a substitution of charcoal for firewood rather a transition to cleaner non-biomass fuels. This becomes worse for the biomass resource and environmental sustainability, because the wood required for total primary energy for charcoal is much higher than that of direct use of firewood. So the irony becomes that poverty reduction and increased incomes increase resource depletion and environmental destruction. Therefore, policy must act to make sure that the economic environment is optimized for fuel switching with prices where alternatives can compete with charcoal and the socio-cultural resistance should be addressed by increased awareness campaign and incentives.

4.8. The Combustion of Wood Fuel and Energy Generated

The moisture content on dry basis (MCdb) represents the proportion of water in the wood in comparison to the weight of oven dried wood. On the other hand, the moisture content on wet basis (MCwb) indicates the weight of water as a patial fraction of the total weight of wood. The two moisture contents are often ignored or confused like it was as in 100% Renewable Energy in Uganda (World Life Fund, 2015, p. 35).

1 kg of oven-dry wood has 0% moisture content (wet basis) and a net calorific value of 20 MJ; 1 kg of air-dry wood has 17% moisture content (wet basis) and a net calorific value of 15 MJ; and 1 kg of green wood (just harvested) contains 60% moisture content (wet basis) and a net calorific value of 8 MJ (Wickens, 2001, p. 256). The air-dry wood is more realistic in this case. Walker too indicates that the net calorific value for hardwood is 18 MJ/kg, whereas that of softwood is 19.2 MJ/kg (due to its higher lignin content) and that of the bark is 19.7 MJ (due to the extractives).

If the Moisture Content wet basis (MCwb) is 17% then the Net Heating Value (wet basis) of wood would be given by: **-0.055 x 17 + 5.1 x 3.6 = 15.0 NHVwb (MJ/kg).** The second stage of combustion is the release of volatile gases, third, the volatiles produced burn, leaving solid charcoal, and fourth, the charcoal left behind burns.

Charcoal does not burn since the gases are emitted during carbonization. Instead it glows giving out heat by radiation and often burning a hot blue flame, which is a result of carbon-monoxide. This is because charcoal despite being impure carbon is still largely carbon; and if other substances are ignored it burns completely producing carbon dioxide:

$C_{(s)} + O_{2((g)} = CO_{2\ (g)}$

On several occasions it burns incompletely, producing some carbon monoxide:

$2C_{(s)} + O_{2(g)} = 2\ CO_{\ (g)}$

Wiskerke et al (2010) reports efficiency of consumption rates of 7-12% for traditional fuelwood consumption and 11 - 19% for charcoal consumption respectively (Wiskerke WT, 2010). MacCarty et al found that under labouratory conditions traditional charcoal stoves were as efficient as three stone fires without including the losses due to production (MacCarty N, 2010).

Bentson et al conducted a test for 14 charcoal cookstoves using Water Boiling Test 4.1.2. and results “show that there is a wide range among the charcoal burning stoves when they are fully loaded, but much less when they are minimally loaded” (Bentson, 2013). According to this study, consumption can vary between 200 – 1600 g when different stoves are used. Since the minimum variation is about the minimum fuel used for cooking rather than the maximum, it should be urged that to maximize the perfomance it would be better to use the minimum. This means there is no difference between the improved and the traditional charcoal stove.

Nevertheless, there should be a testing protocol before promoting the stove to ensure that it passes the creterion. Secondly, there is need to educate the users about how to use the stoves effectively. In order to maximize efficiency it is always important to follow the entire chain of charcoal. The adoption of a charcoal would be a great idea but not sufficient because most of the energy is lost in the process of carbonization. In this process heat energy is lost through the hot flu gases that escape, leaving the carbon skeleton behind. Furthermore, more energy is still lost due to poor management of the kiln. A gradual improvement in the kiln efficiency has the potential to generate substantial savings from 10% to 30% which can translate into huge savings of wood requirement (Miyuki limaya, 2014).

Firewood is primarily used in the 3 stone fire, whose average efficiency is as low as 10%. The services/commercial sub-sector grew in 1990 – 2000 by a rate of 8.2% and in 2000 – 2015 it decreased to 6.3%. The typical commercial services that utilize woodfuel include bakeries and breweries. Wood saving potential given in a report about the major staple food crops in Laela indicated a firewood saving (calculated by averaging the recorded saving for maize 41% and beans 34%), of 37.5% (Adkins E, 2010). But according to the author's experience the fuel savings of a firewood improved stove is normally about 50% on case of average stove. **Table 4-3** shows the estimated quantity of biomass used for combusted to generate energy for household, industrial, commercial and institutional in 2014.

Table 4-3: Sectors Utilizing Biomass – in million tons of wood equivalent.

Sector	Firewood	Residues	Charcoal	Charcoal Wood equivalent	Total wood equivalent
Household	18	1.50	0.597	12.26	34.5
Industrial	4				6.4
Commercial	3		0.293	6.02	2.8
Institutional	1.8				1.8
	25.1		0.890	18.28	45.5

(MEMD, 2012)

Assuming a MCwb of 17% (which could be difficult in ordinary conditions), then the NHVwb of wood and charcoal would be 15 GJ/ton and 25 GJ/ton respectively, and the conversion to energy would be as displayed in **Table 4-4**. Of critical importance is that charcoal wood equivalent is almost the same as the quantity of firewood consumed.

Because it is an analysis of wood energy consumed by the majority of households and constituting 75.7% of the total wood energy, the rest of wood will not be discussed.

Table 4-4: Sectors Utilizing Biomass in terms of Energy (GJ)

Sector	Firewood	Residues	Charcoal	Charcoal Wood equivalent	Total wood equivalent
Household	313,374,600	25,489,800	44,400,000	197,920,800	517,293,000
Industrial	71,971,200	26,989,200			95,961,600
Commercial	8,096,760		8,880,000	38,984,400	41,983,200
Institutional	26,989,200				
	393,442,560	25,489,800	53,280,000	236,905,200	682,227,000

(MEMD, 2012)

Assuming a 10% efficiency for firewood and agro-residue, and a 10% and 15% respectively for efficiency of charcoal carbozation and efficiency of cooking on the stove, then the total amount energy derived from woodfuel in household would be as given in **Table 4-5**.

Table 4-5: Total Wood Energy Consumed in Households

[**Household Wood Conversion in Final Energy (GJ)**]

Types of Household Energy Used	Secondary Energy	Primary Energy	Efficiency	Final Energy
Firewood	273,885,438	273,885,438	10%	27,388,544
Agro residues	22,459,810	22,459,810	10%	2,245,981
Charcoal	17,676,587		2%	265,149
Charcoal Wood equivalent		183,858,413	2%	-
Total wood equivalent	314,021,835	480,203,660		29,899,674

(MEMD, 2012)

The overall efficiency indicates that the energy output is 6.7% of the energy of the energy input for biomass.

CHAPTER 5

BIOMASS STOCK AND BALANCE

Chapter 5 was a detailed discussion of biomass supply. The annual average percentage increase in tons from 1990 to 2005 for Tropical High Forest (THF) – well and low stocked, and Bushland increased, whereas the rest of the land cover declined in their biomass stock. The greatest decline was that of Small Scale Farmland (SSF), which was 112,569,687 and reduced to 53,160,922 which was a percentage reduction of -52.8% and would be an annual percentage decline of 3.52% (this severe reduction from SSF is an indicator of scarcity: people resort to the homestead trees). In terms of area sizes there are land covers that underwent expansion and those which underwent decline. Those, which underwent expansion in area size, are Coniferous plantations, Bushland, Wetland, Small scale farmland, Large scale farmland, built up areas, Open Water and Impediments. This means that though biomass stock reduced the SSF the land cover underwent an expansion in terms of size. On the other hand, those which underwent a decline in size were Broad leaved plantations, THF well stocked, THF low stocked, Woodland and grassland. The most evenly distributed land cover is still the small-scale farmland. Out of the privately-owned land (87%) the net reduction in yields was 9 million tons. Since yields are the ultimate measure of sustainability of biomass this reduction in yield from 35 million tons in 1990 to 26 million tons in 2005 (net annual loss of 1.8%) is a strong signal that biomass is facing a serious degeneration. By 2006, 99% of the districts had sufficient stock to yield enough wood for biomass energy but projections show that at least 64 districts will not have enough biomass stock; 71% of the districts had negative balance by 2006 and it is projected to continue reducing to 43% of the districts by 2040. 85% of the district had a reduction in biomass per capita. Of the ten main charcoal supplying districts only one had a positive balance. Mukono and Wakiso districts are the ones closest to Kampala city and hence they were the greatest losers of biomass. The mean size of the land equivalent (of the five-land cover) required to produce this lost biomass would be 1,688,000 ha, while the mean size of the 10 main charcoal producing districts is only 540,000 ha. So averagely, 3 districts would be required to produce this biomass that was lost in 15 years – one district for every five years. Where there is a problem of wood and land scarcity, the choice has to be made between growing crops and planting trees (food versus energy).

5.1. Biomass stock

5.1.1. Biomass and Land Cover Distribution

Having analyzed demand pattern, we now proceed in this chapter with biomass supply. Uganda is divided into 13 land cover classes. Some land cover types are identified using different names **(Table 3-2;** Error! Reference source not found.**)**

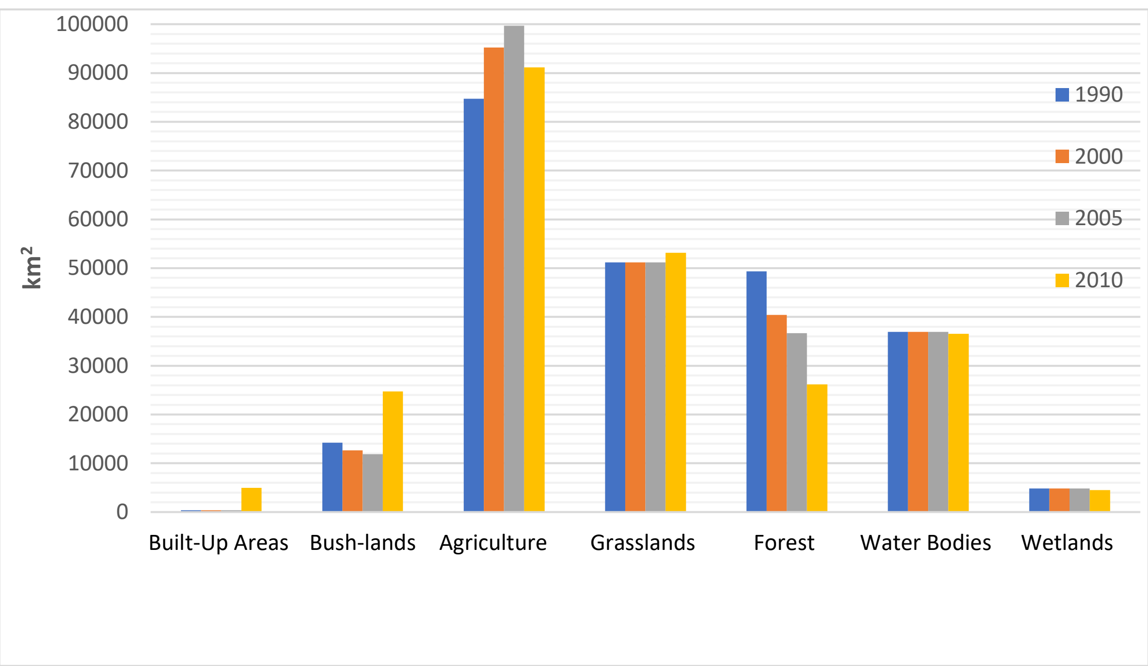


Figure 5.1: Land Cover area by type, 1990-2010 km^2
National Forestry Authority (UBOS, 2015, p. 2)

The countrywide biomass and area size of the various land cover classes for 1990 and 2005 is given in Appendix A.3; page 212. The process of generating biomass data is quite expensive and it takes too much time. The oldest report was report was produced in 1991 and the last report was published in 2005. The author has not come across any comprehensive report 1990 or later than 2005. But the scanty statistical data in **Figure 5.1** confirms that the trend is consistent.

Forest cover area decreased consistently in steps from 49,333.6 km^2, 40,416.4 km^2, 36,654.8 km^2 and 26,196.8 km^2 in 1990, 2000, 2005 and 2010 respectively. Bushland declines in smaller steps from 14,223.9 km^2, 12,624.5 km^2 and 11,893.6 km^2 in 1990, 2000 and 2005 but increases dramatically to 24,705.9 km^2 in 2010. The increase in the bushland could be a gain in landcover class but this is improbable. The most likely explanation is that it was because of landcover change from tropical high forest to bushland, due to forest degradation that caused an increase in the area of bushland. However, this cannot be asserted with certainty, but it is likely to be the case. For nearly the same reason, grassland follows a similar pattern of 51,152.7 km^2, 51,152.7 km^2 and 51,152.7 km^2 in 1990, 2000 and 2005 and then it increases slightly to 53,153.3 km^2 in 2010. Agriculture goes up from 84,694.5 km^2, 95,211.2 km^2 and 99,703.1 km^2 in 1990, 2000 and 2005; then it declined to 91,151.8 km^2 in 2010.

Table 5-1: National Land Cover Area, km^2

Type of land cover	**1990**	**2000**	**2005**	**2010**
Built-Up Areas	365.7	365.7	365.7	4,966.6
Bush-lands	14,223.9	12,624.5	11,893.6	24,705.9
Agriculture	84,694.5	95,211.2	99,703.1	91,151.8
Commercial Farmlands	684.5	684.5	684.5	n.a
Cultivated Lands	84,010.0	94,526.7	99,018.6	n.a
Grasslands	51,152.7	51,152.7	51,152.7	53,153.3
Impediments	37.1 3	7.1 3	7.2	348.9
Forest	49,333.6	40,416.4	36,654.8	26,196.8
Woodlands	39,740.9	32,601.4	29,527.8	n.a
Plantations - Hardwoods	186.8	153.3	138.6	n.a
Plantations - Softwoods	163.8	80.0	121.5	n.a
Tropical High Forest	2,740.6	2,248.2	2,036.3	n.a
Tropical High Forest Normal	6,501.5	5,333.5	4,830.6	n.a
Water Bodies	36,902.8	36,902.8	36,902.9	36,527.4
Wetlands	4,840.4	4,840.4	4,840.6	4,500.0
Total	241,550.7	241,550.7	241,550.7	241,550.7

Source: National Forestry Authority (UBOS, 2015, p. 2)

One might wonder why there is a decline in the land for agriculture when there a rapid population to feed. But perhaps the settlements (Built-Up Areas), have increased from 365.7 km^2 to 4,966.6 km^2 (almost 14 times) during the same period of decline in agriculture: 2005 to 2010. Because the Wetlands too are facing a decline during the same period it becomes logical to suggest that land for settlement might be responsible for agricultural decline.

A comparison between the biomass stock in 1990 and 2005 indicates that apart from bushland, only the Tropical High Forest (well stocked and low stocked) had an increase in the stock.

Table 5-2: Total Biomass Stock in 1990 and 2005

Class	Biomass (Tons) 1990	Biomass (Tons) 2005	Change in Stock (tons)	% Stock Change
Broad leaved plantations	1,702,827	1,438,177	-264,650	-15.5%
THF well stocked	129,591,090	162,126,739	32,535,649	25.1%
THF low stocked	25,906,891	30,882,558	4,975,667	19.2%
Woodland	132,468,709	86,044,859	-46,423,850	-35.1%
Bushland	17,865,384	26,883,367	9,017,983	50.5%
Grassland	44,247,586	29,559,256	-14,688,330	-33.1%
Small scale farmland	112,569,687	53,160,922	-59,408,765	-52.8%
Large scale farmland				
Built up area				
Open Water				
Impediments				
Wetland				
Coniferous plantations				
	464,352,174	**390,095,878**	**-74,256,296**	**-16%**

Source: National forestry Authority 1990 and 2005

The rest were characterized by a decline. In particular, the small-scale farms faced the greatest decline in stock. The large-scale farmland built up areas, open water, impediments, wetland and coniferous plantations had a negligible stock. The rate of stock decline per year is -1%. The landcover with the highest decline is small scale farmland with an annual average reduction in stock of 3.52%; on the other hand, there is an annual average increase in the stock of bushland of 3.37%. However, the increase in stock of bushland cannot be compared with the reduction in stock of small-scale farmland because the latter was over six times compared to the former.

Looking at the figures one cannot avoid making a conclusion that there is no sustainability in regard to biomass consumption. First, the reduction in the quantity of biomass in the small-scale farmland indicates crisis. Secondly, the tree plantations that would act as the substitute are not increasing. Instead there is a gradual decrease of 15.5% in the quantity stock of biomass in the broad-leaved plantations and almost a minor increase in coniferous plantations. But since the area of coniferous plantation is negligible (0.0007) its seemingly meager stock could not even be brought into discussion.

This means there are two points available for making a contrast 1990 and 2005. Nevertheless, there is no big campaign for tree planting to replace the biomass lost during the 15-year period. So, for the sake of comparison of biomass evolution these two reports give a clue regarding the change in the status. The biomass in each land cover as a percentage of the total shows variability in distribution. While some land cover classes have substantial amounts of biomass, others have such a minor share of biomass quantity that does not exceed 0.4%. These include Coniferous Plantation, Wetland, Large Scale Farmland, Built up Area, Open Water and Impediments. **Figure 5.2** has four graphs: percentage share of biomass (A) and area (B), and percentage change in biomass and area (C) and mean biomass stock (D) by land cover class in 1990 and 2005.

Specifically, graphs A and B relate each land cover type to others, while C and D relates it to itself between 1990 and 2005. The change in the share of the biomass quantity and size of land area by tree cover shows a pattern of variation between 1990 and 2005, with some dropping as others rising; and with some changing slightly while others vary considerably (the longer the bar the greater the change in the percentage share). Woodland, which had the highest share of biomass (29%) in 1990, had its proportion cut to 22% by 2005 as it became the second greatest loser of its relative share of the total biomass. Likewise, the share of its land size as a percentage of the total area was reduced from 16% to 12%. Moreover, it had a 29% reduction in its biomass and a 26% cutback in its area. Further, it had a small decline in its mean biomass stock from 33% to 31%.

The Small-Scale Farmland (SSF) remained the third bearer of the large amount of biomass. However, it had the highest drop in the share of its biomass from 24% to 14%

during the same period though the share of its area increased from 35% to 37%. Its size expanded by 5% but it lost more than half of its original biomass (graphs C and D).

On the other hand, the Tropical High Forest well stocked (THFws), which had the second highest share of biomass (28%), in 1990 had such a large increase that made it the land cover class with the largest quantity (42%) by 2005. Nevertheless, the share of its area, which had previously been small (3%) dropped further to 2% (graph B), and while its biomass quantity increased by 25%, its area size decreased by 17% (graph C). This is explained by the fact that THFws, which already had the highest mean biomass stock (199 tons/ha) had it elevated to 300 tons/ha. It could be caused by different methods of quantification (between the two surveys: 1990 and 2005).

But from the strategic point of view there was strictness on the tropical high forest which were seriously guarded, and punishments were slammed on anybody that was caught violating the law prohibiting interfering with those forests. This increase of more than 50% dwarfed the mean biomass stocking for the rest of the land cover classes since it was nearly twice that of the Tropical High Forest low stock (THFls), three times that of Hard Wood plantations (HWP), nearly ten times that of Woodland, more than thirty three times that of Bushland, nearly forty three times that of Grassland and fifty times that of SSF.

There are also two other land cover classes that moderately gained their relative share of the biomass: THFls and Bushland. THFls follows the same pattern as the THFws though to a moderate extent since it is less than the latter in most aspects. The percentage share of its biomass increases from 6% to 8% while its area size relative to the rest shrinks from the tiny 1.1% to a further minimal 0.8%; its biomass increases by a fifth while its area decreases by more than a fourth, and its mean standing stock rises by more than 60%. The Bushland takes slightly a different pathway: the relative share of its biomass and area size rose from 4% to 7% and 6% to 12% respectively, while the quantity of its biomass increases by 50% and its area expands by 109%.

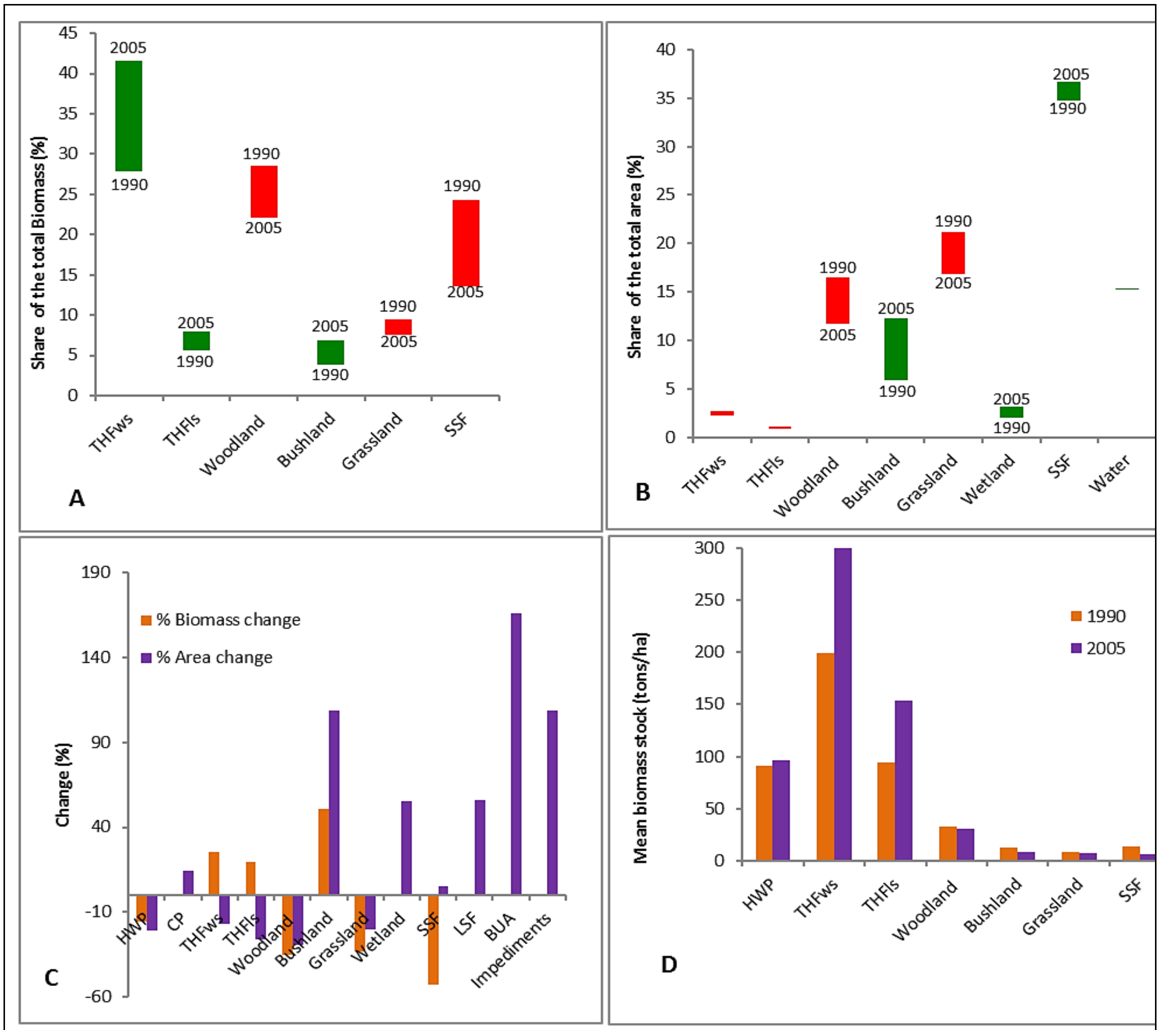


Figure 5.2: Percentage share of biomass (A) and area (B), and percentage change (C) and mean stock (D) by land cover class in 1990 and 2005

Green and red bars indicate increase and decrease respectively in graphs A and B

Source: Author, data from National Forestry Authority 1990 and 2005

Conversely, Grassland experienced a fall in all general aspects under discussion: the share of its biomass and its land area fell from 10% to 8% and 21% to 17% respectively, while its biomass quantity reduced by a third and its area by a fifth and its mean biomass stock reduced from 9 tons/ha to 7 tons/ha. Some land cover classes underwent dramatic changes during the same period but they are not important in terms of biomass: The Built up Areas (BUA), Impediments, Large Scale Farmland (LSF) and Wetland display a substantial increase in area of 166%, 109%, 56%, 56% respectively; Open Water (Water) remained unchanged in the share of its relative size (15%) while Hard Wood Plantations (HWP) had a 16% reduction in its biomass quantity and a 21 decline in its size and the Coniferous Plantation (CP) had an area increase of 15%. The insignificance of the biomass of these land cover classes is due to the fact that some simply have negligible mean standing stock (Open Water and Wetland) while others have it in substantial quantity but have a negligible share of size (HWP and CP) or both aspects (BUA and Impediments).

5.1.2. Accessible Biomass Yield

The accessible biomass yield is the one that can be ideally regarded as the supply for consumption purposes. Accordingly, the biomass in reserve areas has been deducted from the total biomass in the country to obtain the one in private areas, which has been regarded as the one accessible. The total area by land cover class is given in the national woody biomass in Appendix A.4, on page 215. **Figure 5.3** shows the relative size of private and protected areas of selected land cover classes by 2005.

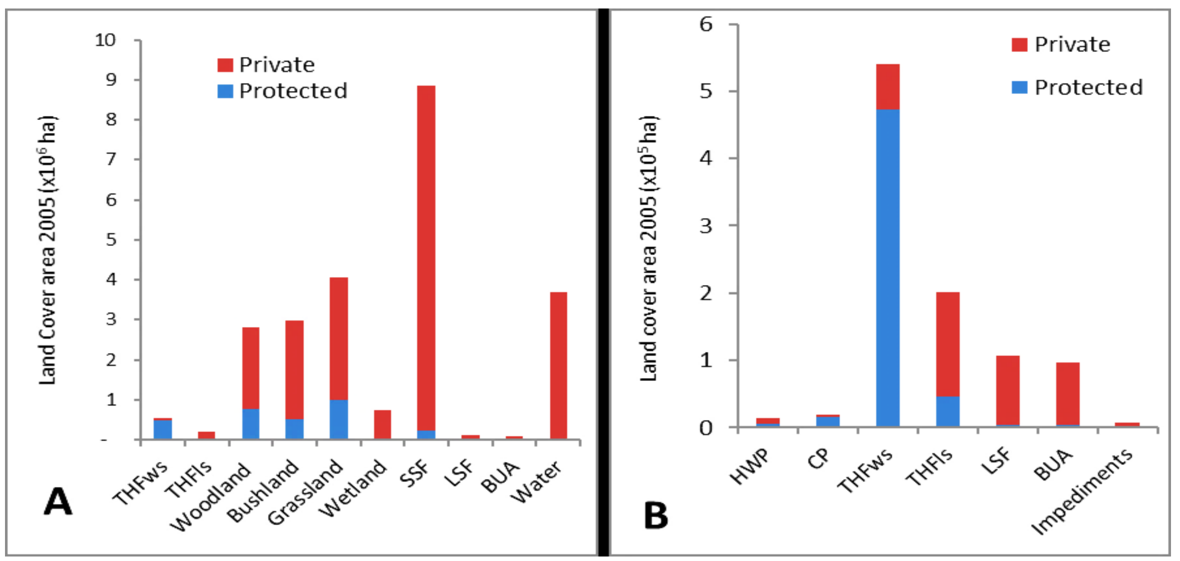


Figure 5.3: Size of private and protected area by land cover both large (A) and small (B) by 2005. Source: Author data from National Forestry Authority 1990 and 2005

Because of the high variation in size of the land cover classes (μ = 1,619,146 ha, σ = 2,389,769 ha) it is not effective to show the smallest of the land cover classes (<20,000 ha) on the same scale of graph A. Therefore, graph B is constructed to cater for the land cover classes with smaller area, while including the smallest land cover in graph A.

The protected area in Uganda is much smaller as portrayed by the graphs. The land cover classes with the highest share of protected area are the THFws and CP where it covers 88% in both cases. Since these are small size land cover classes, their share in terms of the overall land size is negligible, and so their possession of this high proportion of reserve area does not contribute much to the overall size of the protected area. Given that the biggest land cover classes have a relatively smaller share of the protected area, the inevitable consequence is that most of the land in Uganda is private owned. Since this has a strong influence on the dynamics of biomass, it means that the latter in most of the land cover classes is subject to disturbance because the owner may change the land cover without any control, consultation or legislation from the state.

Since (open) Water and Wetland may not be very applicable in relation to biomass their relative size and accessibility may not be of much relevance. On the other hand, THFls, BUA and LSF are relatively small but with some substantial biomass and they are predominantly private owned and therefore accessible. The SSF, which is the single land cover occupying the largest area (close to 9 million hectares) is depicted as 97% privately owned. But practically, it is illogical to designate a subsistence farm as protected. The only explanation is that the three percent of the SSF lies within in protected area by encroachment since it is definitely 100% accessible by the smallholder farmers. Next to the SSF are Grassland, Bushland and Woodland respectively, with a share of private ownership of above 70%. Overall, 87% of the total land area is privately owned.

Figure 5.4 (Appendix A.11, page 229) portrays the dynamics of biomass and size of major[12] land cover classes between 1990 and 2005, showing the total (private and protected) biomass yield (C), and indicating the private area land cover size, biomass stock and yield (A, B and D respectively). A comparison in all these aspects shows essential dynamics in the period between 1990 and 2005.

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[12] The land cover indicated are those which are significant in terms of area and biomass quantity.

In regard to size of privately-owned land (Figure 5.4, graph A), Bush, Wetland and SSF expanded, while Woodland and Grassland shrunk. However, the overall impact of these dynamics is not determined merely by the change in proportion of their original size but also by their relative size in comparison to the rest of the land cover. Therefore, a small increase the SSF – the dominant land cover in terms of size – is equivalent to 365,342 ha, which is greater than a large increase of 57% in the Wetland that is only 255,773 ha. The predominant size of the SSF makes it an extreme land cover that goes above the range of the rest both in 1990 and 2005.

Next in size (but much less) is Grassland, which despite its reduction of 22% in its former size has remained the second largest. Due to the decline of up to 34%, Woodland which was the third largest in 1990 has been overtaken by Bush, as the latter rose by 118%.

In relation to biomass stock in private area (Figure 5.4, graph B), there was a substantial loss of biomass in four land cover classes – THFws, Woodland, Grassland and SSF – and a gain in two land cover classes – Bush and THFls. The SSF which possessed the highest quantity (113 million tons) by 1990 had a radical loss of the stock that reduced it to less than half (53 million tons), bringing down the SSF to the second position in relation to biomass stock. This drastic decline, coupled with the sustained surpassing size (which slightly increased) implies that the mean standing stock in quantity per unit area reduced to less than half, indicating a lower concentration of biomass in the SSF.

In terms of biomass quantity by 1990 the SSF was closely followed by Woodland (101 million tons). Though this quantity dropped by nearly a third, Woodland became the highest bearer of biomass by 2005, following the deeper fall in the SSF stock. A comparison of area and biomass quantity for SSF and Woodland reveals more details. The area size of the SSF exceeded that of Woodland by 2.7 times by 1990 and increased to 4.2 times by 2005. On the other hand, the biomass stock for the SSF was only 1.1 times that of Woodland by 1990, and still reduced further to 0.8 times by 2005. This means there is a much more concentration of stock in Woodland compared to SSF. While the mean stock for SSF reduced from 14 tons/ha to 6 tons/ha between 1990 and 2005, the one for Woodland reduced only slightly from 33 tons/ha to 31 tons/ha during the same period.

In 1990, Grassland was the third most bearer of the biomass stock, but with quantity that was 3 times lower than that of SSF, yet more than 3 times higher than the Bush and 1.2 times that of the THFws. By 2005, Grassland biomass stock had fallen by 40% to 22 million tons – almost equaling with Bush which had risen by 94%. It also makes it only slightly more than that of THFws which dropped by 37% and a little less than THFls which increased by 32%.

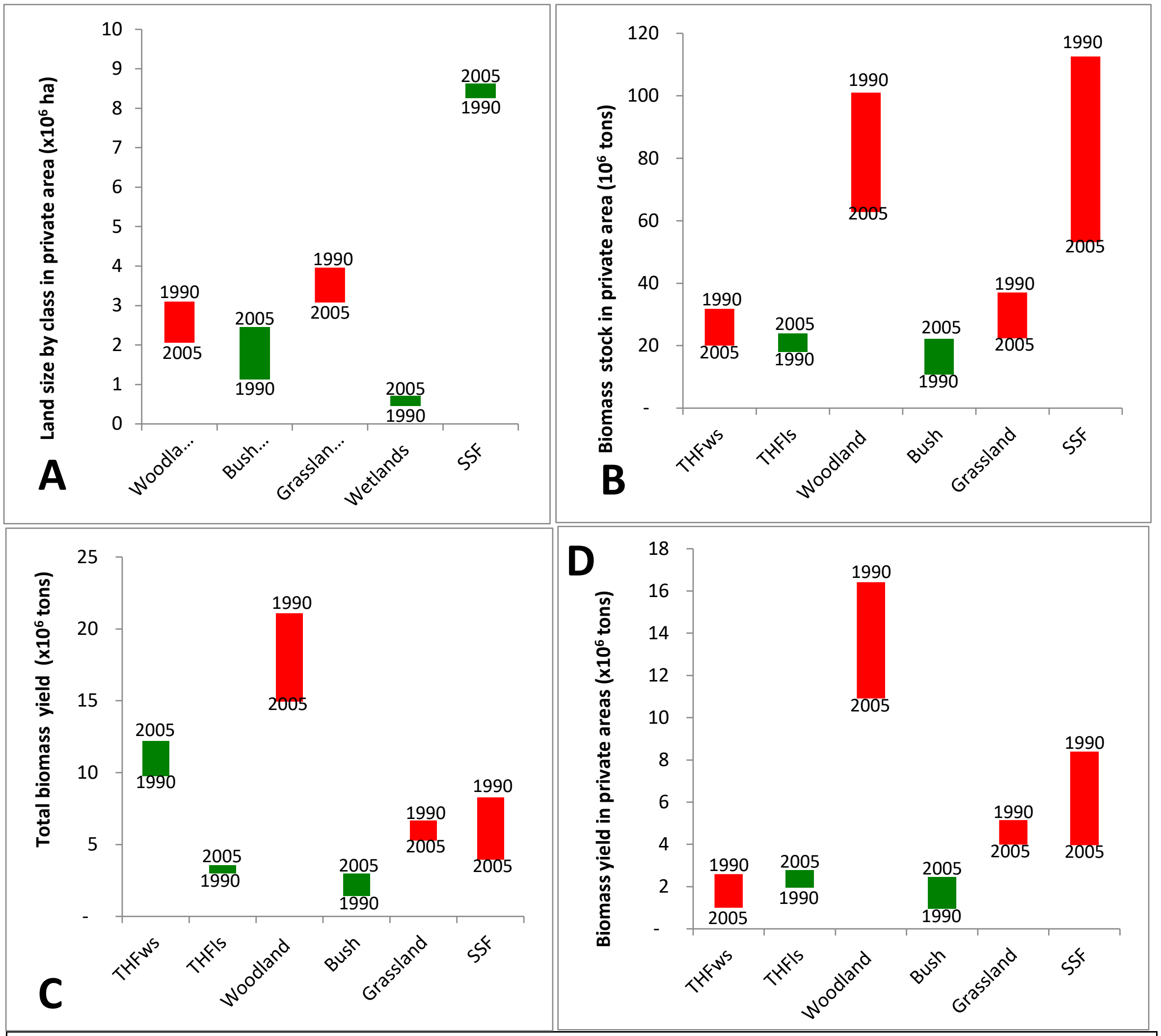

Figure 5.4: Land size in private areas (A), biomass stock in private area (B), total biomass yield (C) and accessible yield (D) in 1990 and 2005.

Green and red bars indicate increase and reduction respectively

Author, data from National Forestry Authority 1990 and 2005

Consequently, the four land cover classes in the private area – THFws, THFls, Bush and Grassland – were in the range of 20.0 – 20.9 million tons of biomass by 2005. The THFws would have been expected to have an increase rather than a reduction in the biomass stock because its mean stock increased by 64%, however, its size shrunk by 62% (Appendix A.5 on page 216), hence eroding any gains that could have arisen. Overall, the estimated increase in stock (from THFls and Bush) summed up to 16.6 million tons, whereas the decrease (from the THFws, Woodland, Grassland and SSF) added up to 124.3 million tons, leading to a net reduction of 34% or an annual decline of 2%.

In terms of stock estimates, this reduction from 313 million tons to 205 million tons is an annual loss of almost 7.2 million tons of wood. Taking the mean per capita consumption of 0.72 tons for biomass cooking energy for rural areas (estimating the round wood for firewood), this loss would be sufficient to meet demand for 10 million Ugandans. On the other hand, taking an estimated per capita consumption for 1.44 tons for urban population (estimating charcoal and firewood), this loss would be sufficient to meet demand for 5 million people. This loss of accessible stock was sufficient to cater for about a third of the entire population of Uganda which was 29 million by 2005.

The total biomass yield, including the one in the reserve areas (Figure 5.4, graph C) is calculated basing on the current annual increment. However, in the land cover classes where the mean standing stock has changed disproportionately the growth rate becomes unreliable. For example, it is possible to have the biomass stock increasing substantially, while the yield is shown to reduce drastically and vice versa. In a tropical natural forest where diversity of species plays a dominant role and the spacing of trees is almost non-existent - there is no systematic order, except the rule of competition. Moreover, mature or young trees tend to have lower yields compared to compared fast growing forest. To lessen this inconsistency, the biomass growth rate value has been adjusted in proportion to the change in the mean stock. So, the growth rate for the THFws and THFls has been increased by 51% and 61% respectively, which are the percentages by which their mean stock increased. For the same reason, the growth rate for the SSF has been reduced by 55%. The assumption for this is that the stock and yield change approximately at the same rate.

The overall biomass yield indicates an increase in 3 main land cover – THFws, THFls and Bush, and a decrease in the remaining three – Woodland, Grassland and SSF. In terms of quantity, Woodland produced the highest biomass yield by 1990. Though it was still leading the rest, its yields dropped by 29% made it the greatest loser of biomass (over 6 million tons) of all the land cover classes. SSF is the main loser of yields in terms of percentage (56%) and the second biggest loser in terms of biomass quantity (4.4 million tons). The least loser of yields is Grassland with a loss of 21% in terms of proportion, which is equivalent to 1.4 million tons.

In terms of gain, THFws had an increase in yield of almost 2.5 million tons of biomass, which is a 25% rise and bringing it closer to Woodland. In terms of percentage, Bush had the highest yield increase (over 100%), which made it the second highest in terms of quantity (1.5 million tons). THFls had the least yield increase in terms of percentage (19%) and quantity (576 thousand tons). Overall, the increase in yield from the tropical high forests (THFws, THFls) and Bush totals up to 4.6 million tons, while the overwhelming reduction in yield from Woodland, Grassland and SSF adds up to 11.9 million tons, leading to a net loss of 7.3 million tons. This reduces the gross biomass yield from 50.6 million tons to 43.5 million tons, which is a decline of 1% per year.

The pattern for the biomass yield in private area (Figure 5.4, graph D) generally has some aspects that mirror that of the stock in same area. In particular, changes in stock and yield tend to move in the same direction (increased stock leads to increased yield and vice versa). But there are also remarkable differences. First the yields tend to be much smaller, depending on the growth rate which is determined by the land cover class. Overall, the yields are almost 8 times smaller than the stock. Secondly, the yield is a function of fertility of the land. Thirdly, human activities can affect the yield in diverse manner. In general overview of the changes reveals more distinction between dynamics of the stock and of the yield. In principle, yield is not constant – it varies with a sigma-like curve, according to the age of the plant. Since there is so much diversity nothing can be uniform.

A comparison between the gross yield (graph C) and accessible yield gives more insights into the pattern of the changes. One remarkable difference relates to the yields in the THFws, which had a substantial gross increase of 2.5 million tons, while they underwent a reduction of 1.0 million tons in the private area. Since gross yields are the total growths in the private and the protected area, this divergent change may appear contradictory. However, it can be simply explained by the fact that there was a plentiful increase in the protected area that was much greater than the reduction in the private area.

This is not surprising since most of THFws are in the protected area – only 12% of the area covered by the THFws is private. Consequently, the increase in the yields in the protected area is because the biomass was intact, which enabled it to thrive, while the one in the private was greatly disturbed hence undergoing a reduction in its yield potential. In the private area THFws reduced by 42%, whereas THFls increased by the same percentage. The result is that the THFls which were only 75% of the THFws by 1990 increased to 183% by 2005.

Woodland still remained the main contributor of biomass yield by 2005, not only for the gross but also for the private yield, despite the fact that it is the land cover with the highest reduction in yields (5.5 million tons equivalent to 1/3 of its yields) during the 15 year period. SSF, which was the second supplier of biomass in terms of yield in private area by 1990, became the second biggest loser, having its yields slashed into half and contributing almost the same quantity as Grassland by 2005.

Bushland had yields that were slightly less than 1 million tons and only half of those of THFls by 1990. Yet the yield increased by 2 ½ times by 2005, making Bush the land cover class with highest growth in terms of proportional raise and becoming only slightly lower than THFls. The increase in yield over a period of 15 years from the THFls and Bushland amounted to 2.3 million tons. This would increase only slightly to 2.6 million tons if the tiny yield from the LSF were added. On the other hand, the reduction in yield from the rest of the land cover totaled up to 12.1 million tons. This gives a net reduction in yield of 9 million tons. Since yields are the ultimate measure of sustainability of biomass this reduction in yield from 35 million tons in 1990 to 26 million tons in 2005 (net annual loss of 1.8%) is a strong signal that biomass is facing a serious degeneration. Increase in charcoal prices is an alternative measure of wood scarcity. A sack of charcoal, which used to cost between 28,000 – 30,000 Ug Shs went up abruptly in a span of two weeks to 60,000 – 70,000 UgShs (Nantaba, 2011).

5.1.3. Land Cover Distribution by District

Apart from the land cover size presented above, distribution equally plays an essential role in determining biomass consumption and sustainability because in most cases biomass production, supply and consumption take place within the same locality, especially in case of fuelwood which is the main cooking fuel. Although this locality is much smaller, it is important to consider the distribution at a higher local government level: the district.

There is no standard size in district because of the diversity of factors considered in creating the district, ranging from the population size, political interest, demographic composition, economic activities, etc. By 2005, there were 80 districts and Appendix A.5, page 216 shows the district names and sizes in terms of area. The district area ranges from 19,700 ha (the capital city) to 1,265,581 ha, with a mean of 301,942 ha and standard deviation of 243,204 ha. **Figure** 5.5 shows distribution of the different aspects of the district in relation to land cover and size.

In **Figure 5.5**, graph A is a histogram of the district Area. In this histogram (as well as the subsequent ones), the upper rather than the lower boundary is included. Accordingly, almost a fifth of the districts has a relatively small area that does not exceed 100,000 ha, while 10% has a large area exceeding 600,000 ha. Both the mode of 200,000 ha and the median of 233,594 ha (graph C) are less than the mean, indicating that the distribution of district size is positively skewed. In other words, most districts have relatively small sizes, but there are a few of them with disproportionately big sizes.

District size does not depend on the population. Overall, the district size is determined, among other things, by the political support for the ruling party. Where the party has low support, the government has no interest in creating new districts. Where there is strong support that is where many districts are created. The creation of new districts means that several MPs will be made available for the ruling party. But in creation of new district the government says that it wants the services to reach the people – decentralization.

While the proportional size of each land cover class may be given in terms of its aggregated area as a percentage of the country size (as discussed before), its distribution may be assessed by the number of district where it is existent as a percentage of the total number of districts. The two measures of size and distribution tend to show no relationship in pattern as can be visualized in the **Figure 5.5**, graph B.

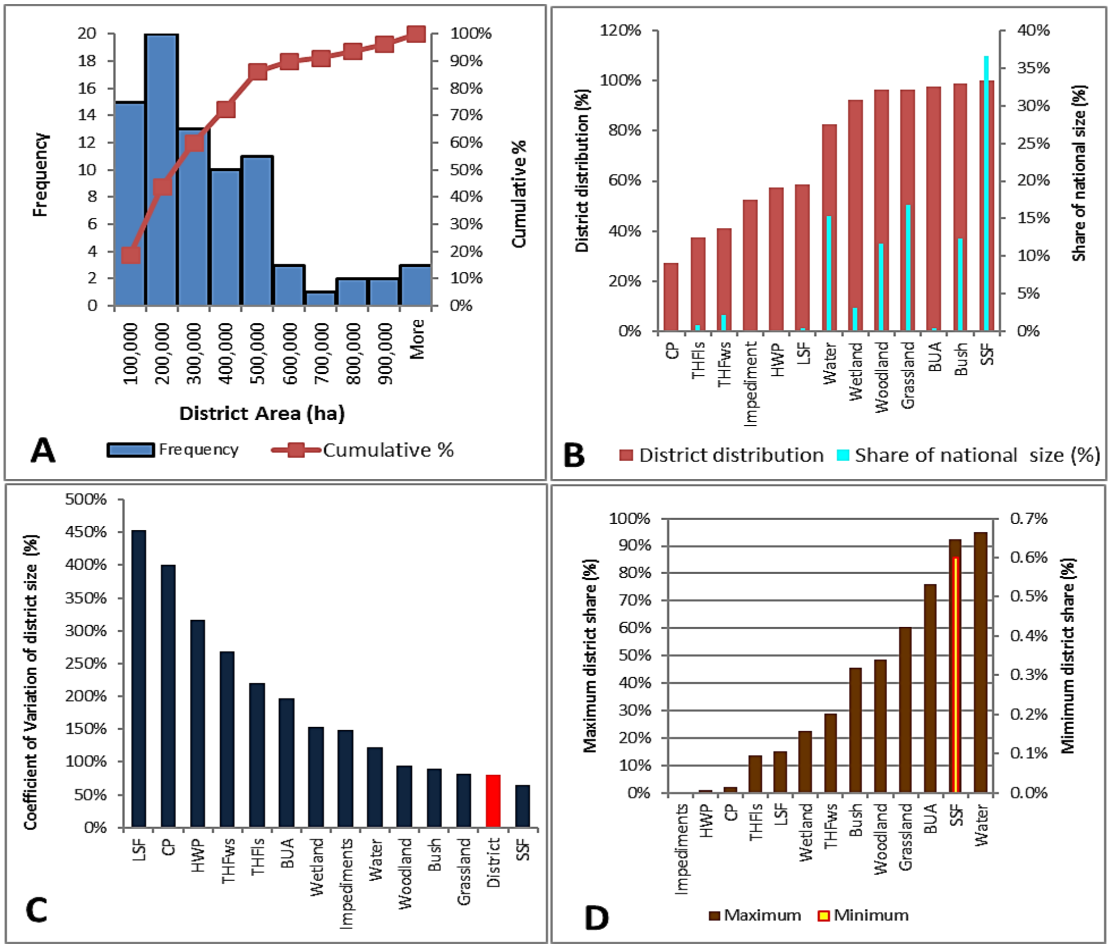

Figure 5.5: Frequency, distribution and size, coefficient of variation and maximum and minimum district sizes.

Source: Author, data from National Forestry Authority 1990 and 2005

The SSF, which takes the national land share of nearly 37%, happens also to be the only one which is distributed in all the districts of Uganda (100% distribution). But the second most distributed land cover type is Bush (99%), which ranks fourth in terms of share of the size (12.3%). The built-up area, being third in terms of distribution (98%), takes an insignificant share of 0.4% in regard to size. Woodland – the fourth in terms of distribution (96%) – is fifth in relation to land share (11.7%), whereas Wetland – the fifth in relation to distribution (93%) – is sixth in terms of land share (3.1%). Then the open water which is sixth in terms of distribution (83%) happens to be the third in terms of land share (15.3%). The seventh, eighth and ninth are LSF (59%), HWP (58%) and impediments (53%); but these three occupy an insignificant land share of 0.4%, 0.1 and 0.0 respectively. The rest of the land cover types are distributed in less than half of the districts and their share in terms of land size is less than 1%, except the well-stocked tropical high forest that has a land share of 2.2% and a distribution of 41%.

From the comparison, it is clear that there is no direct association between size and distribution of land cover types. Undeniably some land cover types are significant in terms of land size and very much distributed among the districts; yet there are those with high distribution but insignificant total land size and those with reasonably big land size but concentrated in few districts. The supply is sufficient when the land cover type with sufficient biomass stocking is adequately distributed in all locality (districts and lower units); and sustainability occurs if this status can be maintained and continued to the future generation.

The specific size of each land cover type by district may not give much information in terms of comparison even if the mean is generated per land cover. This is because the districts do not have a standard size. While the smallest district has only 19,700 ha, the largest one is 1,265,581 ha in size. A more indicative value would be the area of each land cover in each district as a percentage of the area of the district. The mean would be similar to the percentage share of the national size in **Figure 5.5** B, whereas the Coefficient of Variation (CV) for this percentage is shown in **Figure 5.5**, graph C. This graph includes the CV for the district size, which provides a comparison with the land cover classes. The SSF which covers a mean proportion close to 37% of the district area (graph B) has the least variation in mean share – CV = 50% – (graph C) compared to the rest of the land cover classes. It is the only land cover class whose percentage size varies even less than the disparity in district size. So, the subsistence farmlands are the most evenly distributed land cover class in terms of proportionality to the district size. This suggests that it is the most important land use.

The CV Grassland, Bush and Woodland are greater than that of the district, but they are less than 100%. The rest of the land cover classes have CV that is more than 100%. If all the districts are considered, the BUA would have the highest CV of 2105%, but Kampala City, the smallest district, is an outlier that has been excluded because its BUA is extreme (76%), being followed by its neighboring district, Wakiso (5.3%). Actually, Kampala City is expanding into Wakiso district as it is increasingly becoming the main residential area for a big population of those working in Kampala. On the whole the vast majority of the district (94%) has BUA of less than 1%. Excluding Kampala leaves the LSF, CP, HWP, THFws and THFls as the first, second, third, fourth and fifth land cover class with the highest variation in share of the district size.

Moreover, the same **Figure 5.5**, graph D showing the maximum and minimum percentages for each land cover indicates that all the land covers have a minimum of 0 except SSF. In other words, the rest of the other land cover types are found in some rather than in all the districts. That partly explains why the rest of the land cover classes vary more than the variation in district size (CV 81%). Because the SSF is most available throughout all the districts, the abundance, scarcity or fluctuation of biomass within it is essential in answering the question of sustainability of cooking energy in Uganda.

Other land cover classes with sizable area, but relatively distributed are Grassland, Bush, Open Water and Woodland which have a mean of 12.9%, 11.2%, 9.0% and 8.9% respectively, but their distribution varies a lot. While the Bush and Grassland are more fairly distributed as seen from their CV of 98% and 108% respectively, the Open Water has a CV of more than 200%. The rest of the land cover categories have a low mean and a very CV as seen in the graph in C. This means that their mean size and distribution among districts is not very relevant in generalized assessment of the sustainability status. Altogether together, the absence of a land cover class occurs in 27.8% of the districts.

5.1.4. Biomass Growth and Yield

Taking the district land cover area 2005 (Appendix A.5, page 216) CAI is computed and the resultant yield by district is obtained (corresponding to the sustainable yield). It is this yield whose comparison with the demand assesses the sustainability of biomass consumption. Taking the firewood consumption of 0.68 kg per capita which is the figure for rural areas and considering charcoal consumption negligible, the demand is calculated according to the projected population for 2005, based on 2002 population census[13]. Then demand is subtracted from the yield to give the balance that indicates the status of sustainability per district.

A positive balance indicates that the consumption is still sustainable; a zero balance indicates an equilibrium state; a negative balance indicates unsustainability. This method gives the specific quantity of biomass balance. Another method is to use a yield to demand ratio which indicates specifically how many times the biomass supply is greater than the demand. A ratio greater than one 1 indicates sustainability, since yield is greater than consumption; therefore 1 indicates equilibrium and less than one indicates unsustainability (consumption exceeds yield).

Both of these calculations have been made for each district and given in Appendix A.5, page 216. However, it is noteworthy that the assessment has been made in relation to firewood consumption. In practice, however, there is a certain quantity of charcoal that is consumed too especially in the urban areas. If this is considered, the demand would be higher relative to supply. Secondly, the yields considered are those possible from an undisturbed area, except Kampala, which is primarily a built-up area and has no part that is not subject to disturbance. So, the calculations for Kampala have been those related to the disturbed area.

In practice, however, almost all areas in Uganda are subjected to disturbance but the extent varies and may not easily be determined. In addition, the yield calculations include protected areas in the first scenario for two reasons. First, the biomass in protected areas could not be established. Secondly, people within the vicinity of the forest are allowed to collect some dry wood from protected areas as long it is dry and not for commercial purpose. The second scenario excludes the forest reserves. Despite the conservative calculations, which consider only firewood and even include the protected areas in the first scenario, the results of comparing demand and supply by district indicate deficit as seen in the negative balance or a yield to demand ratio less than 1.

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[13] The sensus conducted close to 2005 was taken considered in order to match demand and supply

Figure 5.6 A is a histogram showing the Yield to Demand Ratio by District (including protected areas). The histogram is positively skewed with a Pearson Mode Skewedness of 1.26, which is notably higher than the symmetrical distribution (for example a normal distribution which has a skewness of 0).

Since this is greater than twice the standard error of skewness (0.55) the skewness of the distribution is significant. This indicates that most values are concentrated on the left (as can be seen by the peaks to the left) of the mean, with extreme values to the right. This reveals the fact of disparity: most of the districts have biomass yield per unit demand that is less than the mean, but some few districts having extremely high biomass quantities. In this histogram (and the subsequent), the upper rather than the lower boundary is included. Since calculations have shown no district with a yield to demand ratio of exactly 1, the latter corresponds only to values lower than it (indicating cases where demand is higher than the yield).

Consequently, 22 districts (28% of the districts) had a negative biomass balance (unsustainability) by 2005. There are several definitions of sustainability and some contract each other. But according to Harlem Brundtland, 1987 a sustainable development is one which ensures that the current generation meets its own needs without compromising the ability of the future generation to meet its needs (Brundtland, 1987). With respect to biomass, sustainability ensures that the annual outtake does not exceed the annual increment. In relation to biomass energy supply, there are three aspects: reliability (security of supply), clean (environment) and affordable (economically efficient) (Wolter, 2004). Given that district boundaries are administrative and not generally include natural, topographical or demographic phenomena, the definition "sustainability" as positive biomass balance within a district is rather arbitrary. Nevertheless, it gives a hint to the population in the district that there is a biomass deficit.

Another equal proportion of districts had a yield to demand ratio higher than 1 but not more than 2. There were also a few districts (31%) with abundance of biomass that is more than three times their demand. Further, 20% of the districts have a yield of more than 5 times their demand; and at the extreme end of abundance, 4% of the districts have biomass yield of over ten times their demand. It is these districts with enormous quantities of biomass that pull the mean towards the tail of the distribution, making it higher than the biomass yield per unit demand for most of the biomass district.

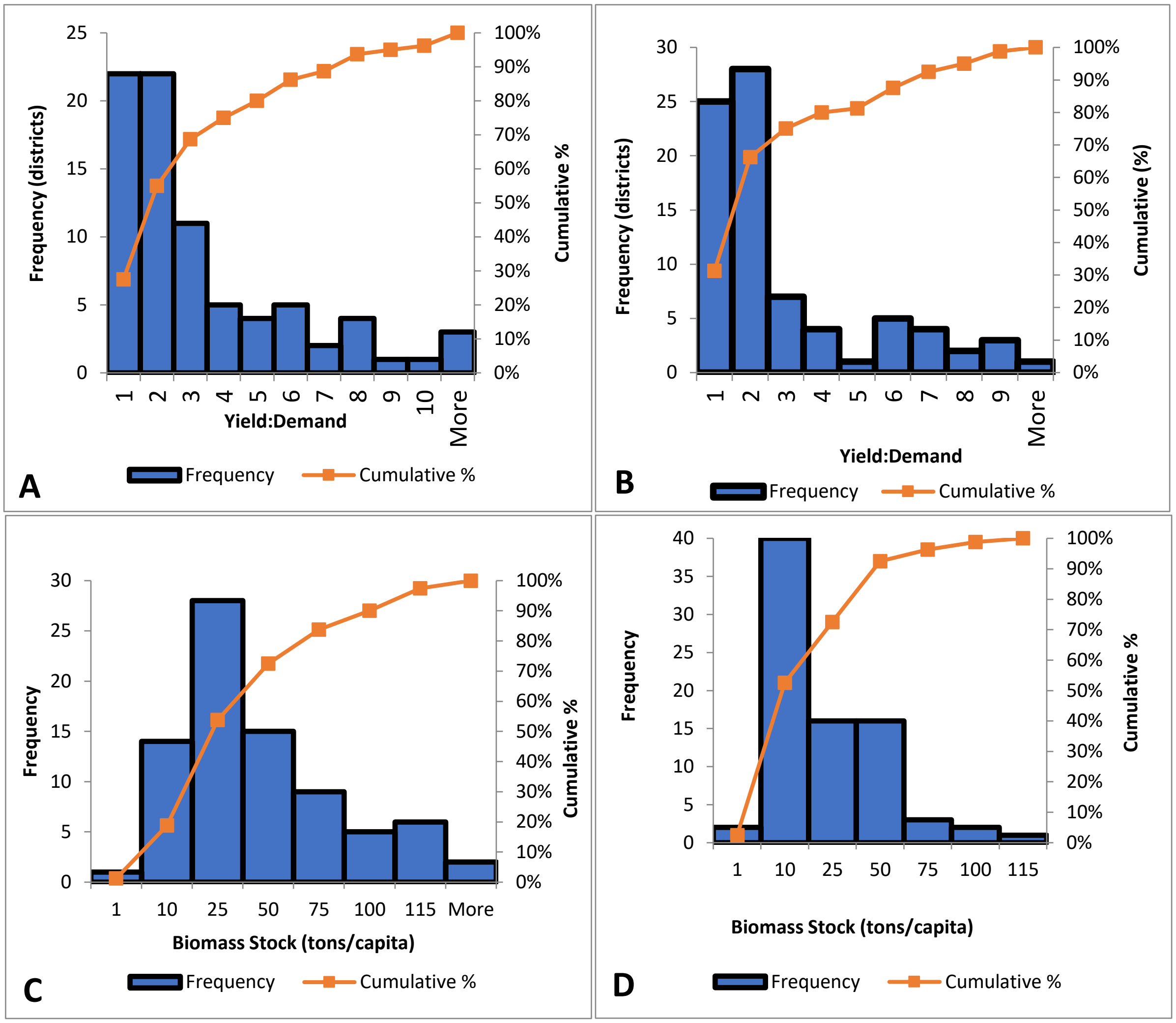

Figure 5.6: Histograms of Yield to Demand ratio with forest reserves included (A) and excluded (B); and per capita biomass stock for 1990 (C) and 2005 (D)

Source: National Forestry Authority 1990 and 2005

If the yield from the forest reserves is deducted the distribution becomes as illustrated in the histogram in **Figure 5.6** B.

Figure 5.6The shape of the histogram would remain the same (positively skewed) but the skewness would slightly increase to 1.31. Accordingly, the districts having a negative biomass balance rises to 31% and the proportion of districts having a yield to demand ratio higher than 1 but not more than 2 would rise to 35%. The districts with biomass that is more than 3 times their demand reduces to 25%.

The per capita (PC) biomass stock is one of the general indicators of availability and sustainability of biomass. A comparison of biomass stock PC of 1990 and that of the 2005 gives a more enlightening picture about the dynamics of biomass stock in relation to the population. Appendix A.7, on page 222 shows this table of Comparison of Biomass per Capita for 2005 and 1990 by District. The two histograms C and D in **Figure 5.6** reveal the key changes. A comparison of the two histograms shows that from 1990 to 2005 there is a general shift to the left of the peak of biomass stock PC, that is, the mode moves from 25 to 10 tons PC. The shift of the peak means that fewer quantities compared to the population were available. In 1990 only 19% of the districts had a biomass stock that did not exceed 10 tons PC. By 2005, the proportion of districts with this quantity had risen to 53% (a share which was almost corresponding to the districts with biomass stock PC of up to 25 tons by 1990). Moreover, 10% of the districts had biomass stock PC above 100 by 1990; by 2005, only 1% of the districts had biomass stock PC above 100 tons. Within this time period, however, there was only a slight increase in districts with per capita biomass stock of less than 1 ton (from 1% to 3%). To capture the pattern of this change, a correlation between the biomass per capita for 1990 and 2005 was investigated. **Figure 5.7** graph A shows this correlation.

There is a significant strong positive relationship between the biomass per capita for 1990 and for 2005, $r = .88$, $p = .001$. The coefficient of determination of $R^2 = 0.7766$ indicates that approximately 78% of the value of biomass per capita by 2005 can be explained by its previous value during 1990. Though part of the decline (22%) can only be explained by other factors, the correlation indicates that the district biomass per capita by 2005 was proportional to that of 1990. Hence those districts with a lower biomass per capita face the greatest risk or threat of crisis and those with abundance are most secure.

To obtain a more detailed investigation about the change in the biomass per capita the ratio of biomass stock per capita for 2005 to that of 1990 is computed per district. The resultant values indicate whether the district had an increase (value > 1), a decrease (less <

1) or no change (value = 1). This ratio too is given in the Appendix A.7. The histogram B in **Figure 5.7** reveals these values.

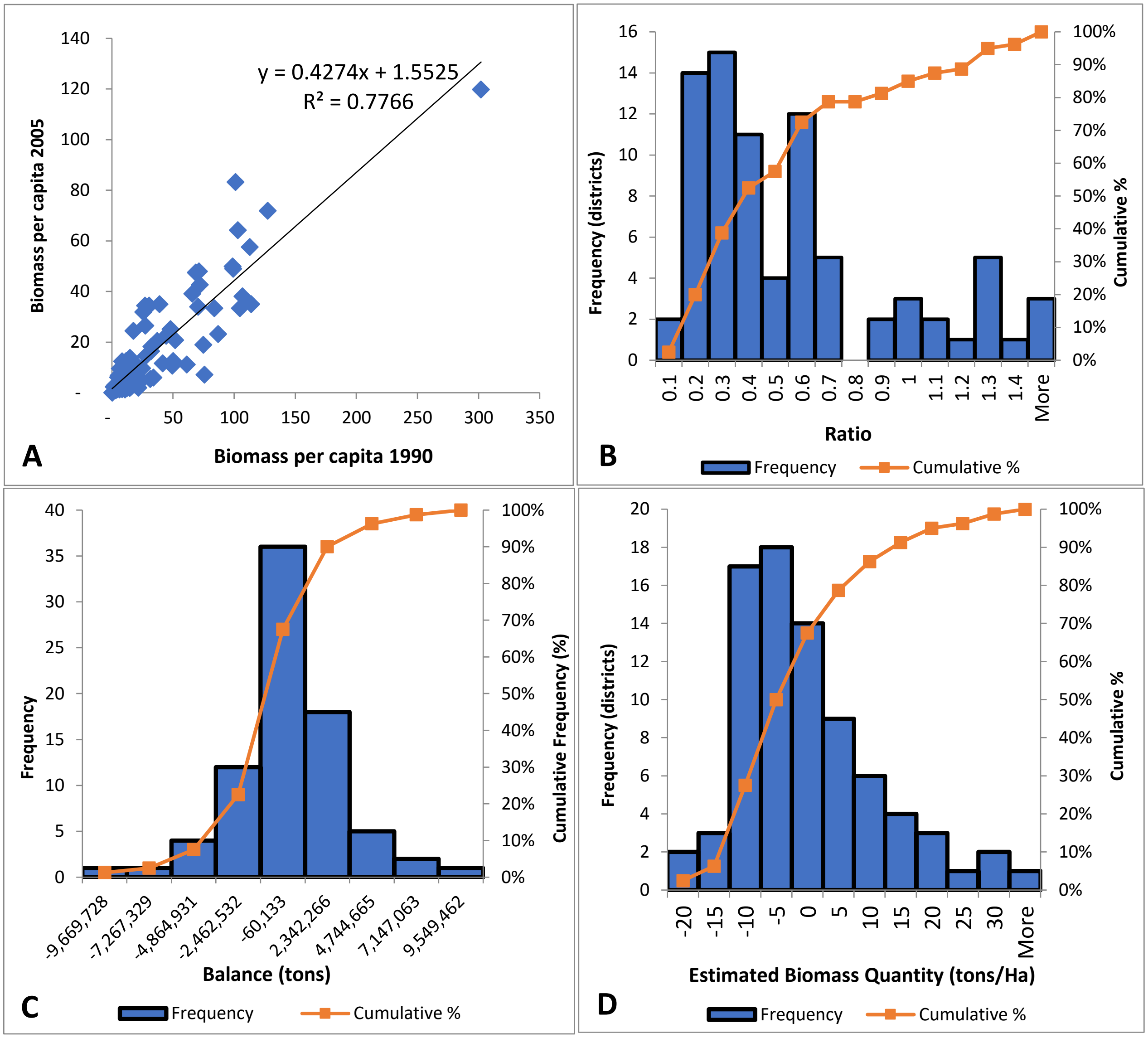

Figure 5.7: Correlation between per BPC 1990 and that of 2005 (A) and histograms for districts for ratio of biomass per capita for 2005 to that of 1990 (B), biomass change (C), biomass change per unit area (D).

The cumulative frequency indicates that up to 85% of the districts had a value of not more than 1. Since no district has a value of exactly 1, this great majority (85%) of districts had a decline in the biomass stock PC. The remaining districts (15%) had a slight increase which is a maximum of 1 ½. This measure of the stock in relation to the population is essential since it is the stock that generates the yield. Since the excess of biomass consumption above the sustainable yield ends up depleting the stock, the reduction in the latter is an implicit indicator of dwindling biomass supply. Though biomass stock PC is not a direct indicator of sustainability, it is a proxy one since there is no doubt that a sharp or continuous decline ends in depletion that is most likely to exceed regeneration.

5.1.5. Biomass change by district between 1990 and 2005

The estimated change in the total biomass stock per district and per unit area (hectare) is shown in Appendix A.7. In **Figure 5.7** the histogram C of biomass change by district between 1990 and 2005 is shown. The mode indicates that nearly 36 districts (45%) have lost between 60,000 to 2.5 million tons of biomass during this period. The cumulative frequency indicates that over 68% of the districts have a decline in biomass stock hence raising the sustainability concern. Coincidentally, the maximum loss and maximum gain is almost the same quantity (approximately 10 million tons). Kitgum district in the northern part of Uganda is the one which lost this amount, while Bushenyi district in the South West gained approximately this same quantity.

Because most biomass is consumed as firewood and it is too bulky to transport over a long distance, the surplus biomass in a district in the South may not be of much help to the district in the North. The exception is charcoal, whose energy density is higher. However, not all wood is appropriate for charcoal and not all people depend on charcoal for cooking. Moreover, the energy losses and environmental consequences of producing charcoal lead to a serious concern.

The change in biomass per unit area per district between 1990 and 2005 is given in the same **Figure 5.7**, histogram D. The distribution skewness (1.23) is greater than twice the standard error of its skewness (0.55), hence it is significantly skewed to the right, again confirming that the majority of the districts had a decline in biomass, though there are a few that gained an abundant quantity. The cumulative frequency corresponding to zero implies that 68% of the districts have a net loss per unit area (no district had exactly the same biomass per unit area within this period).

5.1.6. Business as usual Projection by 2040

Keeping the biomass growth rate, yield to stock ratio and population growth rate constant, and assuming the districts do not produce charcoal (they use only firewood which they generate locally), the projected trends of sustainability of biomass yield and stock in the districts of Uganda is shown in the graph in **Figure 5.8**.

The graph shows the district with sustainable yield (that is, demand is less than or equal to supply yield), district with positive balance on stock (demand is less than the stock of biomass supply) and district regaining sustainable yield due to tree planting effort. It is noteworthy that these tree planting efforts however laborious they could be may not exceed 4%. This is because the district which have lost biomass have adopted several economic options of which tree planting might be the least lucrative.

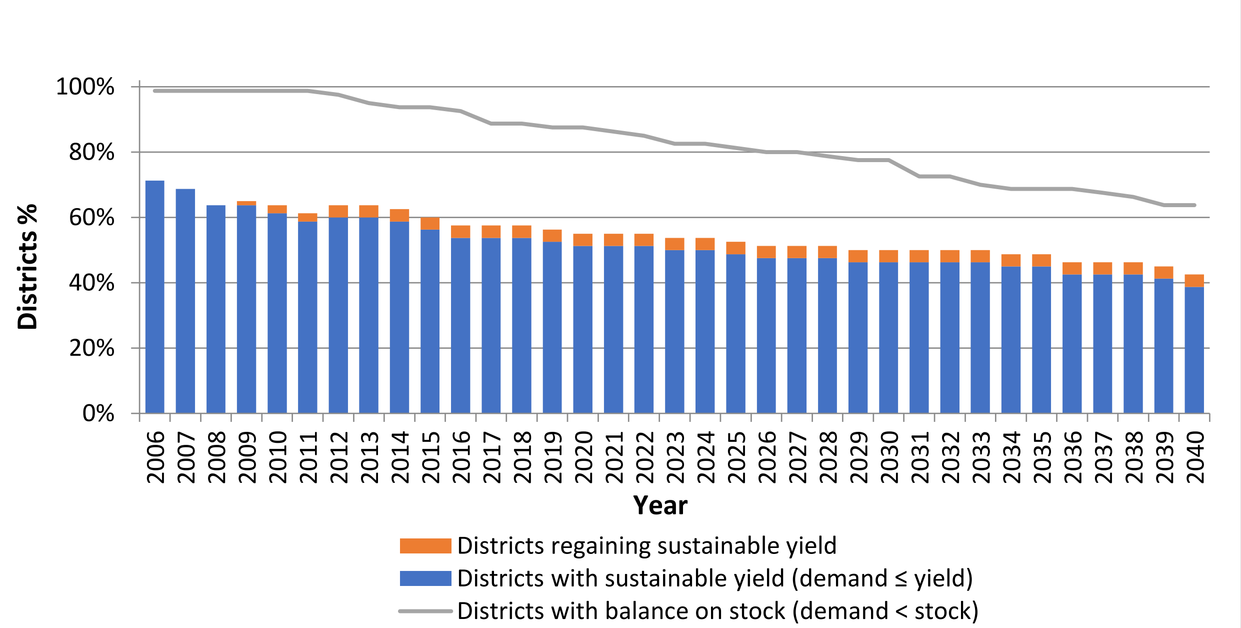

Figure 5.8: Projected Trends of Biomass Sustainability in the Districts of Uganda without segregating the districts into rural and urban setting.

Source: Author, data from National Forestry Authority 1990 and 2005

If each district is divided into two segments assuming the national proportion of urban and rural proportions, using projection made according to the estimates of the UN (UN, 2014), a gloomy picture is painted (**Figure 5.9**).

By 2006, 99% of the districts had sufficient stock to yield enough wood for biomass energy requirement but it is projected to decline as the population grows so that by 2040 at least 64 districts will not have enough biomass stock to meet their energy needs. Yet the biomass yield was negative for 71% of the districts by 2006 and it is projected to continue reducing to 43% of the districts by 2040 (this includes districts that are regaining biomass).

Though by 2005, 99% of the districts had enough biomass stock to yield sufficient wood for meeting the cooking needs of Ugandans, 61% of the district will face a declining biomass stock by 2040. Further, the biomass yield will even be smaller: by 2005 only 51% of the district had enough yield to replace the biomass stock, and by 2040, the districts having enough yield to replace the stock will be reduced to 29%.

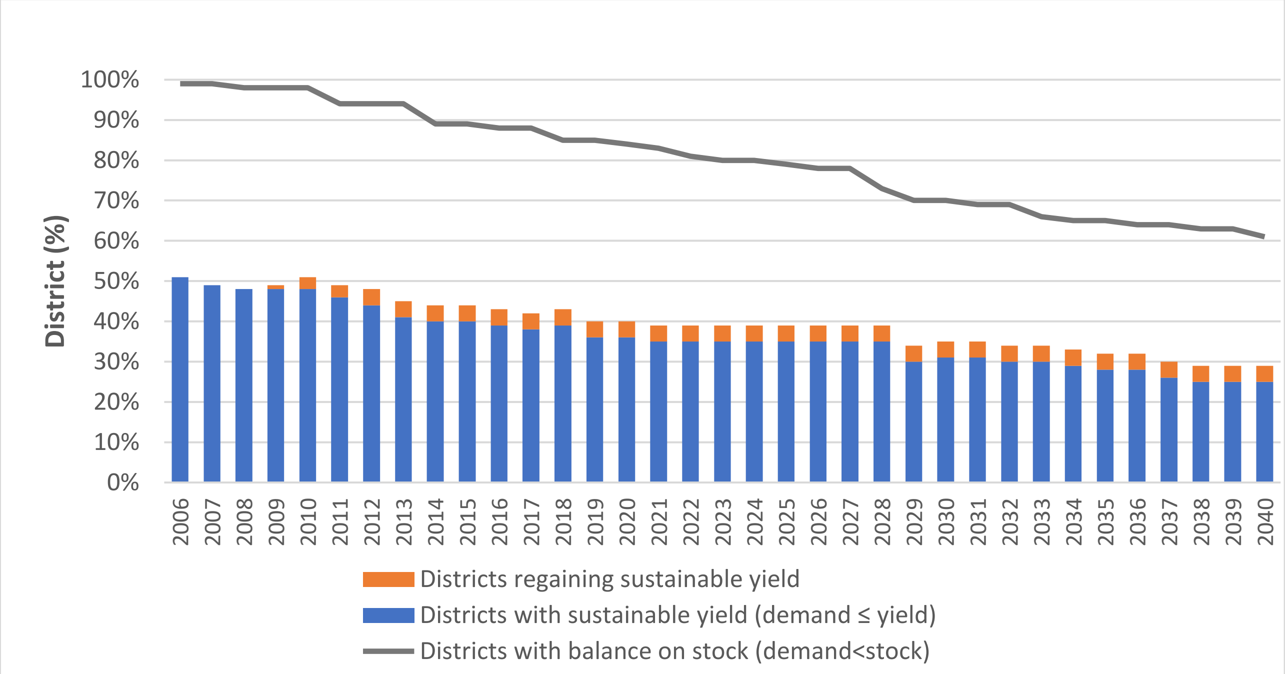

Figure 5.9: Projected Trends of Biomass Sustainability in the Districts of Uganda by Rural and Urban Areas. *Source: Author, data from National Forestry Authority 1990 and 2005*

5.2. Change in Relative Sizes of Land Cover

The growth (current annual increment) in tons per hectare per year is quite diverse: ranging from 1 to 15. However, to reduce this diversity there is need to reduce the land cover types from 6 to 13. The sizes are critically compared between the 15 years. The two land covers can be seen in **Figure 5.10**.

Then the remaining 6 land cover types are sorted according to their purpose. THF well stocked and THF low stocked are eliminated because they are majorly forest reserves. The remaining land cover types: grassland, woodland, bushland and small-scale farmlands should be used to estimate the maximum mean annual increment. This means it is for 5.3 tons per ha per year for woodland given that the rest have relatively little growth (small scale farmland, grassland and bushland have 1.98, 1.3 and 0.85 in tons per ha per year respectively).

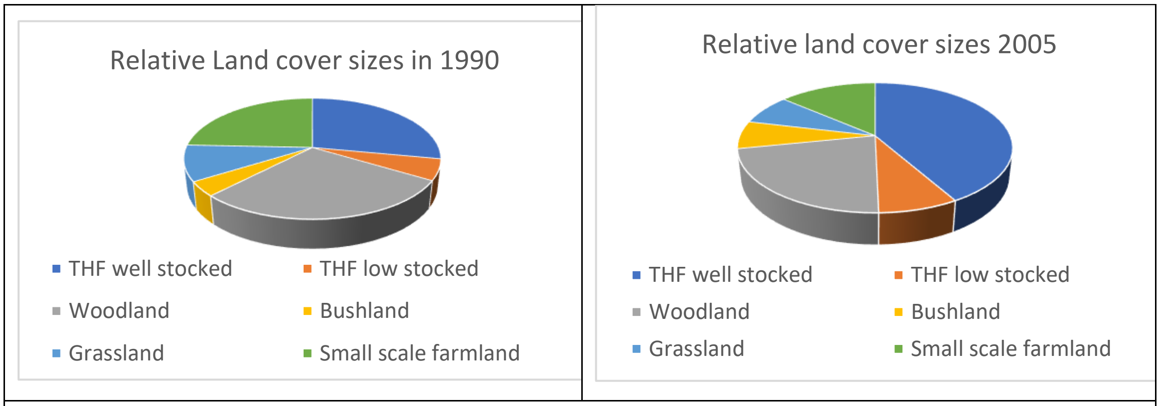

Figure 5.10: The relative land cover sizes in 1990 and 2005.

Source: Author, data from National Forestry Authority 1990 and 2005

Though such figures need to be taken with caution they are nevertheless the only available for use in the estimation of biomass. The other alternative is the use of the Mean Annual Increment which tends to give a more consistent estimate. The difference between the two is shown in graphic illustration in **Figure 5.11**.

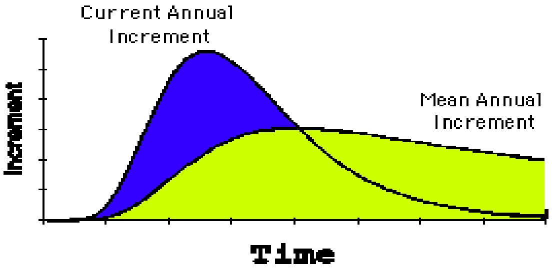

Figure 5.11: Difference between Current Annual Increment and Mean annual Increment (Tompalski, 2016)

5.3. Wood Energy Balance and Land Requirement

Assuming for the sake of maintaining biomass for cooking the deficit is produced by hardwood (deciduous) plantations like Eucalyptus, which is a common energy tree species in Uganda. The biomass density, which is an estimation of mean standing stock in tons or kgs per hectare is a very vital parameter in the quantification of biomass stock. Nevertheless, before proceeding to determine the quantity of biomass it is very important to assess the different parameters which indicate reliability. Reliability is assessed through the following statistics: Standard Deviation (StDev), Coefficient of Variation (CV), Sampling Error, Number of sample plots (N) and Confidence Limits. In this case the CV is a bit high (67%), but in comparison to other tree setting, it is just in the average range.

In terms of energy units (GJ), production of the energy crop (Eucalyptus) required to meet the energy demand will increase as the size of land available decreases, assuming the status quo. If the wood supply required to meet the demand is to be imported, it becomes too expensive. Then the choice has to be made between growing crops for consumption and growing trees for cooking (food versus energy). **Figure 5.12** is based on the total farmland (subsistence and commercial) by 2005, which was 8,961,300 Ha. That is, assuming no expansion and basing on the small scale (subsistence) farmland of 2005 of 8,854,670 Ha and assuming no much expansion.

As a comparison a study conducted in rural India indicates that with a cropping intensity of 1.5, the minimum land area needed to provide for food security when crop distribution is optimized is just over 2 ha (Ralevic, 2010). This places the area requirement at the border between the small and medium landholding categories. Using optimal crop selection and the current 164%[14] cropping intensity (fraction of the cultivated area that is harvested), small households having the average land area of 1.55 ha could potentially satisfy both the basic nutritional requirements within their households as well as the nutritional needs of up to 2 livestock units equivalents.

The per capita land for Uganda is already below this threshold even by the base year: overall of 0.29 ha or 0.34 ha if only the rural population is considered. By all means, it is just a 1/3 Ha - a meagre 15% of the minimum. The arable land per capita which had been 0.45 ha in 1961 diminished to a maximum (rural) per capita of 0.17 ha by 2015 (**Figure 5.13**). The situation becomes worse when the practical reality of unequal land distribution is considered. Several areas in Uganda testify to the tininess of the rural household farmland, which reduces as population increases.

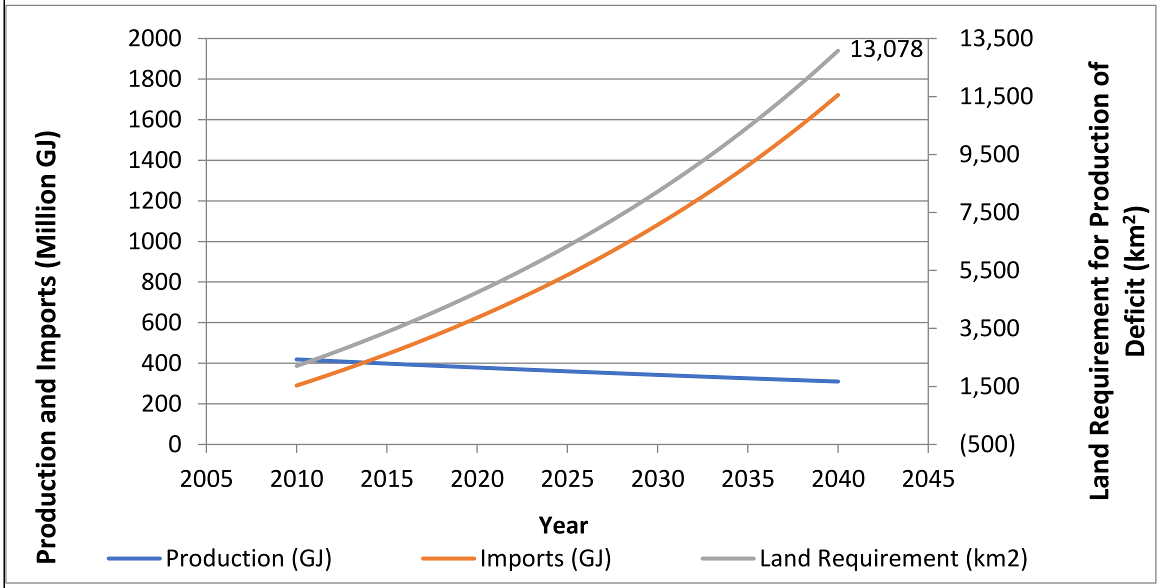

Figure 5.12: Wood Energy Balance and Land Requirement for Production of the Deficit

Source: Author's projection from National Forestry data of 1990

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[14] The cropping intensity may exceed 100% where more than one crop cycle is permitted each year on the same area.

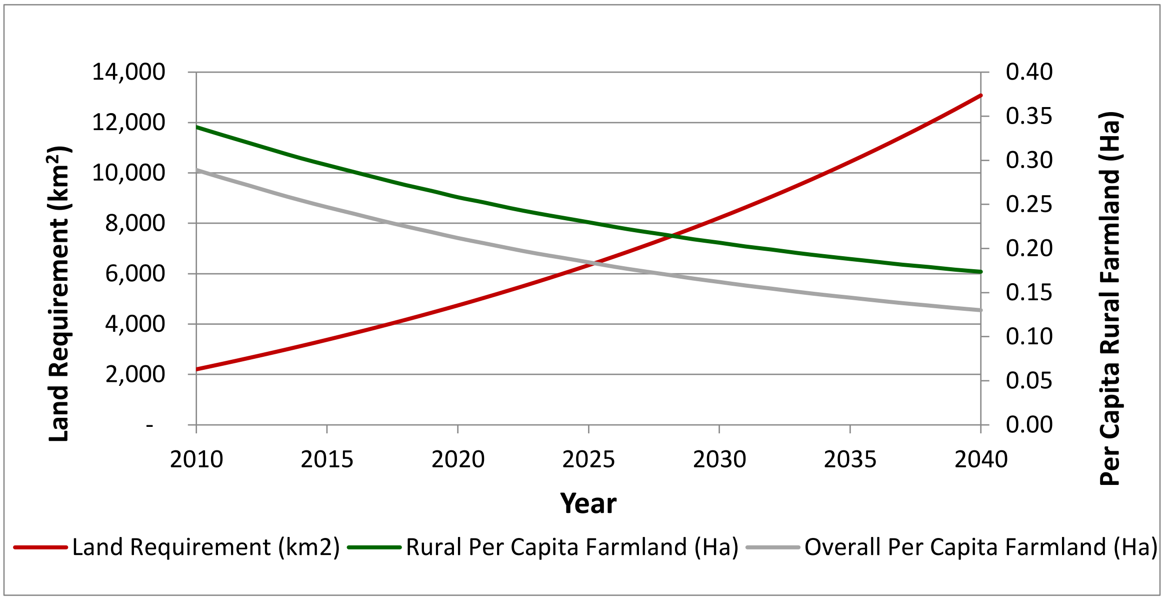


Figure 5.13: Land Requirement for Wood Energy and Per Capita Rural Farmland

Source: Author's projection from National Forestry data of 1990

5.4. Charcoal producing districts

The spontaneous breakdown of wood to produce charcoal is called carbonization. FAO applies a carbonization ratio of 6.6 Tons of wood per Ton of Charcoal for Uganda. However, the National Biomass Study group concluded that the average charcoal burner normally uses almost fresh wood as raw material (air dried from 1 – 15 days). The reasons given were: impatience, no real knowledge of the relationship between dryness and conversion efficiency, no strong motive for increasing the conversion efficiency, or that they find the kiln easier to control, which again reflects a lack of techniques and proper attention (Moreau and Cleemput). Consequently, a realistic conversion ration should be lower. “A Survey of the Earth Kiln Efficiency in Nebbi District” by Collins G. 1986 established a lower efficiency of only 10% by mass of the air-dried wood. This conversion ratio is the one used for most estimates in Uganda’ data. Since there is no indication of significant improvements in the charcoal subsector, over the decades, this figure is applied here also.

5.4.1. The Ten Main Charcoal Producing Districts

In order to assess the supply of biomass a deeper analysis has been done to investigate those districts where charcoal comes from. The source of charcoal consumed in the capital Kampala, are the 10 main supplier districts which include Kayunga, Kiboga, Luweero, Mpigi, Mubende, Mukono, Nakasongola, Wakiso, Masindi and Kamuli. Of these, the first eight listed belong to the central region of Uganda where Kampala is located. This is consistent with the observation that most of the biomass consumption tends to take place within the proximity of its production. Although this is more applicable to firewood because of the lower energy density, it also tends to be true for charcoal, though to a lesser extent.

Of the remaining two main charcoal producing districts one (Masindi) belongs to the West and the other (Kamuli), to the East. Even then, these two districts which are not part of the central region are actually neighboring some of the charcoal producing districts of the central region. Remarkably, the Northern Region, which is the farthest, has no main district that supplies charcoal to Kampala.

Of the 10 districts, the four most significant in terms of production quantity (≥10%) were Luweero, Nakasongola, Koboga and Mpigi, supplying 27%, 15%, 15% and 10% respectively. All these four districts which supplied a total of more than 2/3 of the charcoal consumed in Kampala belonged to the central region. The remaining quantity (1/3) is not produced only by the other six major supplying districts, but also "other" minor ones whose contribution provides 5% of the total.

Definitely there is no such thing as constant supply proportion. The supply can vary according to demand (population, ability and willingness to pay, and price), proximity to the supply, and scarcity. Assuming the same relative proportion of charcoal supply by the 10 districts, projection of demand subtracted from the yield (CAI) has been made to assess the sustainability. The forecast up to 2040 is given in **Figure 5.14**.

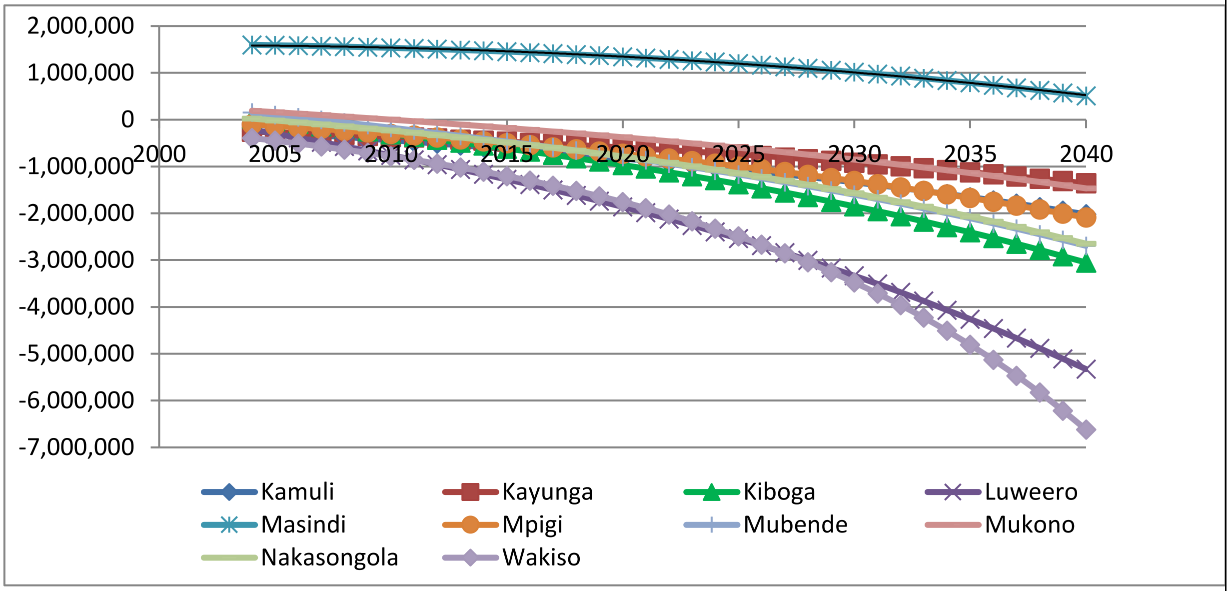


Figure 5.14: The Sustainable Biomass Balance of the 10 main charcoal producing districts

Source: Projection of data of Kisaakye

The trend shows a declining balance for all the charcoal producing districts. The rate of decline varies, being driven by the population growth rate as well of the rate of decline in biomass. Some, like Mukono district, are almost linear, while the majority has the trend of a smooth curve as they descend. Wakiso district has the fastest descending rate and is forecast to have a deficit approaching 7 million tons by 2040. No wonder it is the nearest district next to Kampala – to the demand centre. Nine of the ten charcoal producing districts are projected to have had a negative balance, meaning unsustainability by 2010. Masindi, the exception and the only district with increasing biomass yield, has the highest balance that enables it to persist as the only one with sustainability (positive balance) beyond 2010. Yet due to the consistently declining trend, it is at the verge of losing its sustainability by 2040 as seen by its dwindling balance of only half a million tons and not long after this period, it joins the other 9 districts in unsustainability.

5.4.2. Land Cover in the Charcoal Producing Districts

The ten main producer districts are not only different in total land area but also have divergent composition and size of the various land cover types as can be revealed in A.8, on page 226. A comparison of the type and size of land cover between 1990 and 2005 for each of the ten districts gives a clue of the pattern of change that is taking place. Since the change in the area of every district is regarded to be negligible, the reduction in size of one land cover type is equal to the increase in area of another (or others). In other words, a land cover does not disappear but changes from one form to another. This loss and gain in land cover area is given in the graph **Figure 5.15**.

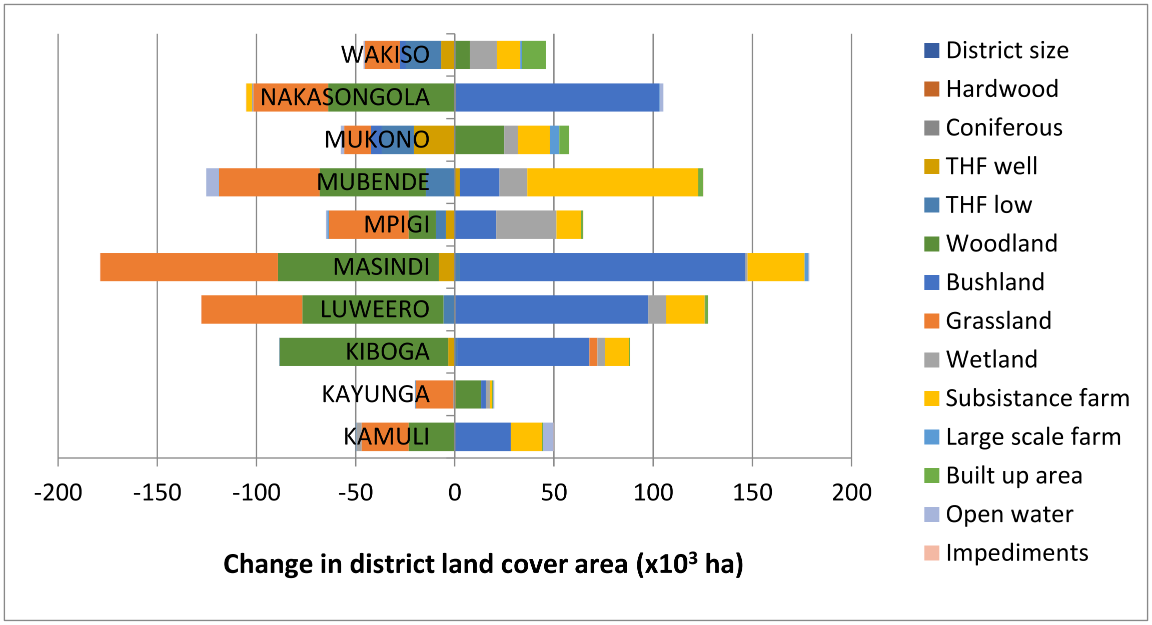


Figure 5.15: Loss and gain of land cover area in the 10 main charcoal producing districts between in 1990 and 2005. *Source: from data of Kisaakye*

From the graph, the districts have undergone various levels of change in their land cover. The top three with the highest change in land cover type are Masindi, Luweero and Mubende respectively. On the other hand, Kayunga remains relatively stable with the least change in land cover type. Six of these districts have a pattern of losing a combination of woodland and grassland and a gain in other land cover types, including Bushland. This pattern becomes hard to assess since biomass stock is higher in woodland followed by Bushland and lower in Grassland. This aggregation is given in **Figure 5.16**.

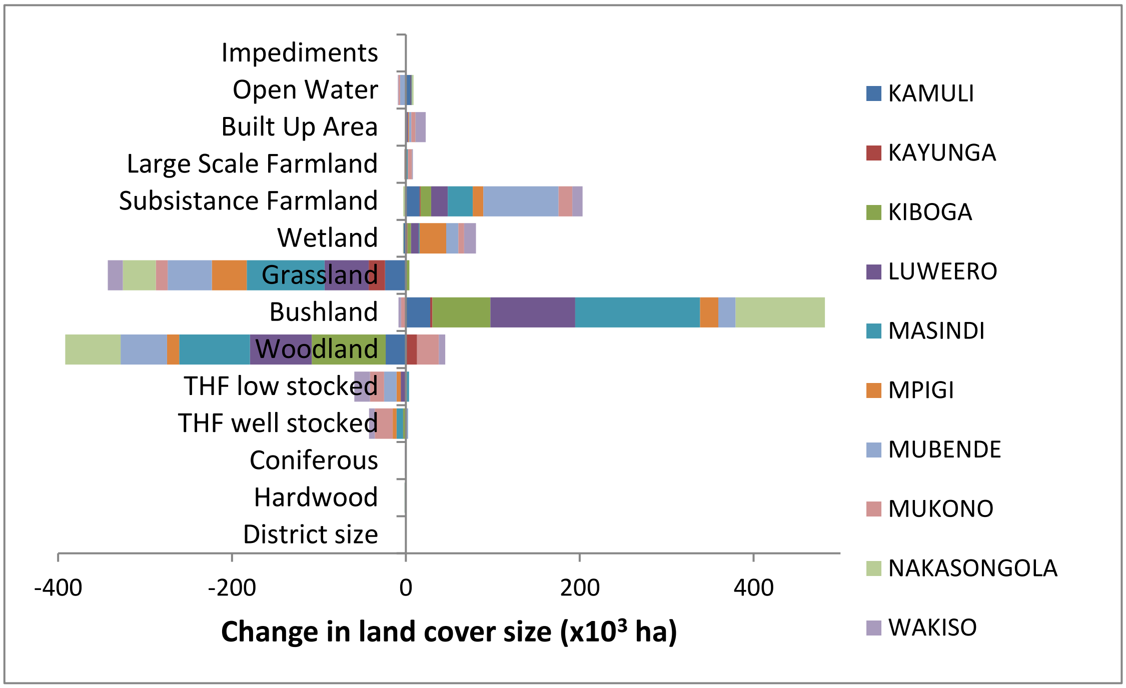


Figure 5.16: Accumulated change in each land cover size (Ha) in the 10 main charcoal producing districts between 1990 and 2005. *Source: from data of Kisaakye*

Therefore, this mode of loss and gain would indicate that a change from grassland to Bushland would be a gain in biomass stocking, while and change from woodland to Bushland is a loss. To obtain more insight the combined change of each land cover in all the ten districts is considered.

The cumulative change shows that Bushland has gained the highest amount of land, followed by the Subsistence farmland, while Grassland and Woodland were the highest losers of land. The change in district size and the wood plantations and impediments remained almost unchanged. Change in the size of the rest of the land cover types is fairly less. But since the land cover types don't have similar coverage the change in specific size may not necessarily reflect how dynamic they are. Therefore, the change in proportion to their previous (1990) size gives further impression. A percentage change in the land cover type gives a picture of how much each land cover has expanded or diminished compared to its original size. **Figure 5.17** shows this reality.

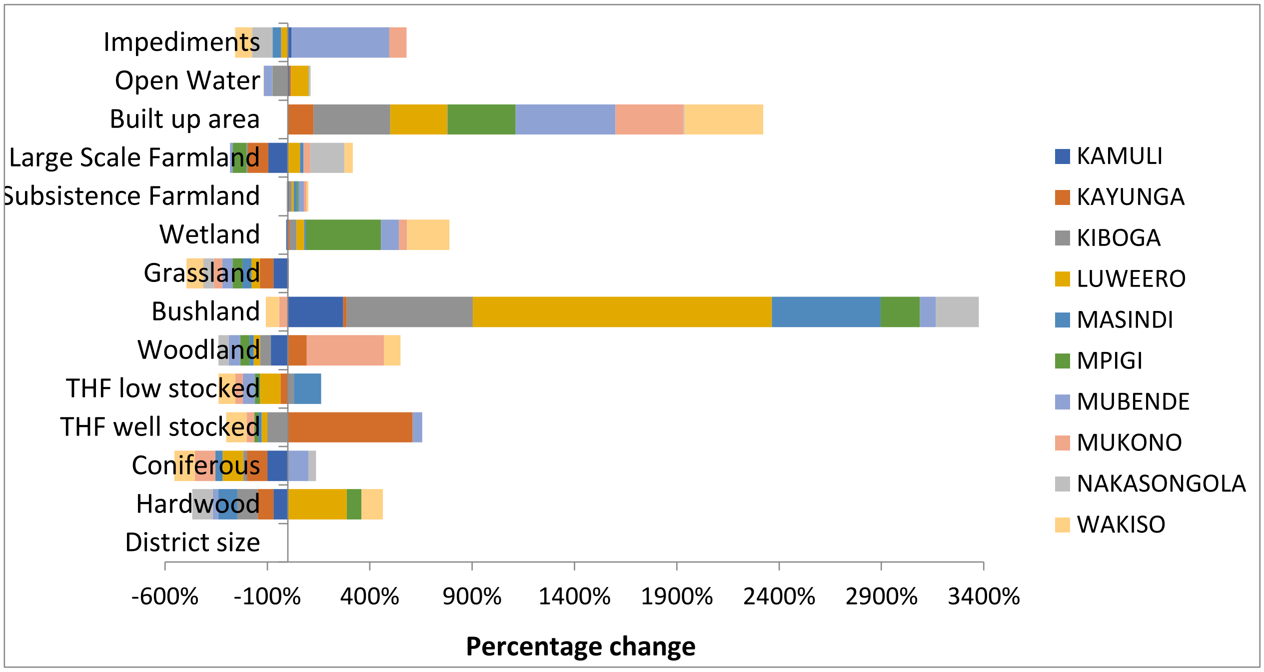


Figure 5.17: Percentage change in land cover area between 1990 and 2005.

Source: from data of Kisaakye

Accordingly, Bushland still takes the top position with an expansion rate of almost 3300% which would indicate, on average, an annual doubling of its size per year in 15 years. The second land cover type with highest expansion rate is Built Up Area with more than 2300% which is an annual increase of 1 ½ times its original size; yet in specific size this increase is nearly 21 times less than that of Bushland. On the other hand, Subsistence Farmland, which is the second largest in expansion in terms of area, is minor in terms of percentage change, with an increase of 94%. Though the percentage increase is tiny in each district, it increases in all the districts except Nakasongola, where it has a minor decline. In contrast, Grassland declines in all districts except Kiboga where it increases slightly.

Although change in the land size is a measure of expansion or shrinkage of a particular land cover it does not necessarily indicate the biomass change in terms of quantities. Biomass per land cover in the 10 main charcoal producing districts in 1990 and 2005 is given in the Appendix A.9, on page 227. The change in biomass during this period is given in **Figure 5.18**.

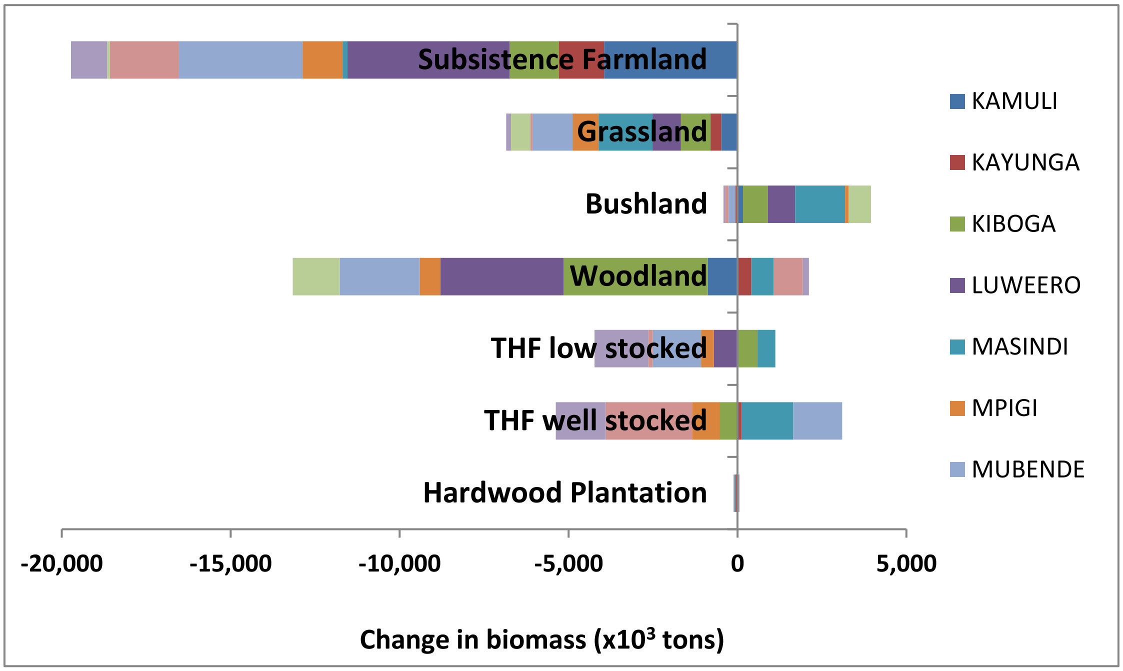


Figure 5.18: Accumulated change in biomass by land cover in the 10 main charcoal producing district between 1990 and 2005. *Source: from data of Kisaakye*

Subsistence Farmland and Grassland lost biomass in all the ten districts, while the rest of the land cover had a loss in some district and gains in others. The balance indicates that only Bushland had a net gain. This means, six out of the seven land cover categories with substantial quantities of biomass had a net loss of it. The greatest loss of biomass was in the Subsistence Farmlands, which was close to 20 million tons, followed by the Woodland whose net loss is over 11 million tons. More elements of this variation are captured by considering biomass change by district (**Figure 5.19**).

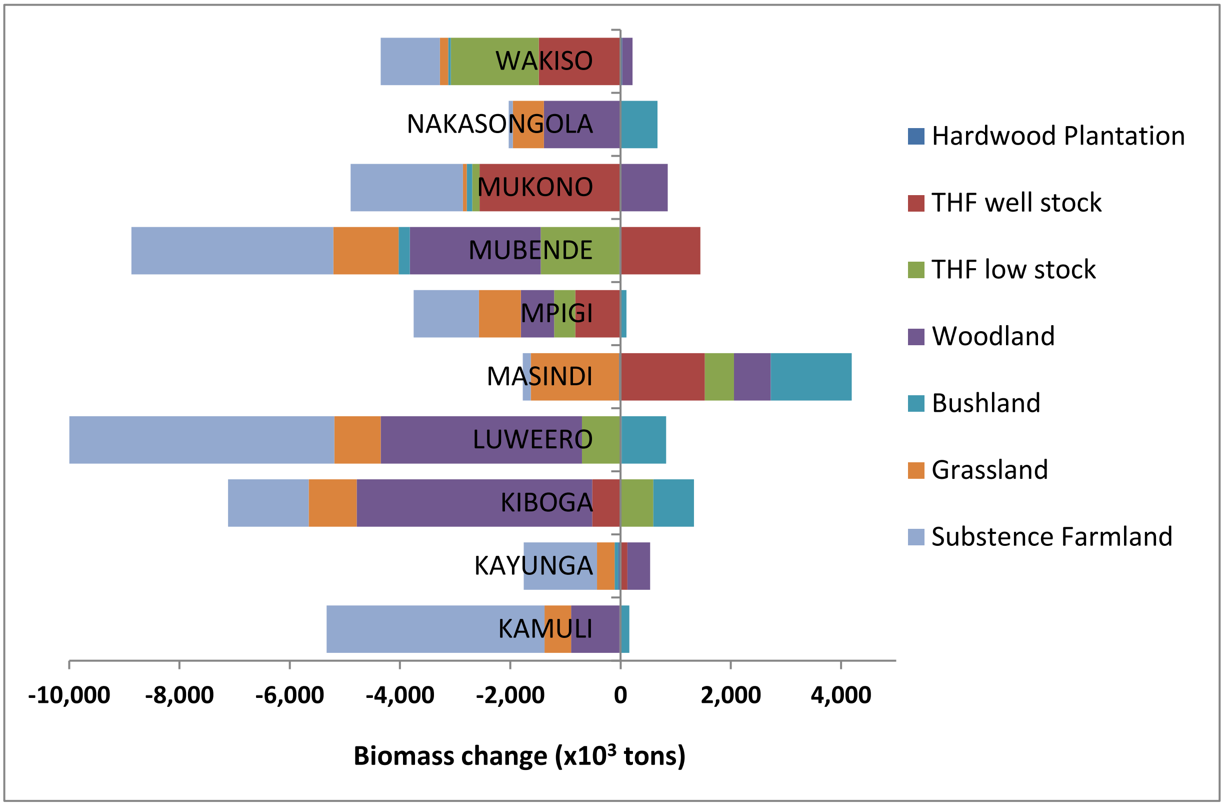


Figure 5.19: Biomass change by district in the 10 main charcoal producing districts between 1990 and 2005. *Source: Author, Data based on data from Kisaakye*

All districts had a loss in biomass from certain land covers and a gain in others. However, 9 out the 10 districts had a net loss. Only Masindi had a net gain. The change in biomass can also be echoed by comparing the mean stock per unit area by district and land cover for 1990 and 2005.

The graph in **Figure 5.20** shows biomass density by district for 1990 and 2005 in tons per hectare in the 10 main charcoal producing districts. Masindi is the only district that remained with nearly the same biomass density. Mukono district, which was leading in biomass stocking by 1990 had its density reduced by more than 5 times; Wakiso had its stocking reduced by 4.5 times; Kamuli it reduced by 4 times. From another perspective, biomass density per land cover gives a picture of how the change is taking place.

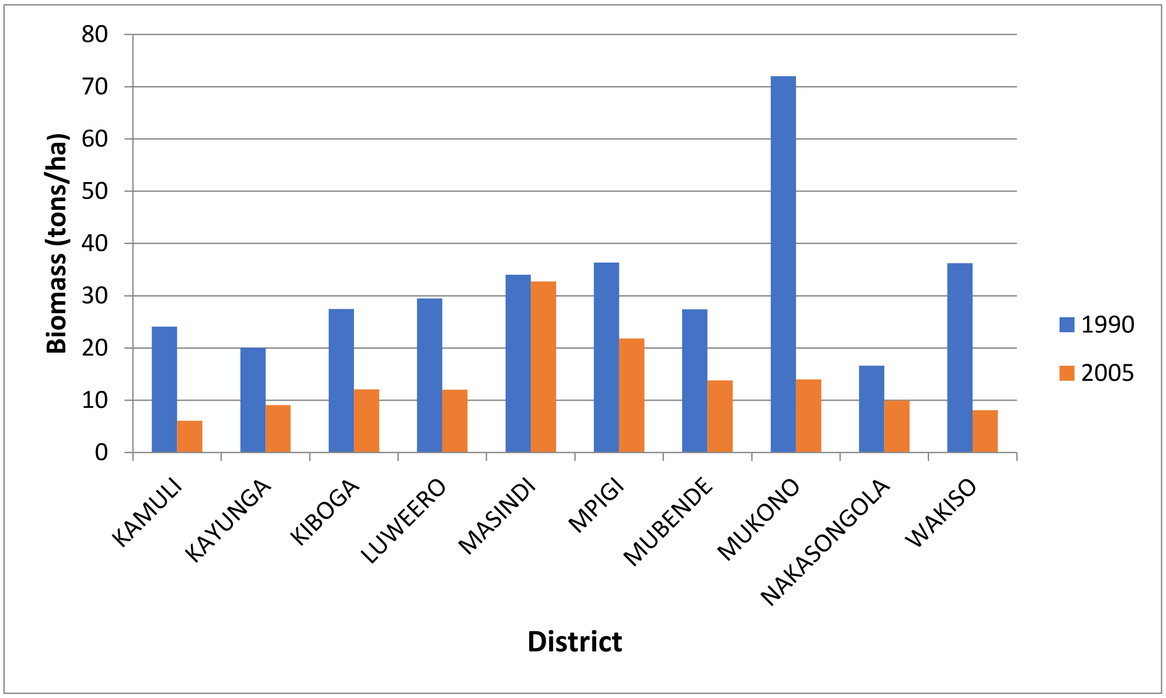


Figure 5.20: Biomass density by district for 1990 and 2005 in the 10 main charcoal producing districts. *Source: Data from National Forestry Authority 1990 and 2005*

The graph in **Figure 5.21** shows the biomass density by land cover for the same districts. The tropical high forest increased in biomass density. The woodland never changed, while Hardwood plantations reduced only slightly. The rest reduced substantially compared to their original sizes.

This change in biomass per unit area in each land cover by district is represented in **Figure 5.22**. The outstanding increases and decreases are the THF of the two categories. The greatest increase in THF well stocked was in Mubende, followed by Masindi, while the greatest reduction occurred in Wakiso, followed by Kiboga. Increases in THF low stocked occurred in Kiboga, Masindi, Wakiso, Mukono and Kayunga, while the greatest decline occurred in Luweero. Kamuli and Nakasongola districts which don’t have these two categories of THF had reductions in the biomass stocking in all their existing land cover types. In most of other land cover types there were more reductions than increases. Theoretically, the 10 major charcoal producing districts, each with a prospect of having 7 main land cover types would generate a total of 70 possible land cover subcategories.

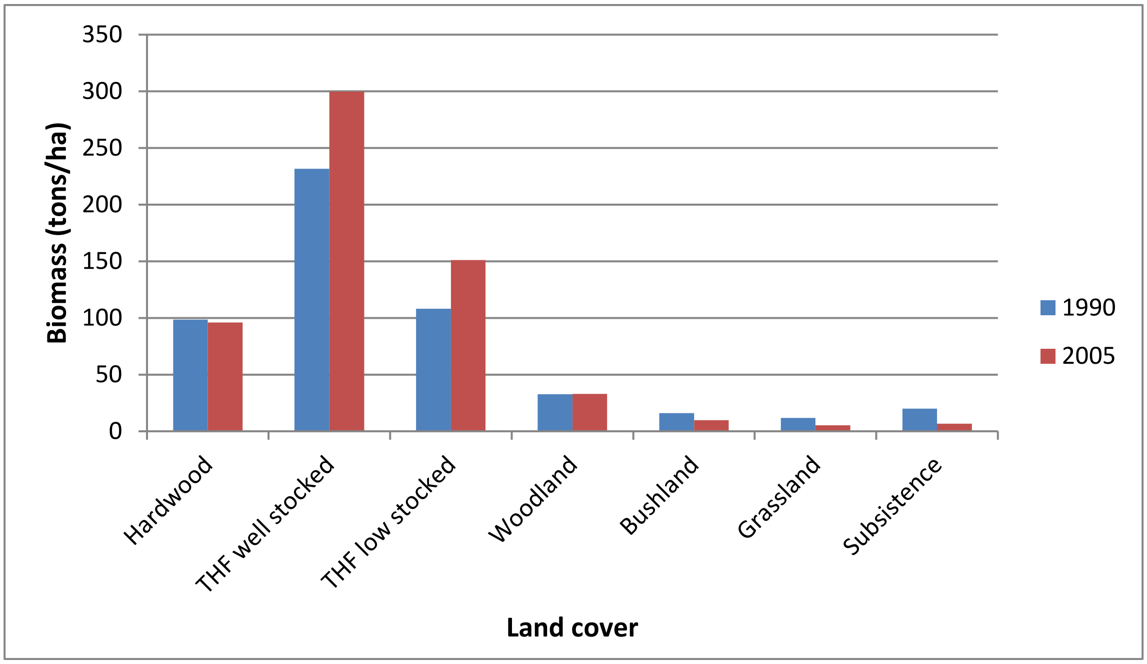


Figure 5.21: Biomass density by land cover for 1990 and 2005 in the 10 main charcoal producing districts. *Source: Data from Kisakye.*

But practically, certain land cover types were not existent in some districts. In particular, Nakasongola had no Hardwood plantation; and besides like Kamuli, it did not have the two categories of THF. That makes it 5 missing land covers subcategories. Of the 65 remaining land cover subcategories 19 had an increase, 2 had no change and the rest (44) had a decline in biomass per ha. This fact that the majority of these land cover subcategories has have a decline in stock per ha is accompanied by the reality that the total biomass per unit area of each district has declined as shown in **Figure 5.23**.

Mukono followed by Wakiso encountered the greatest reductions, while Masindi had the minimum decline in biomass density. The percentage growth rate is necessarily negative and to a certain extent it follows the pattern of the change in biomass density, though not in all cases. For example, change in biomass density in Kayunga district is lower than that of Mubende district, yet the reverse is true for their percentage growth.

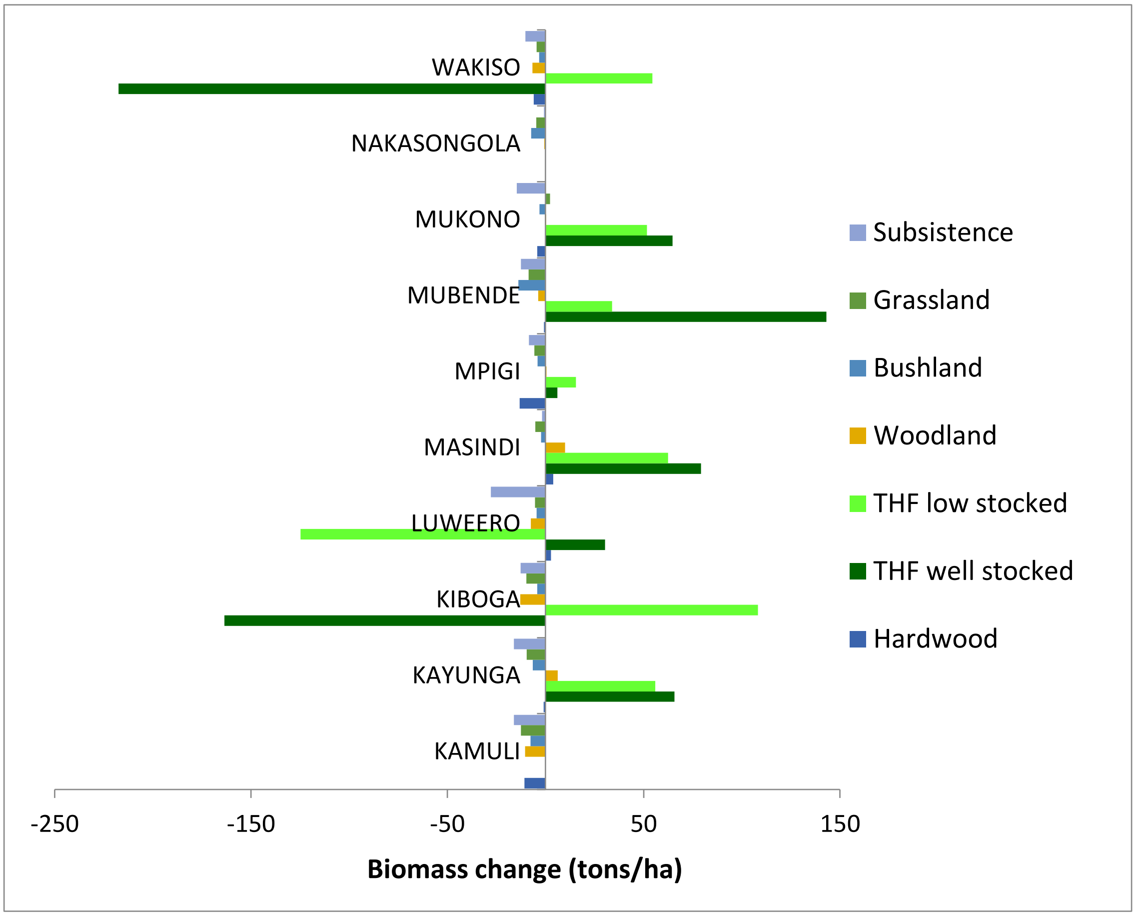


Figure 5.22: Biomass change per unit area by district between 1990 and 2005. *Source: Data from Kisakye.*

Overall, the net loss from all the land cover categories in the ten districts totaled up to 40 million tons of biomass, which is nearly 32% loss from 127 million tons (the total biomass of 1990). The estimated area required to generate or supply this lost quantity of biomass would depend on the stocking, which in turn depends on several factors, especially the land cover or land use. For example, taking the mean standing stock for THF well stocked, Hardwood Plantation, Woodland, Bushland and Subsistence Farmland, the estimated area required would increase in that order.

Since the THF well stocked has the highest stocking it requires the minimum area for production of this biomass equivalent. Compared to THF well stocked, the area would be 3 times for Hardwood Plantation, 6 for woodland, 17 times for Bushland, and 20 times for Subsistence Farmland.

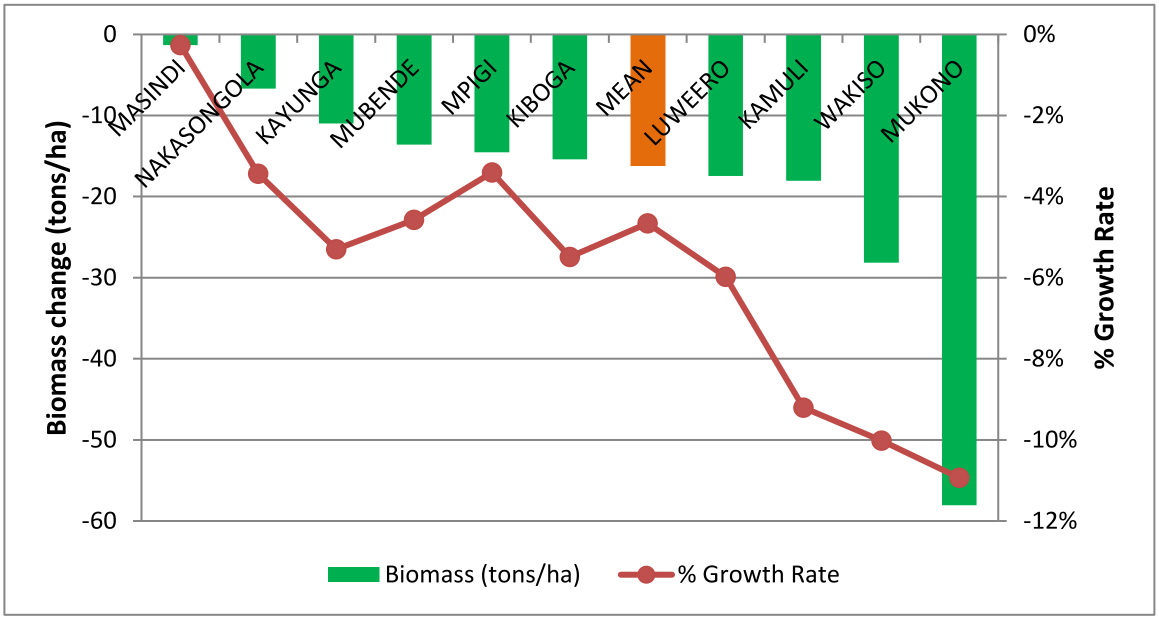


Figure 5.23: Total change in biomass per unit area by district between 1990 and 2005.
Source: Data from National Forestry Authority 1990 and 2005

If the equivalent (EQ) area required to obtain the lost biomass from these selected land cover types is compared to the sizes of the 10 charcoal producing districts the following graph in **Figure 5.24** is obtained.

The 40 million tons of biomass would require a minimum area that is greater than the smallest district (Kayunga) if the highest stocking land cover (THF well stocked) is considered. Since THF occupy a small size of land and cannot exist everywhere, and in many cases, they are protected, it may not be very realistic to use them for comparison. On the other hand, if this wood were to be planted to get Hardwood Plantation, which is the next highest stocked land cover, the area required would be greater than each the single smaller 6 out the ten district (Kayunga, Wakiso, Nakasongola, Mpigi, Kiboga and Kamuli) or a combination of smallest two district (Kayunga and Wakiso).

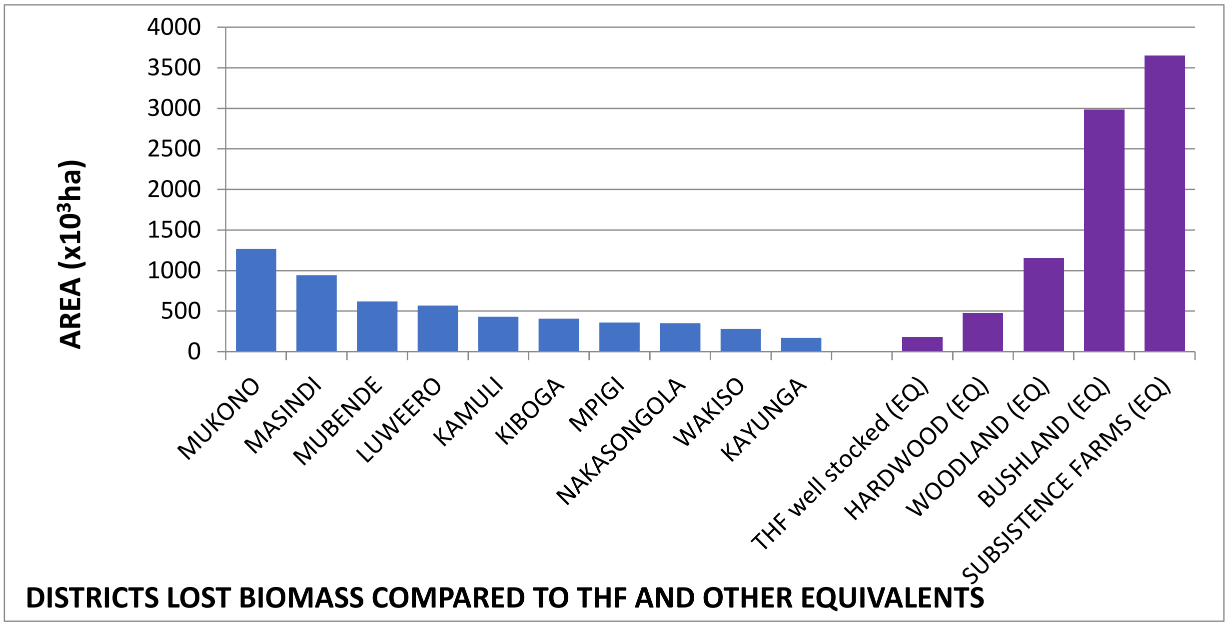


Figure 5.24: Area required for producing the lost biomass compared to the size of the 10 charcoal districts. *Source: Data from Kisakye.*

If Bushland, the land cover that expanded most, is the one from which the lost biomass is to be obtained, the area would be greater than the combination of the smaller 7 district. Finally, if the lost biomass is to be obtained from the Subsistence Farmland, the area required would be equivalent to a combination of the smaller 8 districts or the largest 4 districts.

The mean size of the land equivalent (of the five-land cover) required to produce this lost biomass would be 1,688,000 ha, while the mean size of the 10 main charcoal producing districts is only 540,000 ha. So averagely, 3 districts would be required to produce this biomass that was lost in 15 years – one district for every five years.

5.4.3. Land Tenure System (Ownership)

A forest is a natural resource composed of trees and it is generated from another resource (land) without which it is impossible to grow them. It is critical to establish the existance of land before a discussion is to proceed in the direction of replenishing the forest. As population increases it puts stress on the land, and the resulting conflicts related to land are very complex. According to the Uganda National Land Policy (UNLP, 2013, pp. 1,2), land is the most fundamental commodity in terms of provision of space; it's the foundation for environmental opportunity; and it's a source of capital. Land can be sold and bought and it is indeed a factor of production.

Initially, colonialists introduced ownership of land by individuals in a background where land was owned by the community or by sovereign trustees. This new model of ownership became more important than the indiginous land rights. This generated confusion of how to deal with multiple land rights. Due to the outcry several laws were enacted but this led to a multi-layered structure of rights which persists in Uganda today. This structure is blamed for the rampant conflicts and evictions, continue because the registered owner and the lawful bonafide rarely come to an agreement. On top of this, the the government decree to have the Land Reform in 1975 where the tenants become the owners, and owners become tenant, caused so much confusion (UNLP, 2013, p. 1).

According to article CAP 237 of the constitution all land in Uganda is vested in its people and shall be owned according to 4 different tenures: customary, freehold, mailo and leasehold (The Land Act CAP. 227, 2004, pp. 4985-4987).

Freehold tenure: The Land Act 1998 defines freehold tenure as a tenure that bestows one ownership of registered land forever. It was set by 1900 agreement between Buganda (central region) and the colonial government. The owner has full power to lawfully sell, rent, dispense it by will. The only exception to the rule are the non-Ugandan who are only permitted to hold it by leasing it for 99 years.

Mailo tenure: is mainly in Buganda, Ankole and Tooro sub-region. It is the tenure where large pieces of land are owned by the landlords, who got it by 1900, while at the same time tenants on the same land are allowed to to live and transact business on it. The squatters are protected by constitutional provision that states: "Mailo" land owners are not allowed to use their powers against the the interests of the customary, bona fide, or lawful occupants. Either way this double ownership is a source of confusion and is at the core of the land wrangles in Uganda.

Customary tenure: constitutes over 60% of land in Uganda. Apart from the Buganda region which is mainly held held under mailo ownership the rest of the country is held under customary tenure. This is the tenure where land is owned communally by clan, tribe etc, and there are different rules are applied to customary ownership.

Leasehold tenure: is where someone rents a piece of land to another for a specific period of time in exchange for the payment. Under this kind of tenure the land owner grants the right by (freehold, mailo or customary) lease to another person. In Uganda one can get a lease from an individual, a local authority, or an institution for 49 years or 99 year or in between with agreed conditions (The Land Act CAP. 227, 2004).

CHAPTER 6

COMPARISION OF COOKING OPTIONS AND FUELS

Having described the problem of woodfuel scarcity and lack of space for grow trees in chapter 5, we now turn the options that can be used to overcome this crisis. Ten cooking systems were briefly described, giving the advantages and disadvantages of each device, and were subjected to a Controlled Cooking Test to boil 1 kg of rice using 1 litre of water. These systems were the Traditional 3 stone fire (also known as Firewood traditional), Improved firewood stove (cold), Improved firewood stove (hot), Traditional Charcoal stove, Improved charcoal stove (cold), Improved charcoal stove (hot), Ethanol stove, Kerosene stove, Gas stove and Electricity stove. Time taken for lighting the stove and to cook the rice was also recorded and the stove which fastest in cooking the was Improved Firewood Stove (hot) (33.6 minutes) and the one was the slowest was charcoal improved stove (cold) (91.5 minutes). The mass of the fuel used to cook 1 kg of rice was recorded: It was highest for stoves using firewood – first the 3 stone fire (1.17 kg) and lowest with gas (0.07 kg). Using ranking method food taste was given scores of 1 (tasteless) to 5 (very delicious) and the means ranged from 2.15 (for improved charcoal stove) to electricity (3.95). The power consumed was highest with the 3 stone fire (6.26 kW) and lowest on electricity (0.56 kW Cooking Technology and Fuel

Ten cooking systems are analyzed by advantages and disadvantages. The traditional 3 stone fire is the most common stove used for cooking in Uganda. The efficiency is approximately 7 – 11%, but it can vary more depending on the cooking practices.   The three stone fire stove is the device with the highest level of power. This means that it cooks food faster and is able to cook by steaming. This device is able to cook all kinds of foods without exception. It can be operated on very high and low power. Furthermore, it can be adjusted to accommodate different sizes of pots, yet it has no costs, hence there is constraints regarding affordability. Due to these advantages the disadvantages are often ignored, which include making pots dirty or black, difficulty to light, smoke emission and firewood wastage, because there is no device that can compare to the three stone fire. Furthermore, African meals normally take much time to cook. The practical advantages and disadvantages of the devices are given in

Table 6-1.

Table 6-1: Advantages and disadvantages of the cooking devices

Device	**Advantages**	**Disadvantages**
3-stone	Quick	A lot of smoke
	delicious	not clean (soot)
	flexible (size)	A lot of firewood consumed
	cheap (affordable)	separate room for cooking (not in the house)
	Controllable	
Improved Charcoal	keeps heat	hard to light
	saves charcoal	expensive
	convenient	slow in cooking
	Safety (lower risk of burning than open metal)	
Improved firewood mud	saves wood	easily breaks
	less smoke	Riksy to use outside due to rain
	keeps heat	low mbility
	clean	less clean due to soot
	flexible (uses firewood and charcoal)	
	low risk of burning	
LPG (gas)	fast	risky
	smokeless	gas is too expensive (refill)
	clean	
	easy to light	
	flexible	
Ethanol	Portable	Not available
	easy to light	
	clean	
	smokeless, convenient (you don't attend fire)	
Electricity	quick to start	hard to afford
	cheap	risky
	clean	
	smokeless	
	convenient	
Solar	can be cheap because it requires no fuel	slow cooking

	clean	selective cooking
		subject to weather changes (unreliable)
		limited to sunlight (cannot cook at night)
Kerosene	available	Can be dangerous due to risk of accident
		Smells terribly and when extinguished
		When it is extinguished in a closed space it emits poisonous gases

Electricity cannot be appropriate because the grid is not everywhere because of the scattered nature of the residences particularly in the rural area; that is why electrification has to be done offgrid. Moreover, electricity is quite expensive yet unreliable. Therefore, electricity cannot be the main fuel but one of the alternatives.

The other alternative clean cooking fuel is biogas. It is quite appropriate, it can easily be decentralized and requires no grid. The constraining question is how many households have cattles in Uganda? According to the livestock census the households owning cattle in 2009 in quoted in MAAIF/UBOS 2009 were 26.1% (Balikowa, 2011). When one puts into account the fact that very few Ugandans keep their animals on zero grazing the ability and willing to pay for the costs to adopt the biogas digester, the number of households become very few. It had been estimated that the maximum number of biogas plants were 100,000 in 2009 when the population was about 30,000,000 meaning that it is 1 for every 300 household to possess the biogas plant, but in reality, even 10,000 would be a hustle.

The next cooking technology option would be the solar cooker. This could be indeed a suitable option since Uganda enjoys a lot of sunshine. The constraint with this technology is that it does not work at night and during days when the weather is cloudy or rainy. Even during day time, it cooks only selected meals. So, it would be supplementary rather than the main cooking fuel.

The other cooking option would be ethanol. This is one of the best options because ethanol is a biofuel and it is a renewable energy. However, the crops that can be grown for ethanol tend to compete with those which are grown for food. Consequently, it becomes food versus fuel. This is especially true in the case of the first generation and the second-generation biofuel. In the case of the first generation there is competition with food and land, while in the case of the second-generation biofuel there is competition for land. Where there is competition for scarce resources, the price becomes very high and so it is with ethanol. The only exception to this rule is the third-generation biofuel particularly, the algae. However, the technology to process the biofuel is still expensive by the time of writing of this thesis.

Still another option is kerosene (paraffin). Kerosene as a cooking fuel is appropriate because it is one of the fuels that are most available. But it can generate accidents: first, when it gets mixed with petrol and this results into explosion (very common with type of kerosene which is cheap, smuggled, and not properly refined); second, even without the mix with petrol the kerosene stove can cause minor accidents. Third, the smell which emerges when the kerosene stove is extinguished and especially in a closed space the pungent stench is very irritating. Fourth, when used in cheap wick stoves, kerosene can produce high levels of pollutants, and can significantly contribute to indoor air pollution. Fifth, it is very flammable: every year it leads to a number of fatal accidents and deaths due to poor handling (like fuel spillages, refilling and tumbling). Sixth, kerosene leads to a number of death among the children and frequent skin exposure may lead to skin damage. Seventh stove by itself is normally weak and cannot carry heavy weight foods (Energypedia, 2017).

According to the socio-economic setting of Uganda, propane would be the appropriate choice. Propane is Liquefied Petroleum Gas (LPG) but not all LPG is propane. LPG is flammable hydrocarbon gas liquefied through pressurization. LPG is obtained when natural gas is processed, and oil is refined. There are several gases that are classified under the category of LPG including propane, butane and isobutane (i-butane), as well as mixtures of these gases. These gases can all be compressed into liquid at relatively low pressures.

6.1. Cooking Time

The traditional firewood stove takes less cooking time than improved charcoal stove. Surprisingly a comparison between the two-fuel category – firewood and charcoal in which the traditional stoves are compared in terms of quickness indicates that charcoal stoves takes more time. **Figure 6.1** is a graph of cooking duration in minutes. Data for this graph is in pages 238, 239, 240, 241, 242, 243.

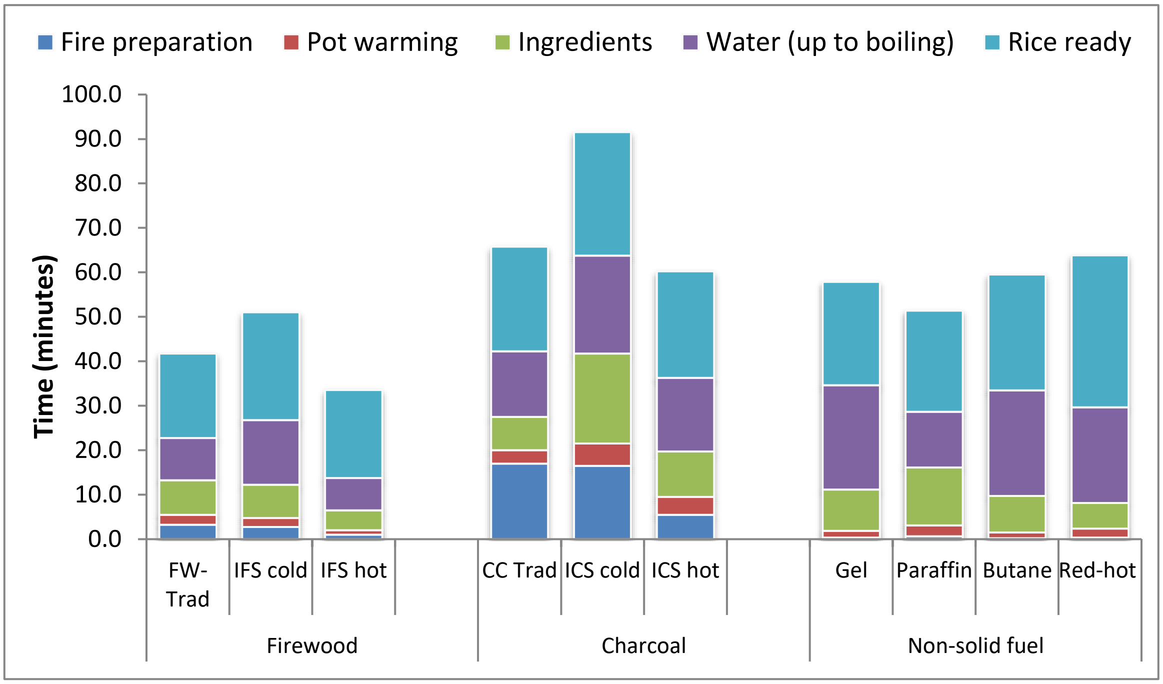


Figure 6.1: Cooking Duration

The stove that takes the maximum time is the improved charcoal stove – cold. This is followed by the traditional charcoal stove and then the improved charcoal stove hot which is the fastest among the charcoal stoves. Yet the firewood stoves are all quicker, competing with modern fuels.

Cooking time is shortest with firewood ICS, hot start (33.5 minutes). In principle, the traditional firewood stove is the fastest if you consider the fact that the hot improved stove has to be heated first. In other words, from a practical point of view, there is nothing like a hot improved stove; rather there is a cold improved stove. Consequently, the cold improved stove lags 10 minutes.

This is the reason why the traditional 3 stone fire is always popular due to its speed of cooking which is unchallengeable. Even the non-solid fuels lag behind the firewood in regard to the time. Due to its speed of cooking, the three traditional stove remains without a competitor despite its many shortcomings, including the indoor air pollution.

Unsurprisingly, it is followed by the traditional 3 stone fire (41.8 minutes). The firewood ICS cold start becomes the third (51 minutes). This implies that the cooking speed of a firewood ICS increases with time as it becomes really hot. It could partly explain the fact that people who want to cook very fast or a short meal would prefer lighting the 3 stone fire rather than starting the cold ICS. Table 6-2 gives descriptives of cooking duration using different devices.

Table 6-2: Cooking duration using different technologies

Descriptives : Time (minutes)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Firewood Traditional	4	41.75	1.5	0.75	39.36	44.14	40	43
Firewood Improved cold	4	51	10.68	5.34	34.01	67.99	40	64
Firewood Improved Hot	4	33.5	3.31	1.66	28.22	38.78	31	38
Charcoal Traditional	4	65.75	3.86	1.94	59.6	71.9	62	71
Charcoal Improved cold	4	91.5	13.48	6.74	70.05	112.95	80	108
Charcoal Improved Hot	4	61	22.4	11.2	25.35	96.65	32	86
Ethanol	4	57.88	14.68	7.34	34.52	81.23	43.5	78
Kerosene (paraffin)	4	51.38	8.44	4.22	37.95	64.8	44	63
LPG (Butane)	4	59.5	4.92	2.46	51.68	67.32	55	66.5
Electricity	4	63.875	14.55	7.28	40.72	87.03	49	80
Total	40	57.71	18.1	2.86	51.92	63.51	31	108

The non-solid biomass cooking options come next in the order: kerosene (51.4 minutes), ethanol (57.9 minutes), LPG (59.5 minutes) and electricity with redhot cooker (63.9 minutes). Then comes the charcoal stoves in the order: ICS hotstart (59.3 minutes), traditional (65.8 minutes) and ICS coldstart (91.5 minutes). Part of the reason for charcoal stoves being slow is the lighting phase, which takes 26% and 18% of the total cooking time for the charcoal traditional stove and the ICS_coldstart respectively, but takes only 9% for the hot start.

A comparison with the firewood stove shows a less firing time. It takes less than 2% for the firewood ICS_hot start; less than 6% for the firewood ICS_coldstart; and less than 8% for the traditional 3 stone fire. The non-solid biomass fuel have almost an instant firing time, which is less than 1% for ethanol, LPG and electricity (red hot) and approximately 1% for kerosene. This enables them to start cooking immediately, though time management can also be a function of the culture.

A Levene Stastistic Test of Homogeneity of Variance was conducted to investigate whether the variances between cooking options are equal. A Levene's test is used to test if the samples have equal variances. Equal variances across samples is called homogeneity of variance. Some statistical tests, for example the analysis of variance (ANOVA), assume that variances are equal across groups or samples. The Levene test can be used to verify that assumption. So a Levene's test is an inferential statistic used for a variable calculated for two or more groups (in this case ten groups). The tests showed however, that they were not actually equal as can be seen in Table 6-3 which indicates that it is significant: F (9, 30) = 2.658, p = 0.021.

Table 6-3: Levene statistic test of homogeneity of variance results

Test of Homogeneity of Variances			
Time (minutes)			
Levene Statistic	df1	df2	Sig.
2.658	9	30	0.021

Accordingly, a one way Analysis of Variance cannot be applied to determine whether cooking time differed among the devices. Instead a Robust Test of Equality of Means is the only option, done by Welch and Brown-Forsythe. Table 6-3 gives cooking duration robust test of equality of means.

Table 6-4: Cooking duration robust test of equality of means

Robust Tests of Equality of Means				
Time (minutes)				

a. Asymptotically F distributed	Statistic[a]	df1	df2	Sig.
Welch	21.38	9	11.71	0
Brown-Forsythe	7.2	9	13.8	0.001
a. Asymptotically F distributed.				

The results show that both tests are significant: With Welch at F(9, 11.71) = 21.38, p = 000; and Brown-Forsythe F(9, 13.80) = 7.20.

The means are compared in the table for subsets 1, 2 and 3 below. Accordingly, there is no statistical difference between the means in subset 1: Hot Firewood Improved Stove (33.50), the Firewood Traditional (41.75), Firewood Improved Cold (51.00), Kerosene (51.38), Ethanol (57.88), LPG (59.50) and Charcoal Improved Hot (61.00). Table 6-5 is cooking duration means of group in homogeneous subsets – a Tukey HSD.

Table 6-5: Cooking duration means of groups in homogeneous subsets

Time (minutes)				
Tukey HSD				
Cook device	N	Subset for alpha = 0.05		
		1	2	3
Firewood Improved Hot	4	33.5		
Firewood Traditional	4	41.75	41.75	
Firewood Improved Cold	4	51	51	
Kerosene (Paraffin)	4	51.38	51.38	
Ethanol	4	57.88	57.88	
LPG (Butane)	4	59.5	59.5	
Charcoal Improved Hot	4	61	61	
Electricity	4		63.88	63.88
Charcoal Traditional	4		65.75	65.75
Charcoal Improved Cold	4			91.5
Sig.		0.058	0.143	0.056

Means for groups in homogeneous subsets are displayed.

However there is a statistical difference between the means in the subset 2, because the cooking time for Hot Improved Firewood Stove is statistically lower compared to the rest in the subset - Firewood Traditional (41.75), Firewood Improved Cold (51.00, Kerosene (51.38), Ethanol (57.88), LPG (59.50), Charcoal Improved Hot (61.00), Electricity (63.88), Charcoal Traditional (65.75). On the other hand, Electricity (63.88), Charcoal Traditional (65.75) and Charcoal Improved Cold (91.50) belong statistically to a different category because they take longer time to cook (subset 3). Surprisingly, the cooking time is independent of the cooking fuel and that is what complicates the cooking fuel choice.

The cooking devices have been compared by the Tukey HSD in a pairwise fashion. Accordingly, the Improved Stove Cold performs significantly slower than the rest. Otherwise there is no significant difference among the rest of the cooking devices. The cooking time for the improved cookstove is notably long as evidenced by the socio-economic behavior of the people possessing them in the households. This is proved by the reluctance of households to cook on them whenever they have a quick meal: breakfast (tea) or warming food. On the other hand, when they have to cook food that requires much time, that is when they use the improved cookstove.

However, there could be a statistically significant difference between other cooking options which were not detected because of the small sample size Table 6-6 is a pairwise comparison of the cooking devices.

Table 6-6: Cooking time pairwise comparison of the cooking devices

Multiple Comparisons						
Time (minutes): Tukey HSD						
(I) Cook device	(J) Cook device	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Firewood Traditional	Firewood Improved cold	-9.3	8.2	1.0	-37.3	18.8
	Firewood Improved Hot	8.3	8.2	1.0	-19.8	36.3
	Charcoal Traditional	-24.0	8.2	0.1	-52.0	4.0
	Charcoal Improved cold	**-49.8***	**8.2**	**0.0**	**-77.8**	**-21.7**
	Charcoal Improved Hot	-19.3	8.2	0.4	-47.3	8.8
	Ethanol	-16.1	8.2	0.6	-44.1	11.9
	Kerosene (paraffin)	-9.6	8.2	1.0	-37.6	18.4
	LPG (Butane)	-17.8	8.2	0.5	-45.8	10.3
	Electricity	-22.1	8.2	0.2	-50.1	5.9
Firewood Improved cold	Firewood Traditional	9.3	8.2	1.0	-18.8	37.3
	Firewood Improved Hot	17.5	8.2	0.5	-10.5	45.5
	Charcoal Traditional	-14.8	8.2	0.7	-42.8	13.3
	Charcoal Improved cold	**-40.5***	**8.2**	**0.0**	**-68.5**	**-12.5**

	Charcoal Improved Hot	-10.0	8.2	1.0	-38.0	18.0
	Ethanol	-6.9	8.2	1.0	-34.9	21.1
	Kerosene (paraffin)	-0.4	8.2	1.0	-28.4	27.6
	LPG (Butane)	-8.5	8.2	1.0	-36.5	19.5
	Electricity	-12.9	8.2	0.9	-40.9	15.1
Firewood Improved Hot	Firewood Traditional	-8.3	8.2	1.0	-36.3	19.8
	Firewood Improved cold	-17.5	8.2	0.5	-45.5	10.5
	Charcoal Traditional	**-32.3***	**8.2**	**0.0**	**-60.3**	**-4.2**
	Charcoal Improved cold	**-58.0***	**8.2**	**0.0**	**-86.0**	**-30.0**
	Charcoal Improved Hot	-27.5	8.2	0.1	-55.5	0.5
	Ethanol	-24.4	8.2	0.1	-52.4	3.6
	Kerosene (paraffin)	-17.9	8.2	0.5	-45.9	10.1
	LPG (Butane)	-26.0	8.2	0.1	-54.0	2.0
	Electricity	**-30.4***	**8.2**	**0.0**	**-58.4**	**-2.4**
Charcoal Traditional	Firewood Traditional	24.0	8.2	0.1	-4.0	52.0
	Firewood Improved cold	14.8	8.2	0.7	-13.3	42.8
	Firewood Improved Hot	**32.3***	**8.2**	**0.0**	**4.2**	**60.3**
	Charcoal Improved cold	-25.8	8.2	0.1	-53.8	2.3
	Charcoal Improved Hot	4.8	8.2	1.0	-23.3	32.8
	Ethanol (gel)	7.9	8.2	1.0	-20.1	35.9
	Kerosene (Paraffin)	14.4	8.2	0.8	-13.6	42.4
	LPG (Butane)	6.3	8.2	1.0	-21.8	34.3
	Electricity	1.9	8.2	1.0	-26.1	29.9
Charcoal Improved Cold	**Firewood Traditional**	**49.8***	**8.2**	**0.0**	**21.7**	**77.8**
	Firewood Improved cold	**40.5***	**8.2**	**0.0**	**12.5**	**68.5**
	Firewood Improved Hot	**58.0***	**8.2**	**0.0**	**30.0**	**86.0**
	Traditional Charcoal	25.8	8.2	0.1	-2.3	53.8
	Charcoal Improved Hot	**30.5***	**8.2**	**0.0**	**2.5**	**58.5**
	Ethanol (gel)	**33.6***	**8.2**	**0.0**	**5.6**	**61.6**
	Kerosene (Paraffin)	**40.1***	**8.2**	**0.0**	**12.1**	**68.1**
	LPG (Butane)	**32.0***	**8.2**	**0.0**	**4.0**	**60.0**
	Electricity	27.6	8.2	0.1	-0.4	55.6
Charcoal Improved Hot	Firewood Traditional	19.3	8.2	0.4	-8.8	47.3
	Firewood Improved cold	10.0	8.2	1.0	-18.0	38.0
	Firewood Improved Hot	27.5	8.2	0.1	-0.5	55.5
	Traditional Charcoal	-4.8	8.2	1.0	-32.8	23.3
	Charcoal Improved cold	**-30.5***	**8.2**	**0.0**	**-58.5**	**-2.5**
	Ethanol (gel)	3.1	8.2	1.0	-24.9	31.1
	Kerosene (Paraffin)	9.6	8.2	1.0	-18.4	37.6
	LPG (Butane)	1.5	8.2	1.0	-26.5	29.5
	Electricity	-2.9	8.2	1.0	-30.9	25.1
Ethanol (gel)	Firewood Traditional	16.1	8.2	0.6	-11.9	44.1
	Firewood Improved cold	6.9	8.2	1.0	-21.1	34.9
	Firewood Improved Hot	24.4	8.2	0.1	-3.6	52.4
	Traditional Charcoal	-7.9	8.2	1.0	-35.9	20.1
	Charcoal Improved cold	**-33.6***	**8.2**	**0.0**	**-61.6**	**-5.6**

	Charcoal Improved Hot	-3.1	8.2	1.0	-31.1	24.9
	Kerosene (Paraffin)	6.5	8.2	1.0	-21.5	34.5
	LPG (Butane)	-1.6	8.2	1.0	-29.6	26.4
	Electricity	-6.0	8.2	1.0	-34.0	22.0
Kerosene (Paraffin)	Firewood Traditional	9.6	8.2	1.0	-18.4	37.6
	Firewood Improved cold	0.4	8.2	1.0	-27.6	28.4
	Firewood Improved Hot	17.9	8.2	0.5	-10.1	45.9
	Traditional Charcoal	-14.4	8.2	0.8	-42.4	13.6
	Charcoal Improved cold	**-40.1***	**8.2**	**0.0**	**-68.1**	**-12.1**
	Charcoal Improved Hot	-9.6	8.2	1.0	-37.6	18.4
	Ethanol (gel)	-6.5	8.2	1.0	-34.5	21.5
	LPG (Butane)	-8.1	8.2	1.0	-36.1	19.9
	Electricity	-12.5	8.2	0.9	-40.5	15.5
LPG (Butane)	Firewood Traditional	17.8	8.2	0.5	-10.3	45.8
	Firewood Improved cold	8.5	8.2	1.0	-19.5	36.5
	Firewood Improved Hot	26.0	8.2	0.1	-2.0	54.0
	Charcoal Traditional	-6.3	8.2	1.0	-34.3	21.8
	Charcoal Improved cold	**-32.0***	**8.2**	**0.0**	**-60.0**	**-4.0**
	Charcoal Improved Hot	-1.5	8.2	1.0	-29.5	26.5
	Ethanol (gel)	1.6	8.2	1.0	-26.4	29.6
	Kerosene (Paraffin)	8.1	8.2	1.0	-19.9	36.1
	Electricity	-4.4	8.2	1.0	-32.4	23.6
Electricity	Firewood Traditional	22.1	8.2	0.2	-5.9	50.1
	Firewood Improved cold	12.9	8.2	0.9	-15.1	40.9
	Firewood Improved Hot	**30.4***	**8.2**	**0.0**	**2.4**	**58.4**
	Charcoal Traditional	-1.9	8.2	1.0	-29.9	26.1
	Charcoal Improved cold	-27.6	8.2	0.1	-55.6	0.4
	Charcoal Improved Hot	2.9	8.2	1.0	-25.1	30.9
	Ethanol (gel)	6.0	8.2	1.0	-22.0	34.0
	Kerosene (Paraffin)	12.5	8.2	0.9	-15.5	40.5
	LPG (Butane)	4.4	8.2	1.0	-23.6	32.4

*. The mean difference is significant at the 0.05 level.

6.2. Used fuel mass per kg of rice

Apart from the electricity which is not measured in kilogram (kg). It is possible to compare the cooking fuels in relation to their weight or mass. Stoves using fuelwood: Traditional Firewood Stove, Improved Firewood Stove (cold) and Improved Firewood Stove (hot), seem to consume a disproportionate quantity of wood. **Figure 6.2** is comparison of cooking appliances in regards to used fuel mass per kg of rice.

The highest quantity is registered by the Traditional Firewood Stove (1.17 kg), followed by the Improved Firewood Cold (1.08 kg) and lastly is the Improved Firewood

Stove (hot) (0.82 kg). In comparison to the Traditional Stove (3 stone fire), the wood consumption would be reduced more by the hot Improved Firewood Stove which is hot (70%) than the cold 92%. This explains the reason why cooking a quick meal does not require use of improved cookstove, yet the improved cookstove would be required when cooking for a long time.

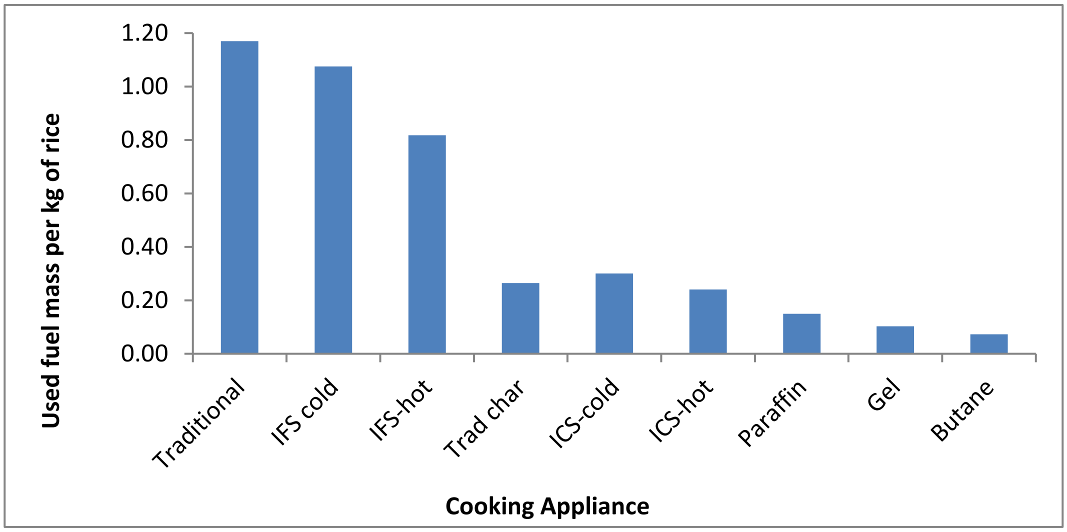


Figure 6.2: Cooking Appliance

Next to these stoves is the charcoal stoves: Traditional Charcoal Stove, Improved Charcoal Stove (hot), Improved Charcoal Stove (cold). Again a comparison with the Traditional Charcoal Stove gives the gains or losses. Accordingly, the Improved Charcoal Stove (cold) consumes more fuel (1.13%), than the traditional type (1.00), while the hot Improved Charcoal Stove reduces the consumption (0.91%). This could be because of the ceramic lining which absorbs heat in the beginning and later on emits it. "Multiple tests of the Lorena stove beginning in 1983 at the Aprovecho Research Center have shown that placing thermal mass near the fire has a negative effect on the responsiveness and fuel efficiency of a cooking stove" (Dean, 2002). But on the other hand, "A masonry heater must have sufficient mass in order to radiantly heat a home. Without sufficient mass the surface temperatures of the heater become too hot resulting in the convection of hot air" (Tulikivi , 2003).

A comparison of results for the metal and ceramic stove show that the two stoves have advantage towards each other. Specifically, in the high power phase the metal stove can generate not more than 2,924W and the ceramic stove is capable of generating up to 5,110W within its ceramic lining. The efficiency of a metal and ceramic charcoal stoves in their high power phases are 19.5% and 14.5% respectively. In the low power phase the fire power given out from the metal and ceramic stoves is 656W and 1793W respectively; whereas, the efficiency is 21.0% and 34.5% respectively (**Table 6-7**).

Table 6-7: A Comparison Between KCJ and Metal Stoves

		Metal	**KCJ**
High power phase	Fire Power (W)	2924	5110
	Efficiency (%)	19.5%	14.5%
Low power phase	Fire Power (W)	656	1793
	Efficiency (%)	21.0%	34.5%

Source: (Yanxia, 2012)

This is because of the difference in conductivity between metal and ceramic. Metal conducts heat faster but ceramic stores it and conducts it away slowly (Yanxia, 2012). This indicates the conduction attribute difference between ceramic and metal: metal conducts heat faster and ceramic stores and conducts heat slowly. So a ceramic liner is able to store heat energy which would have been lost to the environment and it releases it slowly. For this reason it becomes less profitable to boil tea or a light meal (like eggs, tea or breakfast). It becomes counterproductive for two reasons: it takes much more time and consumes a lot of energy. For this reason the Improved Firewood Stove faces the same challenge like the Improved Charcoal Stove. They are both unsuitable for cooking light meals.

The conversion of wood into charcoal is carried out in kilns of which traditional kilns are the commonest. These are earth pit or mound kilns with efficiencies ranging between 8% and 12 %. Due to factors like wood humidity, kiln size, and process control, the relative gain in a charcoal carbonization technology is may be 5% to 50%. Then the kilns too have a big range of losses from -5 to 73 (Energypedia, kein Datum). Then there are storage and transport losses. A comparison between the traditional firewood stove and a traditional charcoal stove with inclusion of carbonization indicates that the traditional firewood stove can be more efficient. On the other hand the paraffin, gel and butane are consumed in less quantity. However the processes to refine them is beyond the scope of this study. Biomass, particularly charcoal is responsible for enviromental crisis in Uganda. **Table 6-8** gives fuel consumption per kg of rice.

An over view of the descriptive indicates that there is variability in the variance just as it is with the mean. The means of fuel used differs in the range of 1.1700 – 0.0725 per kg of rice. Similarly, the standard deviation differs in the range of 0.26808 – 0.00957 per kg of rice – a range of 28 times. That is why there is no surprise that the test of homogeneity of variance which is performed by the Levene test is significantly violated (F (8, 27) = 6.613, p=000). Table 6-9 gives a Levene test of homogeneity of variance on mass of fuel used to cook one kg of rice.

Table 6-8: Fuel consumption per kg of rice

Mass of fuel used per kg of rice								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Firewood Traditional	4	1.17	0.27	0.13	0.74	1.60	0.82	1.38
Firewood Improved cold	4	1.08	0.08	0.04	0.95	1.20	1.00	1.15
Firewood Improved Hot	4	0.82	0.13	0.07	0.61	1.02	0.64	0.95
Charcoal Traditional	4	0.27	0.03	0.02	0.21	0.32	0.22	0.30
Charcoal Improved cold	4	0.30	0.04	0.02	0.24	0.36	0.26	0.34
Charcoal Improved Hot	4	0.24	0.06	0.03	0.15	0.33	0.18	0.32
Ethanol	4	0.15	0.02	0.01	0.12	0.18	0.12	0.16
Kerosene (paraffin)	4	0.10	0.03	0.01	0.06	0.15	0.06	0.12
LPG (Butane	4	0.07	0.01	0.00	0.06	0.09	0.06	0.08
Total	36	0.47	0.42	0.07	0.32	0.61	0.06	1.38

Table 6-9: Test of Homogeneity of Variances

Mass of fuel used per kg of rice			
Levene Statistic	df1	df2	Sig.
6.613	8	27	0

In this case the ANOVA results cannot be applied. Instead robust tests of equality of means can be applied which include Welch and Brown-Forsythe. Table 6-10 indicates the mass of fuel used, applying robust test of equality. Accordingly, the tests are both significant with Welch, F (8, 10.733) = 96.454, p = .000; and Brown-Forsythe at F (8, 5.652) = 66.120, p = 000.

Table 6-10: Mass of fuel use robust test of equality

Robust Tests of Equality of Means				
Mass of fuel used per kg of rice				
	Statistic[a]	df1	df2	Sig.
Welch	96.454	8	10.733	0
Brown-Forsythe	66.12	8	5.652	0
a. Asymptotically F distributed.				

However, the ANOVA does not tell which group is significantly different from the others. The statistical difference is obtained from the table of Multiple Comparison which compares two means at a time. Table 6-11 shows multiple comparisons of mass of fuel used.

Table 6-11: Multiple comparison of mass of fuel use

Multiple Comparisons

Mass of fuel used per kg of rice

Tukey HSD

(I) Cook_device	(J) Cook_device	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Firewood Traditional	Firewood Improved cold	0.10	0.08	0.93	-0.16	0.35
	Firewood Improved Hot	**0.35***	**0.08**	**0.00**	**0.10**	**0.61**
	Charcoal Traditional	**0.91***	**0.08**	**0.00**	**0.65**	**1.16**
	Charcoal Improved cold	**0.87***	**0.08**	**0.00**	**0.62**	**1.12**
	Charcoal Improved Hot	**0.93***	**0.08**	**0.00**	**0.68**	**1.18**
	Ethanol	**1.02***	**0.08**	**0.00**	**0.77**	**1.27**
	Kerosene (paraffin)	**1.07***	**0.08**	**0.00**	**0.81**	**1.32**
	LPG (Butane	**1.10***	**0.08**	**0.00**	**0.84**	**1.35**
Firewood Improved cold	Firewood Traditional	-0.10	0.08	0.93	-0.35	0.16
	Firewood Improved Hot	**0.26***	**0.08**	**0.04**	**0.00**	**0.51**
	Charcoal Traditional	**0.81***	**0.08**	**0.00**	**0.56**	**1.06**
	Charcoal Improved cold	**0.78***	**0.08**	**0.00**	**0.52**	**1.03**

	Charcoal Improved Hot	0.84*	0.08	0.00	0.58	1.09
	Ethanol	0.93*	0.08	0.00	0.67	1.18
	Kerosene (paraffin)	0.97*	0.08	0.00	0.72	1.23
	LPG (Butane	1.00*	0.08	0.00	0.75	1.26
Firewood Improved Hot	Firewood Traditional	-0.35*	0.08	0.00	-0.61	-0.10
	Firewood Improved cold	-0.26*	0.08	0.04	-0.51	0.00
	Charcoal Traditional	0.55*	0.08	0.00	0.30	0.81
	Charcoal Improved cold	0.52*	0.08	0.00	0.26	0.77
	Charcoal Improved Hot	0.58*	0.08	0.00	0.32	0.83
	Ethanol	0.67*	0.08	0.00	0.41	0.92
	Kerosene (paraffin)	0.72*	0.08	0.00	0.46	0.97
	LPG (Butane	0.75*	0.08	0.00	0.49	1.00
Charcoal Traditional	Firewood Traditional	-0.91*	0.08	0.00	-1.16	-0.65
	Firewood Improved cold	-0.81*	0.08	0.00	-1.06	-0.56
	Firewood Improved Hot	-0.55*	0.08	0.00	-0.81	-0.30
	Charcoal Improved cold	-0.04	0.08	1.00	-0.29	0.22
	Charcoal Improved Hot	0.03	0.08	1.00	-0.23	0.28
	Ethanol	0.12	0.08	0.83	-0.14	0.37
	Kerosene (paraffin)	0.16	0.08	0.46	-0.09	0.42
	LPG (Butane	0.19	0.08	0.25	-0.06	0.45
Charcoal Improved cold	Firewood Traditional	-0.87*	0.08	0.00	-1.12	-0.62
	Firewood Improved cold	-0.78*	0.08	0.00	-1.03	-0.52
	Firewood Improved Hot	-0.52*	0.08	0.00	-0.77	-0.26
	Charcoal Traditional	0.04	0.08	1.00	-0.22	0.29
	Charcoal Improved Hot	0.06	0.08	1.00	-0.19	0.31
	Ethanol	0.15	0.08	0.56	-0.10	0.40
	Kerosene (paraffin)	0.20	0.08	0.22	-0.06	0.45
	LPG (Butane	0.23	0.08	0.10	-0.03	0.48
Charcoal Improved Hot	Firewood Traditional	-0.93*	0.08	0.00	-1.18	-0.68
	Firewood Improved cold	-0.84*	0.08	0.00	-1.09	-0.58
	Firewood Improved Hot	-0.58*	0.08	0.00	-0.83	-0.32
	Charcoal Traditional	-0.03	0.08	1.00	-0.28	0.23
	Charcoal Improved cold	-0.06	0.08	1.00	-0.31	0.19
	Ethanol	0.09	0.08	0.95	-0.16	0.34
	Kerosene (paraffin)	0.14	0.08	0.66	-0.12	0.39
	LPG (Butane	0.17	0.08	0.42	-0.09	0.42
Ethanol	Firewood Traditional	-1.02*	0.08	0.00	-1.27	-0.77
	Firewood Improved cold	-0.93*	0.08	0.00	-1.18	-0.67
	Firewood Improved Hot	-0.67*	0.08	0.00	-0.92	-0.41
	Charcoal Traditional	-0.12	0.08	0.83	-0.37	0.14
	Charcoal Improved cold	-0.15	0.08	0.56	-0.40	0.10
	Charcoal Improved Hot	-0.09	0.08	0.95	-0.34	0.16
	Kerosene (paraffin)	0.05	0.08	1.00	-0.21	0.30

	LPG (Butane	0.08	0.08	0.98	-0.18	0.33
Kerosene (paraffin)	**Firewood Traditional**	**-1.07***	**0.08**	**0.00**	**-1.32**	**-0.81**
	Firewood Improved cold	**-0.97***	**0.08**	**0.00**	**-1.23**	**-0.72**
	Firewood Improved Hot	**-0.72***	**0.08**	**0.00**	**-0.97**	**-0.46**
	Charcoal Traditional	-0.16	0.08	0.46	-0.42	0.09
	Charcoal Improved cold	-0.20	0.08	0.22	-0.45	0.06
	Charcoal Improved Hot	-0.14	0.08	0.66	-0.39	0.12
	Ethanol	-0.05	0.08	1.00	-0.30	0.21
	LPG (Butane)	0.03	0.08	1.00	-0.22	0.28
LPG (Butane)	**Firewood Traditional**	**-1.10***	**0.08**	**0.00**	**-1.35**	**-0.84**
	Firewood Improved cold	**-1.00***	**0.08**	**0.00**	**-1.26**	**-0.75**
	Firewood Improved Hot	**-0.75***	**0.08**	**0.00**	**-1.00**	**-0.49**
	Charcoal Traditional	-0.19	0.08	0.25	-0.45	0.06
	Charcoal Improved cold	-0.23	0.08	0.10	-0.48	0.03
	Charcoal Improved Hot	-0.17	0.08	0.42	-0.42	0.09
	Ethanol	-0.08	0.08	0.98	-0.33	0.18
	Kerosene (paraffin)	-0.03	0.08	1.00	-0.28	0.22
*. The mean difference is significant at the 0.05 level.						

6.3. Taste of Food by Ranking

The food cooked on those stoves was tasted by 20 people. Twelve were women and eight were men. The environmental conditions were maintained almost constant so that they may not affect the cooked items. Care was taken to make sure that the cooking devices were not disclosed to the people to avoid bias. Each food was cooked in the same way in order to avoid variation due to test as a result of different ingredients. This was done by putting labels on the food. Furthermore, only two cooks were involved in the cooking and they had to ensure that each of them knew what the other was doing. Food was evaluated by ranking it on the scale of 1 to 5 where, 1=tasteless; 5=very delicious. In Table 6-12 rank score by taste were recorded and a statistical analysis was done.

The challenge of this methodology was the fact that humans may not have the same taste for every food. If is also possible that a person who is hungry may not have the same taste as the one who is satisfied due to variation of appetite.

Table 6-12: Taste of food ranking

Score (1=tasteless; 5=very delicious)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
ICS Firewood	20	2.65	1.27	0.28	2.06	3.24	1	5
ICS Charcoal	20	2.15	0.99	0.22	1.69	2.61	1	4
Traditional 3 stonefire	20	3.3	1.34	0.30	2.67	3.93	1	5
Electricity	20	3.85	1.09	0.24	3.34	4.36	2	5
Traditional Charcoal	20	3.45	1.15	0.26	2.91	3.99	1	5
Kerosene	20	2.95	1.36	0.30	2.32	3.59	1	5
Ethanol	20	2.75	1.29	0.29	2.15	3.36	1	5
LPG (Butane)	20	3.4	1.35	0.30	2.77	4.03	1	5
Total	160	3.062	1.31	0.10	2.86	3.27	1	5

Some statistical operations assume that variances from which the population samples obtained are automatically equal: Levene tests whether this assumption hold. Levene tests checks this assumption. A Levene Test of Homogeneity of Variance was conducted, and it was not found to be violated: F (7, 152) = .811, p=0.579 (Table 6-14).

Table 6-13: Test of homogeneity of variance on taste

Test of Homogeneity of Variances			
Score (1=tasteless; 5=very delicious)			
Levene Statistic	df1	df2	Sig.
0.811	7	152	0.579

Therefore, the Analysis of Variance Test can be performed (Table 6-14).

Table 6-14: Food taste ANOVA test

Score (1=tasteless; 5=very delicious)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.075	7	5.868	3.839	.001
Within Groups	232.300	152	1.528		
Total	273.375	159			

There was a statistically significant difference between groups as determined by one-way Analysis of Variance (F (7, 152) = 3.868, p = .001). The question is, which groups of stoves are statistically significantly than others? However, the ANOVA cannot answer this question. Instead a Post Hoc analysis of Multiple Comparison of means is the best option. Table 6-15 is a multiple comparison of means of food taste cooked on different devices.

Table 6-15: Multiple comparisons of food taste cooked from different devices

Score (1=tasteless; 5=very delicious)

Tukey HSD

(I) Type of Stove	(J) Type of Stove	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
ICS Firewood	ICS Charcoal	0.50	0.39	0.91	-0.70	1.70
	Traditional 3 stonefire	-0.65	0.39	0.71	-1.85	0.55
	Electricity	-1.20	0.39	0.05	-2.40	0.00
	Traditional Charcoal	-0.80	0.39	0.46	-2.00	0.40
	Kerosene	-0.30	0.39	0.99	-1.50	0.90
	Ethanol	-0.10	0.39	1.00	-1.30	1.10
	LPG (Butane)	-0.75	0.39	0.54	-1.95	0.45
ICS Charcoal	ICS Firewood	-0.50	0.39	0.91	-1.70	0.70
	Traditional 3 stonefire	-1.15	0.39	0.07	-2.35	0.05
	Electricity	-1.70	0.39	0.00	-2.90	-0.50
	Traditional Charcoal	**-1.30***	**0.39**	**0.02**	**-2.50**	**-0.10**
	Kerosene	-0.80	0.39	0.46	-2.00	0.40
	Ethanol	-0.60	0.39	0.79	-1.80	0.60
	LPG (Butane)	**-1.25***	**0.39**	**0.04**	**-2.45**	**-0.05**
Traditional 3 stonefire	ICS Firewood	0.65	0.39	0.71	-0.55	1.85
	ICS Charcoal	1.15	0.39	0.07	-0.05	2.35
	Electricity	-0.55	0.39	0.85	-1.75	0.65
	Traditional Charcoal	-0.15	0.39	1.00	-1.35	1.05
	Kerosene	0.35	0.39	0.99	-0.85	1.55
	Ethanol	0.55	0.39	0.85	-0.65	1.75
	LPG (Butane)	-0.10	0.39	1.00	-1.30	1.10
Electricity	ICS Firewood	1.20	0.39	0.05	0.00	2.40
	ICS Charcoal	**1.70***	**0.39**	**0.00**	**0.50**	**2.90**
	Traditional 3 stonefire	0.55	0.39	0.85	-0.65	1.75
	Traditional Charcoal	0.40	0.39	0.97	-0.80	1.60
	Kerosene	0.90	0.39	0.30	-0.30	2.10
	Ethanol	1.10	0.39	0.10	-0.10	2.30
	LPG (Butane)	0.45	0.39	0.94	-0.75	1.65
Traditional Charcoal	ICS Firewood	0.80	0.39	0.46	-0.40	2.00
	ICS Charcoal	**1.30***	**0.39**	**0.02**	**0.10**	**2.50**

	Traditional 3 stonefire	0.15	0.39	1.00	-1.05	1.35
	Electricity	-0.40	0.39	0.97	-1.60	0.80
	Kerosene	0.50	0.39	0.91	-0.70	1.70
	Ethanol	0.70	0.39	0.63	-0.50	1.90
	LPG (Butane)	0.05	0.39	1.00	-1.15	1.25
Kerosene	ICS Firewood	0.30	0.39	0.99	-0.90	1.50
	ICS Charcoal	0.80	0.39	0.46	-0.40	2.00
	Traditional 3 stonefire	-0.35	0.39	0.99	-1.55	0.85
	Electricity	-0.90	0.39	0.30	-2.10	0.30
	Traditional Charcoal	-0.50	0.39	0.91	-1.70	0.70
	Ethanol	0.20	0.39	1.00	-1.00	1.40
	LPG (Butane)	-0.45	0.39	0.94	-1.65	0.75
Ethanol	ICS Firewood	0.10	0.39	1.00	-1.10	1.30
	ICS Charcoal	0.60	0.39	0.79	-0.60	1.80
	Traditional 3 stonefire	-0.55	0.39	0.85	-1.75	0.65
	Electricity	-1.10	0.39	0.10	-2.30	0.10
	Traditional Charcoal	-0.70	0.39	0.63	-1.90	0.50
	Kerosene	-0.20	0.39	1.00	-1.40	1.00
	LPG (Butane)	-0.65	0.39	0.71	-1.85	0.55
LPG (Butane)	ICS Firewood	0.75	0.39	0.54	-0.45	1.95
	ICS Charcoal	**1.25***	**0.39**	**0.04**	**0.05**	**2.45**
	Traditional 3 stonefire	0.10	0.39	1.00	-1.10	1.30
	Electricity	-0.45	0.39	0.94	-1.65	0.75
	Traditional Charcoal	-0.05	0.39	1.00	-1.25	1.15
	Kerosene	0.45	0.39	0.94	-0.75	1.65
	Ethanol	0.65	0.39	0.71	-0.55	1.85

Where the mean difference is significant, it is marked by asterisk. Where there is no asterisk, it implies that there is no significant difference as influenced by the cooking system (same taste as for other cooking devices). To make it clear groups of homogeneous subsets. **Table 6-16** reveals food taste means for groups of homogeneous subsets.

Table 6-16: Food taste means for groups of homogeneous subsets

Score (1=tasteless; 5=very delicious)

Tukey HSD			
Type of Stove	N	Subset for alpha = 0.05	
		1	2
ICS Charcoal	20	2.15	
ICS Firewood	20	2.65	2.65
Ethanol	20	2.75	2.75
Kerosene	20	2.95	2.95

Traditional 3 stonefire	20	3.3	3.3
LPG (Butane)	20		3.4
Traditional Charcoal	20		3.45
Electricity	20		3.85
Sig.		0.072	0.051

Means for groups in homogeneous subsets are displayed.

These scores could be put in 3 categories: low, overlapping and high. The groups are arranged in such a way that those, which are lowest are put in the first group. These followed by the next group in magnitude, and so on. A group is composed of means with no statistically significant difference between the scores. As can be seen from the table some exclusively belong to the first group, others belong exclusively to the second group, and the rest overlap the first and the second group. The significantly low is the Improved Charcoal Stove with score taste of 2.15. Then four stoves fit in the middle category: Improved Cookstove for firewood, Ethanol, Kerosene, traditional three stone fire – with average scores of tastes of deliciousness of 2.650 – 3.300. Then the significantly high taste is of rice cooked with LPG, Traditional Charcoal and electricity, which in terms of scores is 3.400 – 3.850. Surprisingly, it is electricity with the best taste and not any of the firewood cooking stove.

6.4. Energy and Power for Cooking

In order to cook one kilogram of rice, different cooking stoves were compared. The traditional firewood stove consumes the highest amount of power and the lowest is electricity. Considering the consumption in terms of final energy still the traditional firewood stove gives out the largest amount of energy and the least amount is produced by electricity. This does not consider the conversion losses to produce electricity. **Figure 6.3** shows the power and energy consumption by cooking appliance.

This seems to suggest that although the tradional firewood stove might be perceived as inefficient it has the advantage of cooking very fast – something which many modern cooking fuels may lack. Wood combustion goes through four stages. Frst, the moisture in the wood is driven out so wood dries (wood does not burn unless it is completely dry).

Second, as temperature increases chemical decomposition takes place that releases hot flue gases from the wood. Third, the hot flue gases are ignited – this is the main flame burning stage. Fourth, the glowing charcoal oxidizes and burns (Johnson, 1914; Ruusunen, 2013).

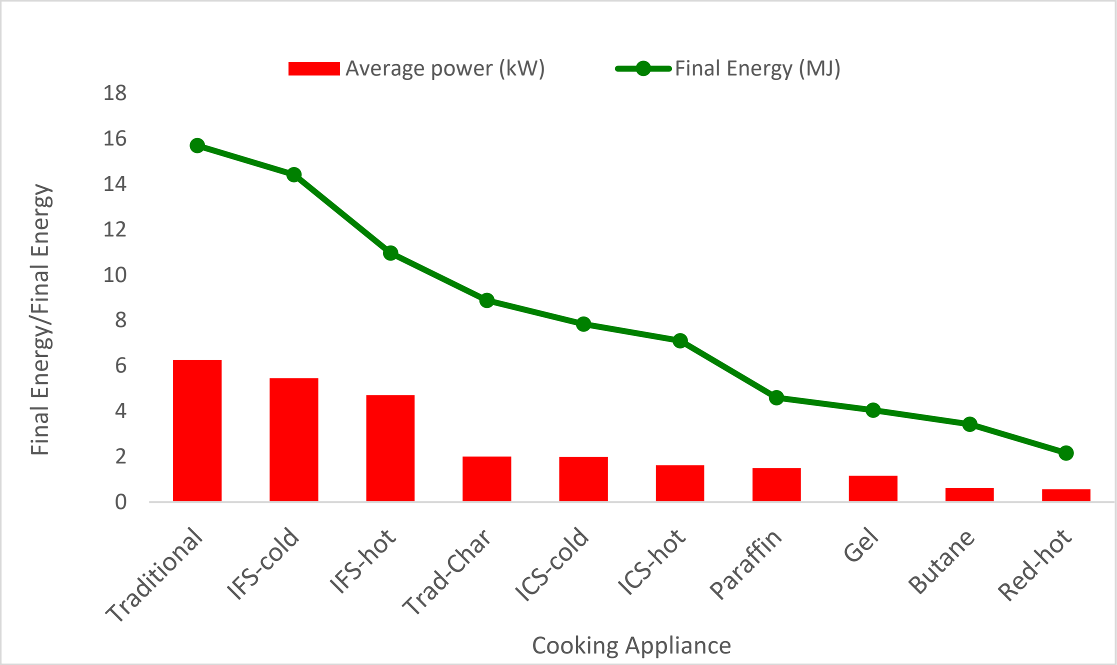


Figure 6.3: Power and energy consumption of cooking appliances

This is because the person cooking can put in quite a lot of wood (depending on the space in the combustion chamber), which leads to rapid conversion of chemical to thermal energy that is transmitted and released to the cooking pot. The traditional stove is able to generate a lot of heat. The temperature in a wood-fired stove generally ranges between about 500- and 700-degrees Fahrenheit (Alternative Daily, 2014). This means that although the primitive cooking stoves consume a lot of energy they tend to radiate a large amount of heat which reduces the time for cooking.

Table 6-17 shows the heat energy used for the cooking of 1 kg of rice by the ten devices. The total heat energy use by the stoves varies depending on the stove, from the minimum of 1.47 MJ to a maximum of 16.14 MJ. In terms of the means it is a minimum of 2.1600 MJ and a maximum 12.9375 MJ.

Table 6-17: Total heat energy use by cooking devices (MJ)

Descriptive

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1. Firewood Traditional		10.88	5.58	.79	2.00	9.76	3.50	16.14
2. Firewood Improved cold	4	12.94	0.90	0.45	11.51	14.37	12.23	14.24
3.Firewood Improved Hot	4	7.56	4.40	2.20	0.55	14.57	1.47	11.56
4. Charcoal Traditional	4	7.84	0.98	0.49	6.28	9.41	6.51	8.88
5. Charcoal Improved cold	4	8.88	1.08	0.54	7.16	10.60	7.70	10.06
6. Charcoal Improved Hot	4	7.10	1.74	0.87	4.33	9.88	5.33	9.47
7. Ethanol	4	4.04	0.54	0.27	3.18	4.90	3.23	4.31
8. Kerosene (paraffin)	4	4.34	1.17	0.59	2.47	6.20	2.69	5.37
9. LPG (Butane)	4	3.42	0.45	0.23	2.71	4.14	2.84	3.78
10. Electricity	4	2.16	0.29	0.15	1.69	2.63	1.80	2.52
Total	40	6.92	3.93	0.62	5.66	8.17	1.47	16.14

Then the standard deviation (which is a measure of variability between the scores), a critical measure of variability or dispersion. Electricity has the least variation 0.29394 followed by LPG 0.44999 and on the higher side the greatest variation is encountered by the traditional three stone stove with 5.58131, followed by firewood improved stove hot 4.40364. However, the Levene Test of Homogeneity of variances of total heat energy in MJ is statistically significant F (9, 30) = 4.392, 0.001. This indicates that the ANOVA is not appropriate in this case. **Table 6-18** is Levene Test of homogeneity of variance for "heat energy use".

Table 6-18: Heat energy use Levene Test of homogeneity of variance

Total heat energy (MJ)			
Levene Statistic	df1	df2	Sig.
4.392	9	30	0.001

A Robust Test of Test of Equality of Means of total heat energy in MJ indicates that both Welch and Brown-Forsythe are statistically significant (Table 6-19).

Table 6-19: Robust test of equality of means of heat energy use

Total heat energy (MJ)				
	Statistic[a]	df1	df2	Sig.
Welch	55.492	9	11.932	0
Brown-Forsythe	8.122	9	7.537	0.004

a. Asymptotically F distributed.

Welch at F (9, 11.932) = 55.492, p = 000 and Brown-Forsythe at F (9, 7.537) = 8.122, 0.004. However, to contrast clearly the heat energy in MJ a Post Hoc Multiple Comparisons table is produced using Tukey HSD. This is done pairwise as indicated in **Table 6-20:**

Table 6-20: Multiple comparisons of heat energy use of the cooking devices

Multiple Comparisons						
Total heat energy (MJ)						
Tukey HSD						
(I) Cook_device	(J) Cook_device	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Firewood Traditional	Firewood Improved cold	-2.06	1.71	0.97	-7.89	3.77
	Firewood Improved Hot	3.32	1.71	0.64	-2.51	9.15
	Charcoal Traditional	3.04	1.71	0.74	-2.79	8.87
	Charcoal Improved cold	2.00	1.71	0.97	-3.83	7.83
	Charcoal Improved Hot	3.78	1.71	0.47	-2.06	9.61
	Ethanol	**6.84***	**1.71**	**0.01**	**1.01**	**12.67**
	Kerosene (paraffin)	**6.54***	**1.71**	**0.02**	**0.71**	**12.37**
	LPG (Butane)	**7.45***	**1.71**	**0.01**	**1.62**	**13.28**
	Electricity	**8.72***	**1.71**	**0.00**	**2.89**	**14.55**
Firewood Improved cold	Firewood Traditional	2.06	1.71	0.97	-3.77	7.89
	Firewood Improved Hot	5.38	1.71	0.09	-0.45	11.21
	Charcoal Traditional	5.10	1.71	0.13	-0.74	10.93
	Charcoal Improved cold	4.06	1.71	0.38	-1.77	9.89
	Charcoal Improved Hot	**5.83***	**1.71**	**0.05**	**0.00**	**11.67**
	Ethanol	**8.90***	**1.71**	**0.00**	**3.07**	**14.73**
	Kerosene (paraffin)	**8.60***	**1.71**	**0.00**	**2.77**	**14.43**
	LPG (Butane)	**9.51***	**1.71**	**0.00**	**3.68**	**15.34**
	Electricity	**10.78***	**1.71**	**0.00**	**4.95**	**16.61**
Firewood Improved Hot	Firewood Traditional	-3.32	1.71	0.64	-9.15	2.51
	Firewood Improved cold	-5.38	1.71	0.09	-11.21	0.45

	Charcoal Traditional	-0.28	1.71	1.00	-6.11	5.55
	Charcoal Improved cold	-1.32	1.71	1.00	-7.15	4.51
	Charcoal Improved Hot	0.46	1.71	1.00	-5.38	6.29
	Ethanol	3.52	1.71	0.57	-2.31	9.35
	Kerosene (paraffin)	3.22	1.71	0.68	-2.61	9.05
	LPG (Butane)	4.13	1.71	0.35	-1.70	9.96
	Electricity	5.40	1.71	0.09	-0.43	11.23
Charcoal Traditional	Firewood Traditional	-3.04	1.71	0.74	-8.87	2.79
	Firewood Improved cold	-5.10	1.71	0.13	-10.93	0.74
	Firewood Improved Hot	0.28	1.71	1.00	-5.55	6.11
	Charcoal Improved cold	-1.04	1.71	1.00	-6.87	4.80
	Charcoal Improved Hot	0.74	1.71	1.00	-5.09	6.57
	Ethanol	3.80	1.71	0.46	-2.03	9.63
	Kerosene (paraffin)	3.51	1.71	0.57	-2.33	9.34
	LPG (Butane)	4.42	1.71	0.27	-1.42	10.25
	Electricity	5.68	1.71	0.06	-0.15	11.51
Charcoal Improved cold	Firewood Traditional	-2.00	1.71	0.97	-7.83	3.83
	Firewood Improved cold	-4.06	1.71	0.38	-9.89	1.77
	Firewood Improved Hot	1.32	1.71	1.00	-4.51	7.15
	Charcoal Traditional	1.04	1.71	1.00	-4.80	6.87
	Charcoal Improved Hot	1.78	1.71	0.99	-4.06	7.61
	Ethanol	4.84	1.71	0.17	-0.99	10.67
	Kerosene (paraffin)	4.54	1.71	0.24	-1.29	10.37
	LPG (Butane)	5.45	1.71	0.08	-0.38	11.28
	Electricity	**6.72***	**1.71**	**0.01**	**0.89**	**12.55**
Charcoal Improved Hot . Ethanol	Firewood Traditional	-3.78	1.71	0.47	-9.61	2.06
	Firewood Improved cold	**-5.83***	**1.71**	**0.05**	**-11.67**	**0.00**
	Firewood Improved Hot	-0.46	1.71	1.00	-6.29	5.38
	Charcoal Traditional	-0.74	1.71	1.00	-6.57	5.09
	Charcoal Improved cold	-1.78	1.71	0.99	-7.61	4.06
	Ethanol	3.06	1.71	0.74	-2.77	8.90
	Kerosene (paraffin)	2.77	1.71	0.83	-3.07	8.60
	LPG (Butane)	3.68	1.71	0.51	-2.16	9.51
	Electricity	4.94	1.71	0.15	-0.89	10.78
	Firewood Traditional	**-6.84***	**1.71**	**0.01**	**-12.67**	**-1.01**
	Firewood Improved cold	**-8.90***	**1.71**	**0.00**	**-14.73**	**-3.07**
	Firewood Improved Hot	-3.52	1.71	0.57	-9.35	2.31
	Charcoal Traditional	-3.80	1.71	0.46	-9.63	2.03
	Charcoal Improved cold	-4.84	1.71	0.17	-10.67	0.99
	Charcoal Improved Hot	-3.06	1.71	0.74	-8.90	2.77
	Kerosene (paraffin)	-0.30	1.71	1.00	-6.13	5.53
	LPG (Butane)	0.61	1.71	1.00	-5.22	6.44
	Electricity	1.88	1.71	0.98	-3.95	7.71
Kerosene (paraffin)	Firewood Traditional	-6.54*	1.71	0.02	-12.37	-0.71
	Firewood Improved cold	**-8.60***	**1.71**	**0.00**	**-14.43**	**-2.77**
	Firewood Improved Hot	-3.22	1.71	0.68	-9.05	2.61
	Charcoal Traditional	-3.51	1.71	0.57	-9.34	2.33

	Charcoal Improved cold	-4.54	1.71	0.24	-10.37	1.29
	Charcoal Improved Hot	-2.77	1.71	0.83	-8.60	3.07
	Ethanol	0.30	1.71	1.00	-5.53	6.13
	LPG (Butane)	0.91	1.71	1.00	-4.92	6.74
	Electricity	2.18	1.71	0.95	-3.65	8.01
LPG (Butane)	**Firewood Traditional**	**-7.45***	**1.71**	**0.01**	**-13.28**	**-1.62**
	Firewood Improved cold	**-9.51***	**1.71**	**0.00**	**-15.34**	**-3.68**
	Firewood Improved Hot	-4.13	1.71	0.35	-9.96	1.70
	Charcoal Traditional	-4.42	1.71	0.27	-10.25	1.42
	Charcoal Improved cold	-5.45	1.71	0.08	-11.28	0.38
	Charcoal Improved Hot	-3.68	1.71	0.51	-9.51	2.16
	Ethanol	-0.61	1.71	1.00	-6.44	5.22
	Kerosene (paraffin)	-0.91	1.71	1.00	-6.74	4.92
	Electricity	1.27	1.71	1.00	-4.56	7.10
Electricity	**Firewood Traditional**	**-8.72***	**1.71**	**0.00**	**-14.55**	**-2.89**
	Firewood Improved cold	**-10.78***	**1.71**	**0.00**	**-16.61**	**-4.95**
	Firewood Improved Hot	-5.40	1.71	0.09	-11.23	0.43
	Charcoal Traditional	-5.68	1.71	0.06	-11.51	0.15
	Charcoal Improved cold	**-6.72***	**1.71**	**0.01**	**-12.55**	**-0.89**
	Charcoal Improved Hot	-4.94	1.71	0.15	-10.78	0.89
	Ethanol	-1.88	1.71	0.98	-7.71	3.95
	Kerosene (paraffin)	-2.18	1.71	0.95	-8.01	3.65
	LPG (Butane)	-1.27	1.71	1.00	-7.10	4.56

*. The mean difference is significant at the 0.05 level.

The Means for "total heat energy" are categorized in four subsets, according to their statistical significance. Table 6-21 shows means in the homogeneous subsets. Looking at the means reveals that there is an overlap between the means as revealed in the subsets. The most overlapping appliances happen to be "Firewood Improved Hot" and the "Charcoal Traditional". In other words, these two appliances are in all the four subsets. This indicates that they not statistically different from the rest of the appliance in terms of heat energy consumption.

Table 6-21: Total heat energy use in MJ (means of groups)

Tukey HSD					
Cook device	N	Subset for alpha = 0.05			
		1	2	3	4
Electricity	4	2.16			
LPG (Butane)	4	3.43	3.43		
Ethanol	4	4.04	4.04		
Kerosene (paraffin)	4	4.34	4.34		

Charcoal Improved Hot	4	7.1	7.1	7.1	
Firewood Improved Hot	4	7.56	7.56	7.56	7.56
Charcoal Traditional	4	7.84	7.84	7.84	7.84
Charcoal Improved cold	4		8.88	8.88	8.88
Firewood Traditional	4			10.88	10.88
Firewood Improved cold	4				12.94
Sig.		0.061	0.082	0.473	0.09

Means for groups in homogeneous subsets are displayed.

In subset 1 there is electricity (which consumes the least energy) followed by LPG, ethanol, kerosene Charcoal Improved Hot, Firewood Improved Hot, Charcoal Traditional respectively. But the second subset has LPG, ethanol, kerosene, Charcoal Improved Hot, Firewood Improved Hot, Charcoal Traditional and Charcoal Improved respectively. Subset 3 has Charcoal Improved Hot, Firewood Improved Hot, Charcoal Traditional, Charcoal Improved Cold and Firewood Traditional respectively. Firewood Improved Hot, Charcoal Traditional, Charcoal Improved Cold, Firewood Traditional and Firewood Improved Cold respectively.

6.5. Cost of Cooking

The annual cooking costs in US$ are calculated and given in Table 6-22.

Table 6-22: Annual cooking costs (US $)

Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
Annual_CookCost					Lower Bound	Upper Bound		
1. Firewood Traditional	4	55.66	12.90	6.45	35.14	76.19	38.69	65.70
2. Firewood Improved cold	4	51.28	3.64	1.82	45.48	57.08	47.45	54.75
3. Firewood Improved Hot	4	38.87	6.12	3.06	29.14	48.61	30.66	45.26
4. Charcoal Traditional	4	65.88	8.18	4.09	52.87	78.90	54.75	74.46
5. Charcoal Improved cold	4	74.46	9.33	4.66	59.61	89.31	64.24	84.68
6. Charcoal Improved Hot	4	59.68	14.71	7.36	36.26	83.09	44.53	79.57
7. Ethanol	4	87.60	11.68	5.84	69.01	106.19	70.08	93.44
8. Kerosene (paraffin)	4	96.00	26.90	13.45	53.19	138.80	56.21	112.42
9. LPG (Butane)	4	169.36	22.37	11.18	133.77	204.95	140.16	186.88

10. Electricity	4	87.60	11.92	5.96	68.63	106.57	73.00	102.20
Total	40	78.64	37.43	5.92	66.67	90.61	30.66	186.88

Assumption

These costs are computed according to the daily cooking costs which in practice vary just as the quantity and type of food keeps on changing. But for this calculation quantity (costs of cooking 1 kg), quality of food (rice) and price of fuels are all kept constant.

Two meals a day is an assumption for common practice. Some household have one other have three meals a day.

Common year (365 days). Unlike a leap year with one additional day to maintain the calendar year synchronized with the seasonal year (366 days).

Cooking costs = daily cooking costs × 2 × 365 days

The minimum mean costs of cooking are $38.87 and maximum are $169.36. The Improved Charcoal Stove Hot is the one with the lowest costs $38.87 among all devices, while among the biomass devices the maximum is the Charcoal Improved Cold $74.46. But the costs for none biomass cooking system are more than those of biomass. The lowest among the non-biomass is the one for ethanol $87.60 and the highest is $169.36. A test of Homogeneity of variances was conducted for the annual cooking costs and results were not significant (Table 6-23).

Table 6-23: Annual cooking cost test of homogeneity of variance

Test of Homogeneity of Variances				
Annual_CookCost (US $)				
Levene Statistic		df1	df2	Sig.
2.131		9	30	0.058

Therefore, the Analysis of Variance was performed, Table 6-23and results are recorded in

Table 6-24: Annual Cooking cost ANOVA

ANOVA					
Annual_CookCost (US $)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	48358.13	9	5373.1	0.71	0.00

Within Groups	6269.435	30	208.98		
Total	54627.566	39			

There was a statistically significant difference between the groups as determined by one-way Analysis of Variance (F(9, 30) = 0.711, p=000). Pairwise comparison was made to contrast the cooking devices in regard to the annual costs of cooking and the results are given in Table 6-25.

Table 6-25: Annual cooking cost multiple comparisons

Annual_CookCost (US $)

Tukey HSD

(I) Cook_device	(J) Cook_device	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Firewood Traditional	Firewood Improved Cold	4.38	10.22	1.00	-30.49	39.25
	Firewood Improved Hot	16.79	10.22	0.82	-18.08	51.66
	Charcoal Tradition	-10.22	10.22	0.99	-45.09	24.65
	Charcoal Improved Cold	-18.8	10.22	0.71	-53.67	16.07
	Charcoal Improved Hot	-4.02	10.22	1.00	-38.88	30.85
	Ethanol	-31.94	10.22	0.09	-66.81	2.93
	Kerosene (Paraffin)	**-40.33***	**10.22**	**0.01**	**-75.20**	**-5.46**
	LPG (Butane)	**-113.70***	**10.22**	**0.00**	**-148.57**	**-78.83**
	Electricity	-31.94	10.22	0.09	-66.81	2.93
Firewood Improved Cold	Firewood Traditional	-4.38	10.22	1.00	-39.25	30.49
	Firewood Improved Hot	12.41	10.22	0.96	-22.46	47.28
	Charcoal Tradition	-14.6	10.22	0.91	-49.47	20.27
	Charcoal Improved Cold	-23.18	10.22	0.44	-58.05	11.69
	Charcoal Improved Hot	-8.4	10.22	1.00	-43.26	26.47
	Ethanol	**-36.32***	**10.22**	**0.04**	**-71.19**	**-1.45**
	Kerosene (Paraffin)	**-44.72***	**10.22**	**0.01**	**-79.58**	**-9.84**
	LPG (Butane)	**-118.08***	**10.22**	**0.00**	**-152.95**	**-83.21**
	Electricity	**-36.32***	**10.22**	**0.04**	**-71.19**	**-1.45**
Firewood Improved Hot	Firewood Traditional	-16.79	10.22	0.82	-51.66	18.08
	Firewood Improved Cold	-12.41	10.22	0.96	-47.28	22.46
	Charcoal Tradition	-27.01	10.22	0.24	-61.88	7.86
	Charcoal Improved Cold	**-35.59***	**10.22**	**0.04**	**-70.46**	**-0.72**
	Charcoal Improved Hot	-20.81	10.22	0.58	-55.67	14.06
	Ethanol	**-48.73***	**10.22**	**0.00**	**-83.60**	**-13.86**
	Kerosene (Paraffin)	**-57.12***	**10.22**	**0.00**	**-91.99**	**-22.25**
	LPG (Butane)	**-130.49***	**10.22**	**0.00**	**-165.36**	**-95.62**
	Electricity	**-48.73***	**10.22**	**0.00**	**-83.60**	**-13.86**
Charcoal Tradition	Firewood Traditional	10.22	10.22	0.99	-24.65	45.09
	Firewood Improved Cold	14.6	10.22	0.91	-20.27	49.47
	Firewood Improved Hot	27.01	10.22	0.24	-7.86	61.88
	Charcoal Improved Cold	-8.58	10.22	1.00	-43.45	26.29
	Charcoal Improved Hot	6.21	10.22	1.00	-28.66	41.07
	Ethanol	-21.72	10.22	0.53	-56.59	13.15
	Kerosene (Paraffin)	-30.11	10.22	0.14	-64.98	4.76

	LPG (Butane)	**-103.48***	**10.22**	**0.00**	**-138.35**	**-68.61**
	Electricity	-21.72	10.22	0.53	-56.59	13.15
Charcoal Improved Cold	Firewood Traditional	18.8	10.22	0.71	-16.07	53.67
	Firewood Improved Cold	23.18	10.22	0.44	-11.69	58.05
	Firewood Improved Hot	**35.59***	**10.22**	**0.04**	**0.72**	**70.46**
	Charcoal Tradition	8.58	10.22	1.00	-26.29	43.45
	Charcoal Improved Hot	14.78	10.22	0.90	-20.09	49.65
	Ethanol	-13.14	10.22	0.95	-48.01	21.73
	Kerosene (Paraffin)	-21.54	10.22	0.54	-56.40	13.33
	LPG (Butane)	**-94.90***	**10.22**	**0.00**	**-129.77**	**-60.03**
	Electricity	-13.14	10.22	0.95	-48.01	21.73
Charcoal Improved Hot	Firewood Traditional	4.02	10.22	1.00	-30.85	38.88
	Firewood Improved cold	8.4	10.22	1.00	-26.47	43.26
	Firewood Improved Hot	20.81	10.22	0.58	-14.06	55.67
	Charcoal Tradition	-6.21	10.22	1.00	-41.07	28.66
	Charcoal Improved Cold	-14.78	10.22	0.90	-49.65	20.09
	Ethanol	-27.92	10.22	0.21	-62.79	6.95
	Kerosene (Paraffin)	**-36.32***	**10.22**	**0.04**	**-71.19**	**-1.45**
	LPG (Butane)	**-109.68***	**10.22**	**0.00**	**-144.55**	**-74.81**
	Electricity	-27.92	10.22	0.21	-62.79	6.95
Ethanol	Firewood Traditional	31.94	10.22	0.09	-2.93	66.81
	Firewood Improved cold	**36.32***	**10.22**	**0.04**	**1.45**	**71.19**
	Firewood Improved Hot	**48.73***	**10.22**	**0.00**	**13.86**	**83.60**
	Charcoal Tradition	21.72	10.22	0.53	-13.15	56.59
	Charcoal Improved Cold	13.14	10.22	0.95	-21.73	48.01
	Charcoal Improved Hot	27.92	10.22	0.21	-6.95	62.79
	Kerosene (Paraffin)	-8.40	10.22	1.00	-43.26	26.47
	LPG (Butane)	**-81.76***	**10.22**	**0.00**	**-116.63**	**-46.89**
	Electricity	0	10.22	1.00	-34.87	34.87
Kerosene (Paraffin)	**Firewood Traditional**	**40.33***	**10.22**	**0.01**	**5.46**	**75.20**
	Firewood Improved cold	**44.71***	**10.22**	**0.01**	**9.84**	**79.58**
	Firewood Improved Hot	**57.12***	**10.22**	**0.00**	**22.25**	**91.99**
	Charcoal Tradition	30.11	10.22	0.14	-4.76	64.98
	Charcoal Improved Cold	21.53	10.22	0.54	-13.33	56.40
	Charcoal Improved Hot	**36.32***	**10.22**	**0.04**	**1.45**	**71.19**
	Ethanol	8.40	10.22	1.00	-26.47	43.26
	LPG (Butane)	**-73.37***	**10.22**	**0.00**	**-108.23**	**-38.50**
	Electricity	8.395	10.22	1.00	-26.47	43.26
LPG (Butane)	**Firewood Traditional**	**113.70***	**10.22**	**0.00**	**78.83**	**148.57**
	Firewood Improved cold	**118.08***	**10.22**	**0.00**	**83.21**	**152.95**
	Firewood Improved Hot	**130.49***	**10.22**	**0.00**	**95.62**	**165.36**
	Charcoal Tradition	**103.48***	**10.22**	**0.00**	**68.61**	**138.35**
	Charcoal Improved Cold	**94.90***	**10.22**	**0.00**	**60.03**	**129.77**
	Charcoal Improved Hot	**109.68***	**10.22**	**0.00**	**74.81**	**144.55**
	Ethanol	**81.76***	**10.22**	**0.00**	**46.89**	**116.63**
	Kerosene (Paraffin)	**73.37***	**10.22**	**0.00**	**38.50**	**108.23**
	Electricity	**81.76***	**10.22**	**0.00**	**46.89**	**116.63**
Electricity	Firewood Traditional	31.94	10.22	0.09	-2.93	66.81

	Firewood Improved cold	**36.32***	**10.22**	**0.04**	**1.45**	**71.19**
	Firewood Improved Hot	**48.73***	**10.22**	**0.00**	**13.86**	**83.60**
	Charcoal Tradition	21.72	10.22	0.53	-13.15	56.59
	Charcoal Improved Cold	13.14	10.22	0.95	-21.73	48.01
	Charcoal Improved Hot	27.92	10.22	0.21	-6.95	62.79
	Ethanol	0	10.22	1.00	-34.87	34.87
	Kerosene (Paraffin)	-8.40	10.22	1.00	-43.26	26.47
	LPG (Butane)	**-81.76***	**10.22**	**0.00**	**-116.63**	**-46.89**

*. The mean difference is significant at the 0.05 level.

Results in the multiple table of comparison indicate that several devices show a statistically significant difference. The statistically significant figures indicate that the annual cooking costs (in $ US) are different.

The subsets of homogeneous categories indicate that there are five groups of means statistically the same, yet each group overlaps the succeeding one or even the one after the succeeding one. These groups are given in the homogeneous test in Table 6-26. In subset 1 the cheapest stove is recorded but it is not but it is not nature to have a hot stove unless you warm. Still the two stoves are in the same subset, though the cold belongs also to the second subset. What is outstanding in Table 6-26 is the fact that the gas is alone in its own subset and it is the one with the highest cooking costs. This explains why most people would prefer kerosene to gas. As can be seem from

Table 6-26: Annual cooking cost homogeneous test.

Annual Cooking Cost (US $)

Tukey HSD						
Cook_device	N	Subset for alpha = 0.05				
		1	2	3	4	5
Firewood Improved Hot	4	38.87				
Firewood Improved cold	4	51.28	51.28			
Firewood Traditional	4	55.66	55.66	55.66		
Charcoal Improved Hot	4	59.68	59.68	59.68		
Charcoal Tradition	4	65.88	65.88	65.88	65.88	
Charcoal Improved Cold	4		74.46	74.46	74.46	
Ethanol	4			87.6	87.6	
Electricity	4			87.6	87.6	
Kerosene (Paraffin)	4				96.1	
LPG (Butane)	4					169.36
Sig.		0.242	0.437	0.094	0.137	1

Means for groups in homogeneous subsets are displayed.

Figure 6.4 the costs of cooking with kerosene can be identified with other fuels or stoves: Charcoal Traditional, Charcoal Improved Cold, Ethanol, Ethanol and Electricity. It indicates the cost of cooking [US$ x (h x 100)] multiplied by time and unit energy price US$/GJ. This multiplication is based on the assumption that the most attractive option is that which is both cheap and fast (takes less money and less time). Surpringly, the Improved Firewood Stove hot becomes the best option because of the ceramic liner which acts as a source of radiant heat.

The Traditional Firewood Stove becomes the second best because of ease of lighting. There is a minor increase between Improved Firewood Stove cold and the Traditional Firewood Stove and it looks like the two stoves might overlap at one point and overtake each other at different times, depending on the items being cooked. On the other hand looking at the maximum (cost*time), Butane (gas) takes the highest position followed by the cold Improved Charcoal Stove then Electricity, Paraffin and Gel. This means that the cheapest fuel is the firewood, even if one integrates the cooking cost and time.

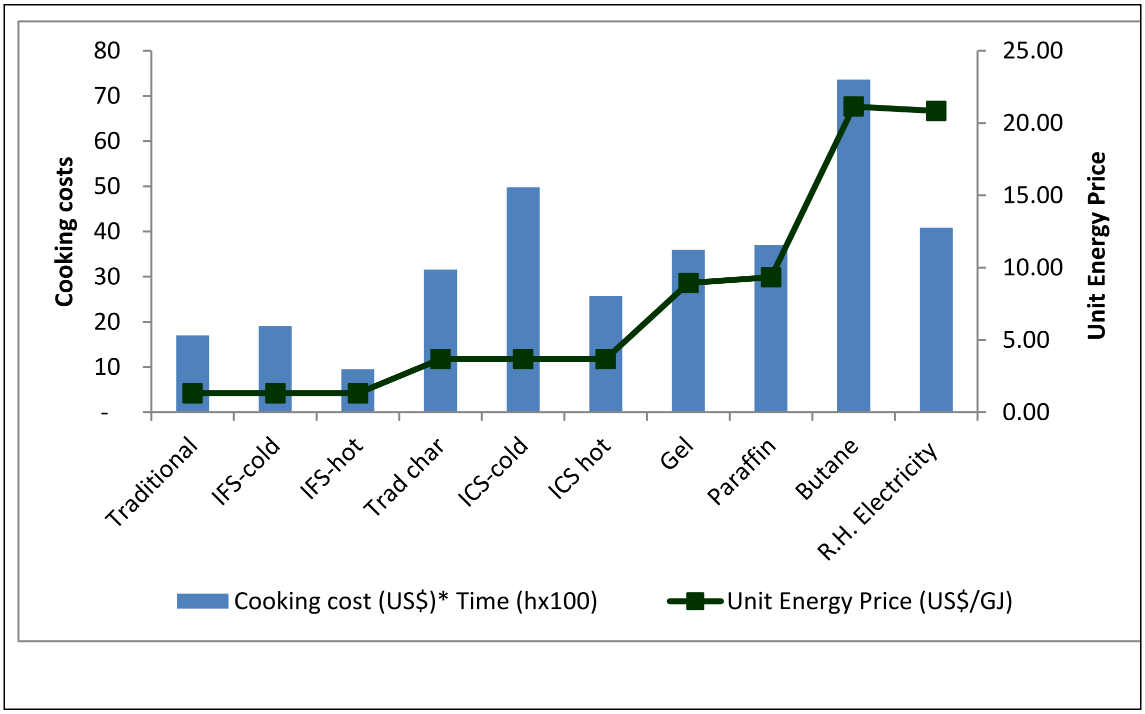


Figure 6.4: Cost of cooking

Among the cooking devices biogas is the cheapest in terms of annual fuel costs because it has no fuel costs (the fuel is not purchased). The Hot Improved Firewood Stove (IFS-hot), is the second cost-effective device, but as noted earlier the device does not exist in its hot form: it has to be made hot. The third cost effective device is the Cold Improved Firewood Stove (IFS – cold): this is what is warmed to obtain the hot one. So among the cooking fuels the improved cookstove is the most cost effective, and among all the cooking devices (apart from biogas and IFS-hot) it is the most saving device. Butane (gas) is the most is the most expensive in terms of fuel.

Biogas is investment disproportionately too high ($1,000). Whereas it is cheaper in relation to fuel it is the costliest in terms of capital investment costs. This could explain why few households have biogas despite its great benefits. It is followed by butane (gas), electricity (red hot) and paraffin (kerosene). The prices for the rest of the stoves are almost negligible is an attempt to eliminate biogas, butane (gas) and Electricity (red hot) in order to make the investment costs and annual average costs of the remaining devices visible.

Concerning Life Time (years), it could be urged that the three stone fire has the least durability, but it also costs nothing. But the stove that bears the least costs is the Traditional Charcoal stove (1 year) and it is followed by IFS-cold or hot (1.5 years). On the other hand, the device that lasts longest is the biogas followed by Electric cooker (red hot). On this note I have to state that the duration of the cooking device depends on the handling. Annual average total costs integrate the three components: annual fuel costs, capital investment and lifetime. Again, biogas is the most expensive, followed by butane and Electricity (red hot), and the rest are negligible.

CHAPTER 7

PROJECTIONS OF FUTURE SCENARIO

Having analyzed biomass scarcity (chapter 4) and confirming it by detailed investigation of biomass stock (chapter 5), the author made an inquiry into several cooking options (chapter 6) and decided to choose LPG (gas) to be the necessary substitute for biomass. In chapter 7 an introduction to the increasing demand and diminishing supply is portrayed. The equilibrium points at which demand, and supply are equal is depicted. Beyond this point it's a negative balance, widening the gap between demand and supply. Yet this is biomass at national level. Practical reality happens at local level at least some of the districts are facing severe lack of fuelwood. This is the core essence of unsustainability. The main drivers of biomass decline are pointed out: population growth – everyone requires biomass for cooking, agricultural expansion – everyone requires food for survival: hence more land is put under cultivation, and deforestation: because of woodfuel and agricultural expansion. Then the projection of different scenarios will be made and described: business as usual scenario, efficiency scenario for households, reduced population growth and gas for commercial subsector; reduced population growth, switching to gas for commercial sub-sector and middle class, and the remaining wood balance.

7.1. The Trend of Biomass Demand and Supply

There is a data gap, for a period of 5 years: no data could be obtained about wood consumption. Nevertheless, a comparison between demand and supply indicates a positive balance before 2004, an equilibrium by 2005 and thereafter a negative balance continues to date. Of course, this assumes that the increasing population increases demand and depletes supply. Data on demand in 1990 – 1998 and 2003 – 2011 was obtained from NFA and UBOS respectively, and confirmed by data from MEMD, while the supply comes from a decline in the two biomass studies separated by a period of 15 years: 1990 – 2005. The graph is shown in **Figure 7.1.**

7.1. Biomass Demand

The quantity of wood in Tons of Oil Equivalent (TOE) that was consumed in 2010 was **16,320,661**. This was broken down as follows: 1st , 2nd and 3rd rows give the quantity in terms of sectors: Residential, Industrial and Commercial and Institution for firewood, residues and charcoal (2, 3 and 4), while column 5 gives the quantity of charcoal multiplied by 10 to get the approximate amount of wood carbonized. Of course this ignores the quantity that turned to charcoal fines during transportation and selling. The last column gives the total. The total wood equivalent (wood plus charcoal) is given in column 5 and the last conversion (given in column 6) is calculated in terms of tons of wood (**Table 7-1**).

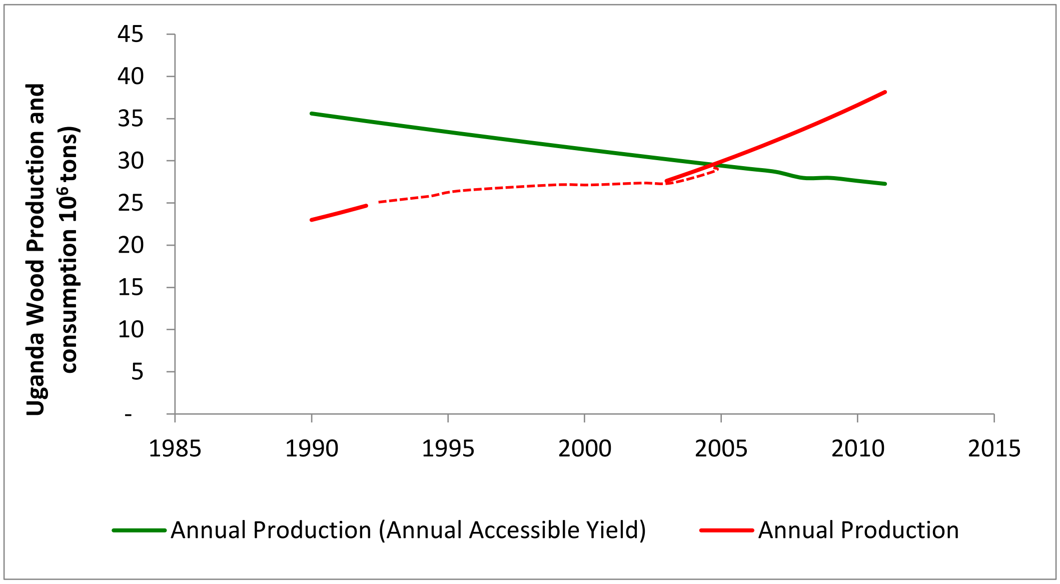


Figure 7.1: Demand Compared to Supply

1 Ton of Wood = 15 GJ.

Table 7-1 Quantities of Firewood and Charcoal in Different Sectors

Sector	**Firewood (million tons)**	**Residues**	**Charcoal (million tons)**	**Charcoal Wood equivalent**	**Total wood equivalent**
Household	18.0	1.50	0.597	12.26	34.5
Industrial	4.0				6.4
Commercial and institution	4.8		0.293	6.02	2.8
	25.1		**0.890**	**18.28**	**45.5**

(FAO, 1997; MEMD, 2012)

The quantity of wood consumed in household in 2010 is in agreement with the estimated figures of energy balance of 2014, with a difference of - 452,440 which may be accounted for by the conversions or population. The fact that the estimates of the population were used for the case of 2010, while the actual population figures were used to estimate the consumption, shows that not much has changed during the previous decade.

The category of sectors consuming wood are household, industry and commerce. The main sector in the consumption of wood is household and it can be big or small, consuming firewood or charcoal, both being categorized as woodfuel. The second sector that takes wood least amount of wood but will take the largest proportion of wood by 2050 is the commercial sector which includes small and large restaurants and cooking by road side including breakfast, lunch and super. Then the third sector is the industrial.

7.1.1. The Population Growth

Population growth is the main driver of consumption of woodfuel which influences woodfuel and charcoal consumption. Uganda's population grew from 6 million people to 34 million from 1955 to 2014, and is expected to increase to more than 100 million as shown in **Figure 7.2** (Worldometers, 2017).

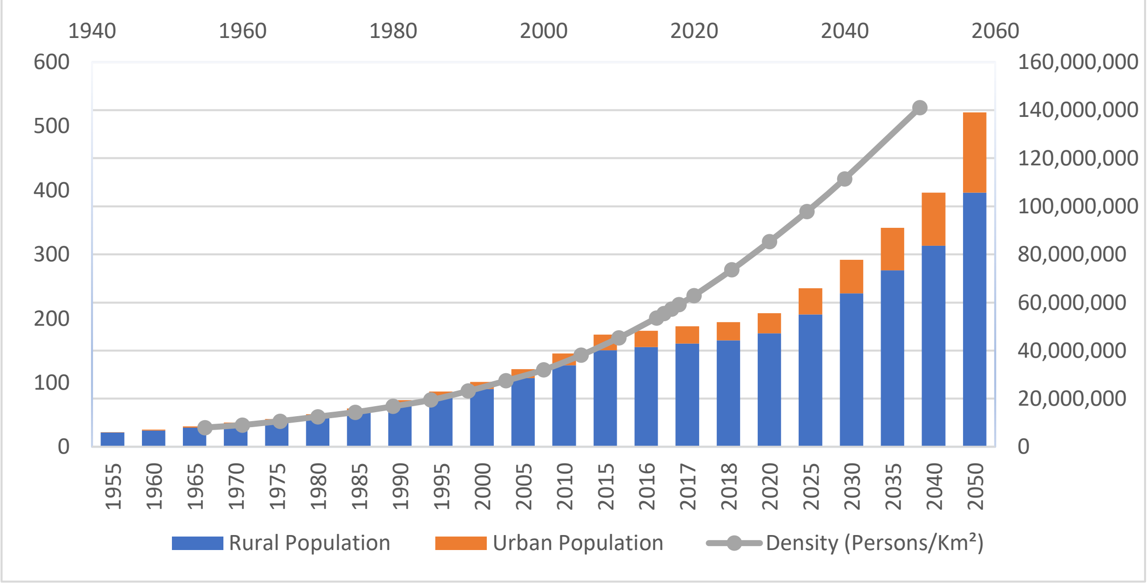


Figure 7.2: Population growth of Uganda

Source: data in Appendix C.1. UN, 2014.

Uganda has one of fastest growing population in the world and it goes unchecked. The population characteristics include increasing population both in rural and urban areas. In the same way the population density in terms of persons per km^2 has increased to 5.6 times during the same period (World Bank , 2017; Expansion, 2015; Worldometers, 2017). The only single factor that will stop Uganda from achieving vision 2040 is the high population growth rate, characterized by young age structure hence increasing child dependence burden (UNFPA, 2017).

Fertility is the measure of reproductive activity of a woman throughout her life. One indicator of fertility is the Total Fertility Rate (TFR) which may be defined as the number of children a woman can give birth during the age of her child bearing (15 – 49) (UBOS, 2016). TFR varies according to the type of residence, education, and economic status of the woman. Uneducated women living in rural areas have twice as many children as those with secondary or higher education (7.7 children compared to 4.4) (Kyaddondo Betty, 2011). Education is the key that empowers a person towards economic development and general welfare; and it is one of the major determinants that influence one’s knowledge, attitude and behavior (UBOS, 2013, p. 19).

Along with education urbanization puts pressure on the family due to the scarcity of resources for women. Women who are educated tend to show different pattern of behavior, consumer choice and general awareness about the costs related to the family and able to plan accordingly. Second, the years spent in school and in the University, reduce the possibility of having a high fertility rate. Thirdly, in addition to educated women get a lot of pressure from professional work which tends to reduce time for rearing children; hence their total fertility rate goes down (they are unwilling to have many children). Nevertheless, the Uganda’s urban population is only 17.1% (7,583,654 people in 2018) and the employment rate decreased to 47.8% in 2012 from 88.3% in 2009. That means there is no serious impact yet on women.

The population growth rate gives no time to have recovery for the environment. This would be disastrous for the environment because the greater the population the less the trees. This is not only because of demand for fuelwood and housing contraction materials, but also demand for space for settling and carrying out economic activities, especially farming. Other negative impacts include severe soil erosion, rapid desertification and competition for woodfuel.

The population living in the urban area will increase from the current 6.1 million to more than 32 million by 2050. This is because due to concentration of economic activities wages are higher (on average) and poverty levels are lower in the urban compared to the rural areas. However the key challenge facing urbanization is that the rate of job creation is lower than the rate of growth in urban population; the result is unemployment and underemployment becomes the order of the day. Furthermore, congestion restricts movement of people and goods, and for a large section of the population, quality housing remains a challenge. In addition, the delivery of quality services pauses a big challenge (The World Bank, 2015).

The situation can become even worse as population grows. The economic, social and environmental threats like overcrowding, flooding of water, air pollution and serious health risks are already too great, even with this meager 12% of urban dwellers. It would be necessary to have a clear urban plan which includes jobs, food, transport, housing, school, health, and sanitation and recreation facilities in order to enable the absorption of influx of people from the rural to urban centres (Kyaddondo Betty, 2011). On the other hand, driving factors like demographic factors, the increase in modernization of agriculture, the increase in non-farm activities and the expected beginning of oil exploration are expected to draw a greater proportion of the population towards the cities and towns (The World Bank, 2015, p. vi).

The driving factors sustaining high total fertility rate are gender inequality and low status of women; a culture placing high value on children as security for their old parents; children as a source of labour; sex preference by some parents; lack of family planning ervices and poverty (Kyaddondo Betty, 2011). The National Population Council (NPC) secretariat gives the following causes of high Total Fertility Rate: high unmet need for family planning of 28%, low contraceptive use of 39%, high desired family size of 5.7 for men and 4.8 for women, high teenage pregnancy of 25 and male sex preference by couples (NPC Secretariat, 2016). Consequently, about half of Uganda’s population (48.5%) is below 14 years of age; 28.3% is in the 25-64 age group; 21.2% mainly consists of 15-24 age group and only 2.04% of the population is above 65

This is because Uganda, which is one of the poorest countries in SSA, has at the same time the highest teenage pregnancy in SSA, with half of the girls giving birth at an age below 18; and with a national teenage pregnancy of 25% . This suggests that teenage pregnance is mainly caused by poverty, in that the girls are easily seduced by men who are mature and are working. The girls accept in order to gain some money so meet their social and physical needs. Because they lack the means of protection they risk unprotected sex, which ends up traping them with pregnancy. The victims experience fear, panic and illness due to unplanned pregnancy and in many cases the girls get married before ending their childhood (Kyaddondo Betty, 2011).

7.1.2. Agricultural Expansion and Soil Exhaustion

The high population density imposes several restrictions on land use. First, it limits the expansion of agricultural production per capita and puts restraint on tree production (reforestation). Secondly, the limited size of land only encourages subsistence farming rather than commercial agriculture. Third, land which is cultivated several times needs time to rest, but this is not possible where land is scarce. Consequently, soil exhaustion occurs due to repeated cultivation. Fourth, subsistance farming does not encourage use of fertilizers or protection against soil erosion, leaching, and nutrient losses. The underlying driving factors maybe related to poverty, lack of access roads, infrastructure, market, limited farmer awareness of appropriate technology, land fragmentation, and tenure insecurity, etc. (Ephraim Nkonya, 2012).

However, Pander et al, did not find conclusive evidence that population pressure was responsible for land degradation since farmers tend to adopt inputs such as manure and fertlizers and seeking off-farm livelihood (Ephraim Nkonya, 2012). But this depends on the level of population increase. Population density was associated with lower yields and soil erosion.

7.1.3. Deforestation

U.N. FAO, estimates that only 15.2% (which is about 2,988,000 ha of Uganda is forested and the planted forest constitutes only 51,000. Between 1990 and 2010 Uganda lost an average of 88,150 ha or 1.86%, which comes to a total of 37.1% of its forest cover, or about 1,763,000 ha. Deforestation continues today at a rate of 2.2 percent per year, mostly due to subsistence farming, cutting for fuelwood, and colonization by the expanding population (U.N. , 2004).

According to estimate of 2010 the household, commercial and industrial woodfuel consumption was 32,067,706, 10,231,418 and 3,166,476, totaling up to 45,572,458 for woodfuel. If a factor of 8.1% is included to cater for sown timber the overall total wood consumption would be 49,263,827. Demand steady increases as shown in **Figure 7.3**.

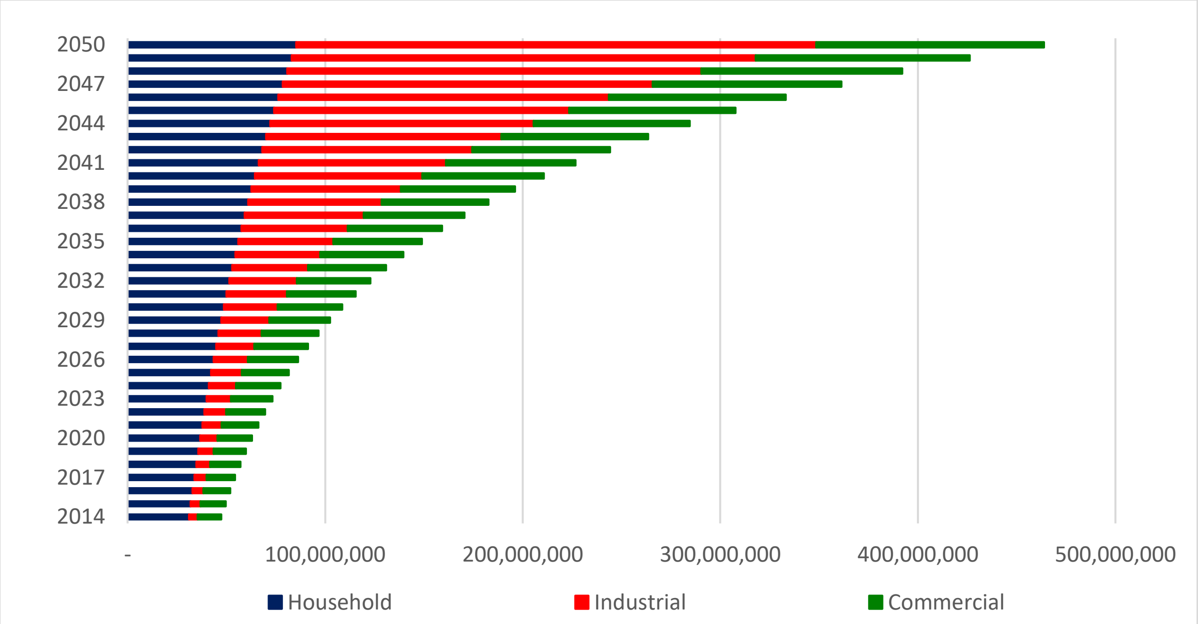


Figure 7.3: The growth and increase of the sectors demand biomass

Source: Calculation in Appendix C.2

7.2. Biomass Supply

Assuming the population growth does not change (3.03%), and commercial and industrial sector continue to grow at the same rate of 6.5% and 12.0% respectively, and the non-energy use of wood (pole and timber) continues to grow at 8.1%, then the biomass would continue to decline until all the sustainable yield that is accessible (privately owned land) is completely depleted. **Table 7-2** shows the year when the accessible yield will be finished, total biomass demand, biomass stock, annual accessible yield in percentage, sustainable yield based on annual accessible yield and biomass balance.

Table 7-2: Total Biomass Demand, Biomass Stock and Sustainable Yield

Year	Total Biomass Demand	Biomass Stock	[a]% AAY	[b]S.Y.AAY (tons)	Balance (tons)
2010	47,190,206	180,539,759	5%	9,568,607	(37,621,599)
2011	49,263,827	142,918,160	5%	7,574,663	(41,689,165)
2012	51,457,710	101,228,996	5%	5,365,137	(46,092,573)
2013	53,781,102	55,136,423	5%	2,922,230	(50,858,871)
2014	56,244,119	4,277,551	5%	226,710	(56,017,408)
2015	58,857,837	(51,739,857)	5%	(2,742,212)	(1,600,050)
2016	61,039,260	(113,940,366)	5%	(5,697,018)	(66,736,278)
2017	63,829,545	(180,676,644)	5%	(9,033,832)	(72,863,377)
2018	66,793,050	(253,540,022)	5%	12,677,001)	(79,470,052)

[a]Annual Accessible Yield; [b]Sustainable Yield from Annual Accessible Yield

But if all areas producing biomass are considered, then the percentage annual accessible yield would be: 29141034 ÷204107129 = 14.2%. Even if this figure (14.2%) is held constant, still the annual accessible yield from private land would be finished by 2016. Even then, there is no substantial difference in quantity that could be considered nor is there a difference in time that can be regarded as substantial. Given the prevailing conditions the time it would take to have all the biomass from the private areas to be depleted would not exceed 2018 as seen in Table 7-3

Table 7-3: The Biomass Increase – Taking a Conservative Scenario

Year	Total Demand	Biomass Stock	% AAY	S.Y.AAY (tons)	Balance (tons)

2010	47,190,206	180,539,759	14%	25,275,566	(21,914,640)
2011	49,263,827	158,625,119	14%	22,207,517	(27,056,310)
2012	51,457,710	131,568,809	14%	18,419,633	(33,038,077)
2013	53,781,102	98,530,732	14%	13,794,303	(39,986,799)
2014	56,244,119	58,543,933	14%	8,196,151	(48,047,968)
2015	58,857,837	10,495,965	14%	1,469,435	(57,388,402)
2016	61,634,397	(46,892,437)	14%	(6,564,941)	(68,199,338)
2017	63,829,545	(113,301,674)	14%	(15,862,234)	(79,691,779)
2018	66,793,050	(192,993,454)	14%	(27,019,083)	(93,812,134)

The conclusion is clear that given the status quo, the Ugandan community will continue to suffer woodfuel scarcity, and scarcity of land due to increased population and no option to grow trees. That is the general impression that is created by the projection. However, there are certain aspects that need to be born in mind.

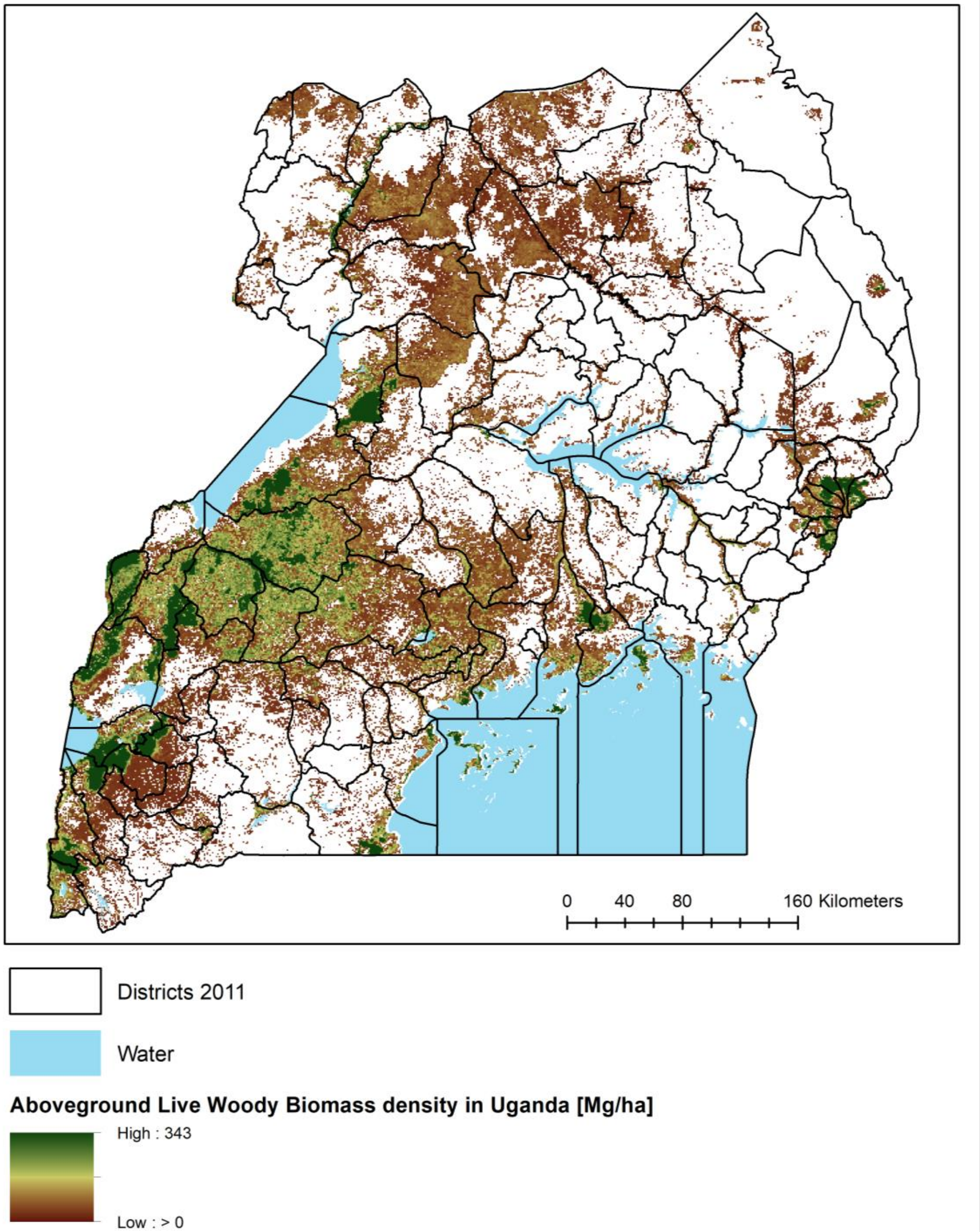
First, as the price for commercial and industrial wood increases, there is a tendency to switch towards modern fuels. Biomass is partly preferred because it is inexpensive. On the other hand, the households also tend to skip some of the cooking activities that consume a lot of biomass.

Second, FAO, estimates that the biggest proportion (42%) of woodfuel is obtained from scattered trees (Trossero), according to the wood supply study by type of land in Viet Nam (**Figure 2.2**). That suggests that the main wood supply source is not actually the forest. The degraded forests and other sources contribute only 28%. The plantations and industrial plantations contribute 20% and 10% respectively.

Third, biomass by its nature is locally produced and consumed not far from the same vicinity. Therefore, it is not factually true that biomass in Uganda is zero or negative. This is because there could be a lot of biomass in one area (perhaps because of a lower population and low accessibility), while at the same time there could be severe scarcity biomass within a radius of 10 km where there is high population density. In other words biomass that lies within a radius of 10 km and beyond is considered inaccessible because of distance.

This means that within such a small area, there could be a very severe scarcity of biomass and all the indicators of lack of it can be experienced. On the one hand, selective cooking is inevitable including reduced number, variety, quantity and type of meal per day (avoiding hard foods); on the other hand, cooking with inferior fuels like grass, leaves, reeds, and other inferior biomass. This is because biomass is a poor man’s fuel, incapable of adjusting to long distances because of costs.

Generally, biomass is scanty in most parts of Uganda, especially the northern area and the extreme southern part of Uganda. It is in the central and western part that biomass is concentrated as shown in **Figure 7.4**.



(A. Baccini, 2012) Author has included the districts.

Figure 7.4: Live Woody Biomass Density in Uganda (Mg/ha**)**

Furthermore, it does not really make economic sense to transport biomass for a long distance due to low energy density. In other words, it becomes too expensive to transport biomass fuel, instead, substitution is logical. What happens, the affluent can sometimes afford wood even if it is too expensive or the substitute fuel; while the poor reduce on their meals per day or try to use the inferior fuels or avoid certain cooking or boiling tasks that can be considered luxurious.

7.3. Business-as-Usual Scenario

The following assumptions have been adopted based on the status quo. The population is assumed to slightly more or less than 3% (see **Figure 7.5** A). This is not expected to change drastically unless a serious policy is put in place. Uganda's urbanization rate is said to be at 5.43% (Fortune of Africa, 2013), but according to the UN it only 2.11% and it will decrease slightly until 2035 when it will decline below 2.0% (UN, 2014).

Though the Uganda Government puts it at a higher figure, the UN has more reliable data. The total population curve corresponds in shape but higher than the rural population curve (the two are parallel). This is because the rural population is significantly higher than the urban population. Since the rate of urbanization is lower than the population growth rate, it means the rural population will increase more than it is today.

Nevertheless, taking an average per capita rural consumption of firewood of 680 kg/yr and charcoal of 4 kg/yr, and an average per capita urban consumption of firewood of 240 kg/yr and of charcoal of 120 kg/yr (MEMD, 2007, p. 37), and assuming the charcoal kiln efficiency η=10%, then the average per capita consumption would be 890 kg by 2014 (as seen **Figure 7.5 B**).

The kiln efficiency varies according to the type of kiln and its management. The most common kiln is the traditional kiln of low efficiency. In reality the kiln can generate an efficiency that is too low due to the aspect of management. This is because the people who are producing charcoal do not do it as a business. Often they make charcoal while they are in the process of drinking wine or beer. Then the attendence of the kiln suffers because it needs proper timing of carbonization process.

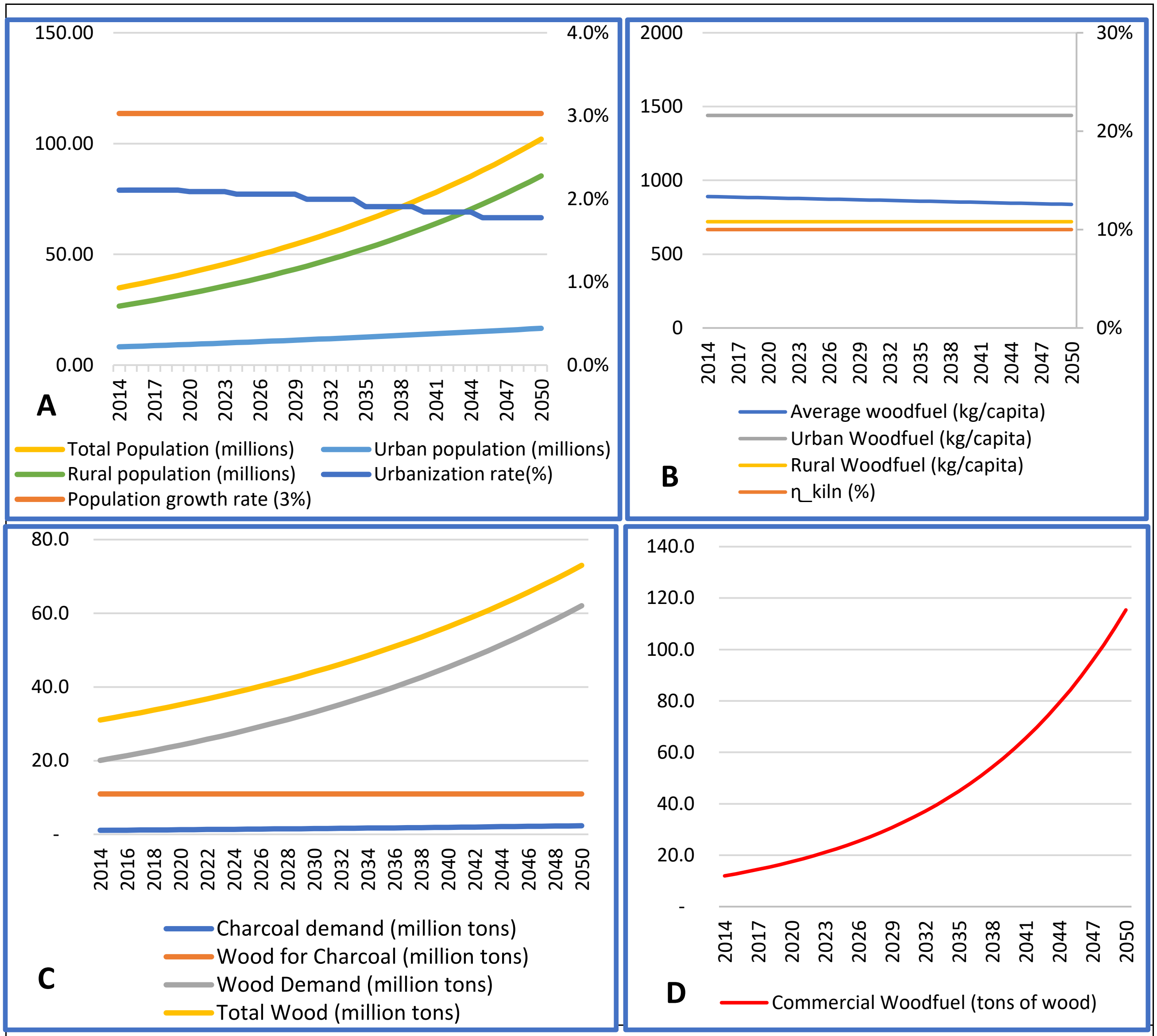


Figure 7.5**:** Population (A), Driving Factors (B), Household Biomass Energy Consumption (C) and Commercial Demand (D) of Woodfuel

Appendix C.3

This ensures that as soon as the moisture is driven off and carbonization starts to occur, the inlet holes that admit air must be closed immediately. Otherwise it becomes the process of combustion rather than carbonization. There are several factors influencing wood consumption. First, wood consumption depends on the number of persons per household. Second, the entire population cannot be cooking the same type of meal even for one day. Third, young and old persons have different levels of consumption and specific quantity of woodfuel is required. Fourth, the amount of woodfuel depends on the cook and people from different regions use various amount of fuel (input). Fifth, thermal efficiency depends on the cook device. Sixth, the quantity of wood also depends on the frequency (number of meals per day) and type of meal cooked (depends on the cooking practice).

However, Kisakye 2012, took a firewood sample of 227 and a charcoal sample of 54, and obtained the mean for wet wood of 1.62 kg and standard deviation of 0.99 kg per capita per day, whereas for dry wood the mean was 1.12 kg and standard deviation was 0.70 kg per capita per day. For wet charcoal it was a mean of 0.57 kg and standard deviation of 0.47 kg, and the dry charcoal was 0.48 kg per capita per day (Kisakye, 2012, p. 12). Both the mean and standard deviation are high (especially for wood). This emphasizes the need of seasoning firewood, yet it is a challenge to season it amidst severe scarcity. The annual per capita consumption for wet firewood was 591.3 kg/yr and dry firewood was 408.8 kg/yr, and for charcoal wet and dry it was 208.1 kg/yr and 175.2 kg/yr respectively. These figures are lower in comparison with those given in the Renewable Energy Policy.

The average woodfuel consumption per capita varies with the size of the household. Kisakye (2012) further investigates per capita firewood by regression in **Figure 7.6.**

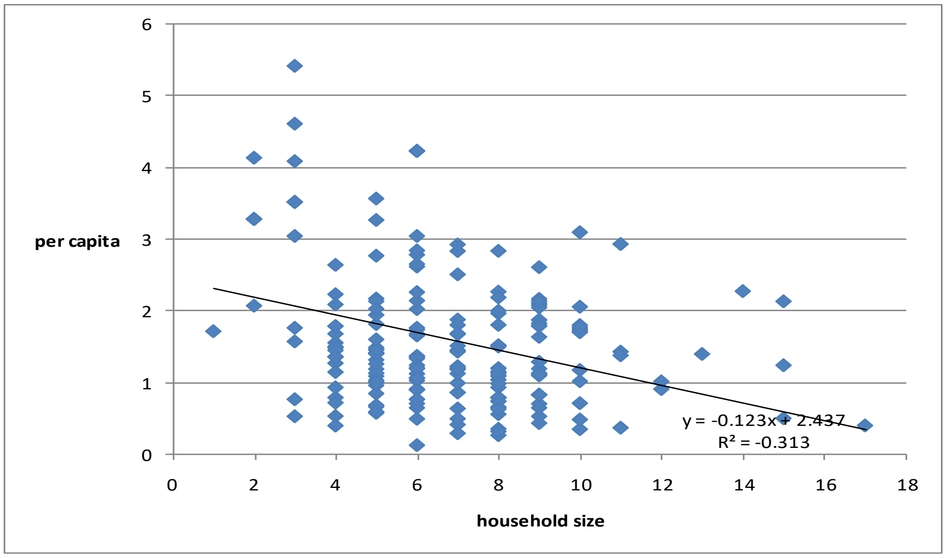


Figure 7.6: Per Capita Firewood Consumption and Household Size

The Correlation Coefficient (measuring the strength of the relationship from 0 to 1) is giving a value of $R^2 = -0.313$. The correlation is significant with a p-value of 0.000 (Kisakye, 2012, p. 19). This indicates that the relationship is not caused by chance alone (as indicated by a probability of 0.000) but rather the per capita consumption of firewood varies with household size.

However, the correlation indicates a relatively weak inverse relationship as portrayed by the sign and the numeric value of -0.313. First, it is a negative relationship indicating that consumption reduces with increase in the household size. Second, the numeric value indicates that 68.7% of relationship cannot be explained by the model. Several factors determine the consumption including the cooking practices, food being cooked, wealth or poverty of the household, number of meals cooked per day, whether firewood is purchased or collected, and the distance of collection, wet or dry wood improved or traditional stove, area of residence, and fuel wood scarcity or abundance.

Wiskerke et al (2010) reports efficiency of consumption rates of 7–12% for traditional fuelwood consumption and 11–19% for charcoal consumption respectively (Wiskerke WT, 2010). MacCarty et al found that under laboratory conditions traditional charcoal stoves were as efficient as 3 stone fires without including the losses due to production (MacCarty N, 2010).

The Graph in **Figure 7.5** C indicates that the total consumption was 31 million tons by 2014. The population growth curve (total) and the rural population curve are slightly parrallel and in tandem with the consumption of total wood and charcoal curves. Fuelwood used for cooking service sector is the hardest to estimate. The services industry grew by a revised rate of 6.5% in FY 2012/13, compared to the 4.8% estimate in the June release. Because data is scarce except that of MEMD (which also a form of estimates) it is assumed that the one of FY12/13 is used.

There are so many complex issues connected with cooking with firewood including the informality of the sector, yet it is an intersectoral in nature, unclarity of roles and responsibility of the stakeholders, and lack of regulation and absence of legislation. But above all, the non-profit nature of the sector, it is difficult to intervene: due to the rural and spread nature of the sub-sector it is difficult for planning. Consequently, due to lack of research, it has a very low investment, and poor technical and economical efficiency. It is generally ignored. The schematic diagram in **Figure 7.7** illustrates the causes and effects of the traditional biomass consumption.

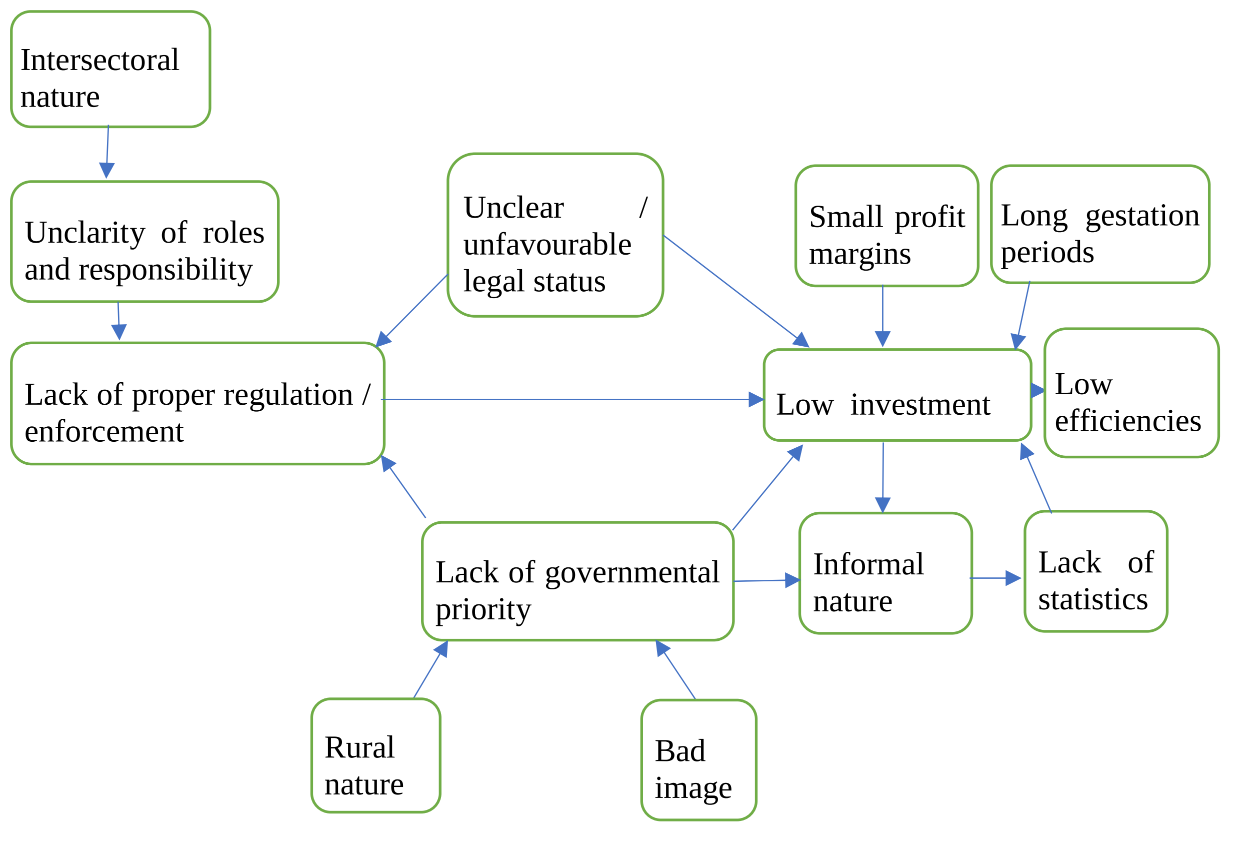


Figure 7.7: Schematic Diagram Showing the Interrelated Cause and Effects of Traditional Biomass Consumption

Source: (EUEI PDF-giz, 2014, p. 13)

Just as already stated the drivers of wood scarcity include population growth, agricultural expansion and deforestation. Because of increasing population there will be not much space left for growing trees and for agriculture, both subsistence and commercial. The only trees for growing will be the high value trees particularly for sawing timber and farmers that are able to grow trees are those that have sizeable land.

This means wood will increasingly become commercial and scarce. Because of the increased level of biomass depletion, it is assumed that tree planting serves only to recover the biomass lost, to meet demand and to ensure environmental sustainability, rather than increasing supply. It is assumed that the total population continues to grow at 3.03% (because the effort to curb it is only theoretical). Resources, particularly those being cooked (food) and those used for cooking (woodfuel), and land continue to diminish critically per capita. Moreover, due to urbanization, the woodfuel used by the urban dwellers is almost twice that of the rural inhabitants. To put it in another way, without switching, every development in Uganda requires clearing of trees, which in turn affects the environment.

7.4. Efficiency to be Maximized

In this scenario the population growth rate is controlled: reducing it from 3.03% down to 0% (which means the population should not grow but should be maintained). No sustainability is possible unless there is a policy to reduce the population growth gradually towards two children by 2050 (zero growth), which ensures that the population does not reach 60 million (58.4 million). If the population reduction efforts and actions are engaged through sensitization of the benefits of a small family size and provision of free family planning options (including pills) and population targets for every year, it is actually possible to curb the population. In this scenario, sensitization is done especially in rural and also urban areas. The message of sensitization regarding the benefits of family planning is mainstreamed in all development sectors (knowing that the price of raising a child is greater than price of the pill that prevents conception) then it is possible to level or reduce the population growth as depicted in **Figure 7.8 A**.

If the improved charcoal and firewood stoves are adopted, and improved charcoal kilns embraced to the extent that no cooking is done without them and no charcoal making is carried out without improved kilns it would be a step towards biomass sustainability. A per capita woodfuel saving of firewood and charcoal of 37.5% (Adkins E, 2010) and 50% (Envirofit, 2017) is assumed for the respective stoves; a charcoal production kiln of 30% efficiency is developed through a gradual introduction of improved kilns. This scenario is shown in **Figure 7.8** B.

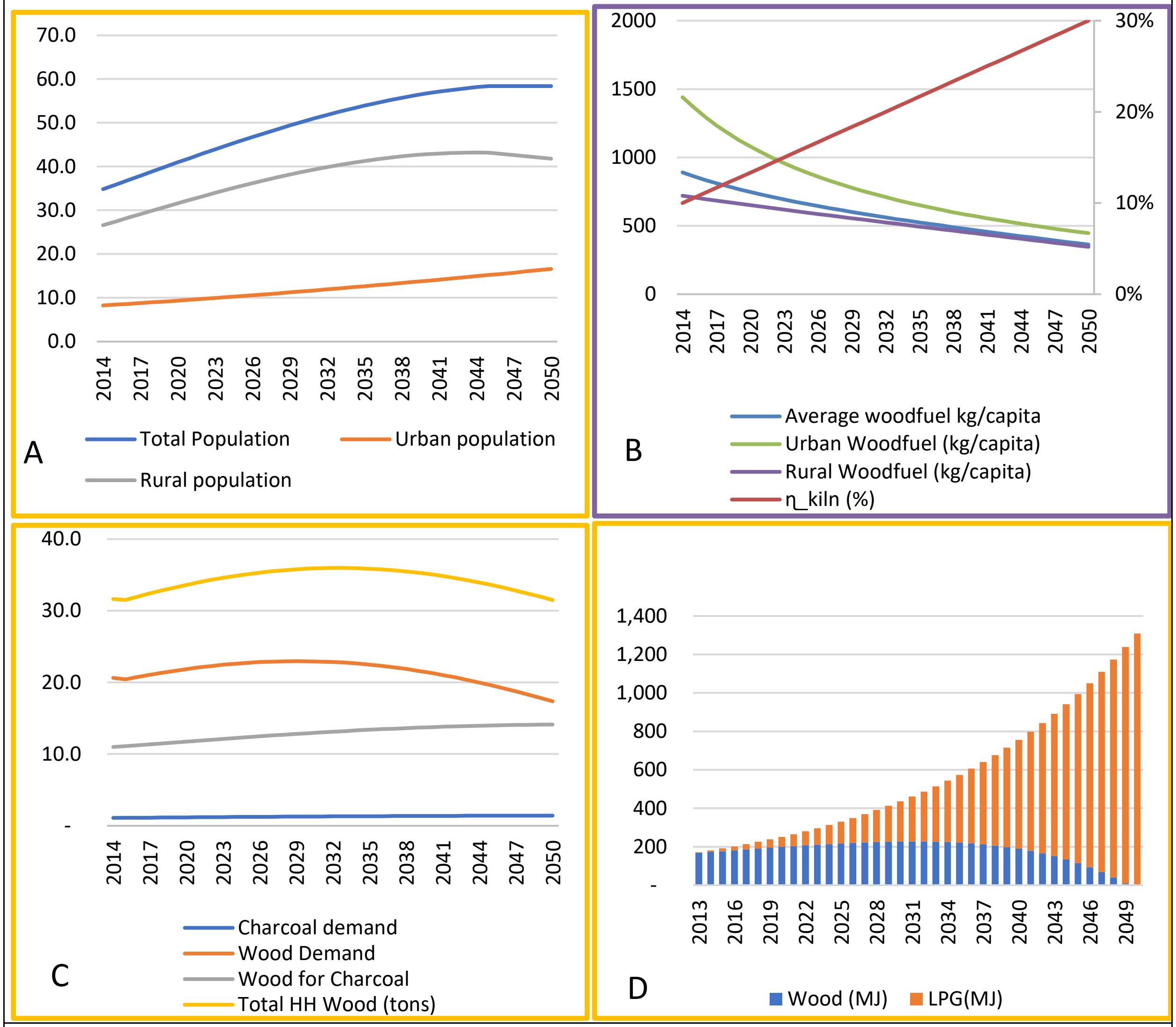


Figure 7.8: Population Growth Control Implemented, Commercial Sector Substitution with gas (D) and Efficiency Maximized

Appendix C.4 and C.5

It is assumed that improved cookstoves which are really third generation type are disseminated. This applies both to charcoal and firewood stoves which are traditionally made out clay: which makes them "high mass". The designs of these stoves is beyond the scope of this thesis. But high mass stoves take along time to warm up which makes them inferior to the three stone fire for cooking a light meal. However, it is noteworthy that the new technology goes hand in hand with the techniques. When someone is very conversant with a three stonefire, she needs a training in using an improved stove. Similarly a traditional charcoal stove is not the same as an improved charcoal stove in design. The insulation inside the charcoal holder is the distinct feature of the improved stove.

A fixed kiln requires a lot of investment that one cannot breakeven before finishing the biomass within the vicinity and to transport more biomass requires more investment. For this reason the most recommended kiln is Kasamance charcoal kiln – based on the idea that it is efficient and can be adopted to local conditions. It is inexpensive to build, easy to operate, easy to train operators, capable of producing high yield and quick carbonization evidence (Karch, 1987). If this type of kiln is gradually is disseminated among the charcoal producers it can be greatly welcome for raising the profit margins of the charcoal producers, generating incomes for the local goverments of those areas which produce charcoal and protecting the environment. Because of this combined efficiency of the firewood stoves, charcoal stoves and kilns, it is assumed that the consumption will go down as per capita consumption reduces and the overall population is slowly curbed.

7.5. Substitution of Woodfuel by Gas

Given the scarcity of wood and the likely environmental consequences which would include soil erosion, deforestation, femine and drought, it is very urgent that a substitute cooking fuel is sourced, particularly for the commercial sector.

As analyzed in Chapter 6, the most appropriate option would be gas except the exceptionally high costs. This is because of the prospect of exploring it. By 2014, the Government of Uganda estimated that there were close to 6.5 billion barrels of oil, but the quantity that can be recovered is between 1.8 and 2.2 billion barrels. The barrel production per day is between 200,000 and 250,000, meaning that Uganda is a mid-level African producer being in the same category with present day levels in Equatorial Guinea and Gabon (University of Oxford, 2015). The local production of gas is going to be a step forward in the cooking energy solution, since it is likely to be very cheap.

Concerning the envisaged challenges and opportunity in the exploration of oil and gas, along with "insight on upstream, midstream and downstream opportunities, risks, infrastructure, trade and competition" an expert report has been compiled to this effect and it has all the detailed integrated research findings including the forecast and value chain (Wood, 2017). But the aspects related to this report are beyond the scope of this thesis.

However on the user side, ESMAP has enumerated gas dissemination drivers and barriers. The drivers are the increasing middle class – people with increasing incomes, desire to be in a high class, urbanization, increasing cost or scarcity of substitute fuels, increasing awareness about the danger of traditional fuels (IAP – with its constraints including: headaches, eye irritation, coughs etc, and deforestation) and mobilization of funding from donors. The constraints are consumer investment costs, high fuel costs as a percentage of the household income, poor supply networks, stealing of cylinders and other forms of cheating, unpredictable safety recommendations, weak regulation and poor enforcement, and corruption (ESMAP, 2012).

ESMAP also indicates the success factors gas scaling up as following in three categories: supply chain, consumer and government. In relation to supply chain, it is necessary to maintain the reliability of supply and low-cost distribution, taking advantage of the economies of scale, retail SME capability building and access to capital. Concerning the consumer, it critical to support the initial costs (special financing), cylinder sizes should be appropriate, gas stoves compatibility with culture, and multifaceted consumer education. In regards to the government, the policies and regulations should be appropriate (including taxes and duties) and sufficiently enforced. A market structure that motivates the companies to invest in remain, in the market, and that balances the private profit of the company with the public social benefit, is necessary.

The pattern of Uganda LPG in thousands of barrels per day is shown in **Figure 7.9** (The GlobalEconomy.com, 2017)**.**

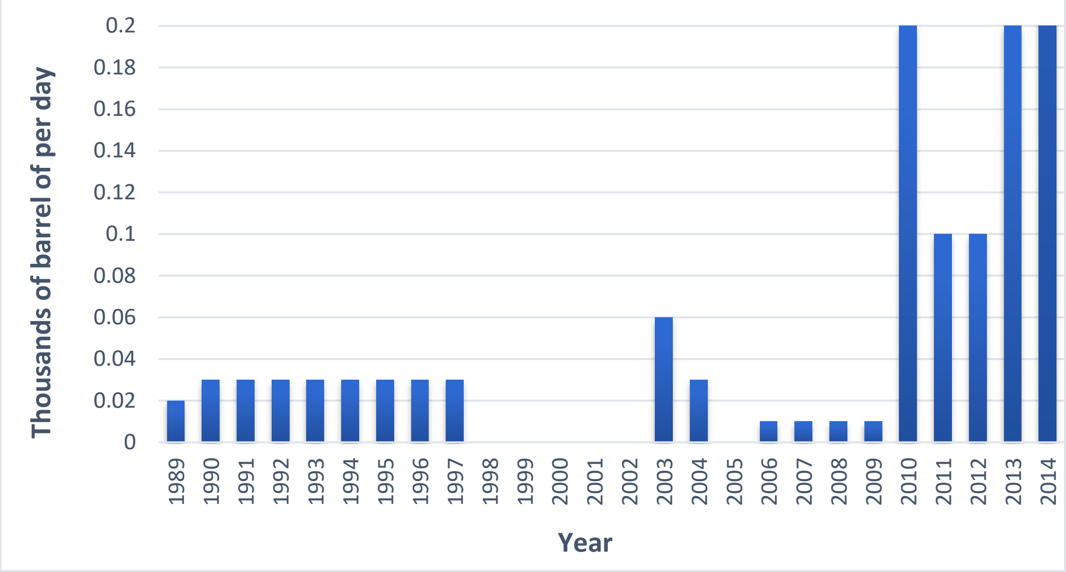


Figure 7.9: Uganda LPG Trend

For the above indicator, the U.S. Energy Information Administration provides data for Uganda from 1989 to 2013. The average value for Uganda during that period was 0.06 thousand barrels per day with a minimum of 0.01 thousand barrels per day in 2006 and a maximum of 0.2 thousand barrels per day in 2010. Figure 7.9 shows Uganda gas price comparison.

However, the different fuels could be combined in accordance to the restaurant preference and to the food being prepared. Furthermore, it is the price that can dictate the ease of substitution of the cooking alternative. So different fuels could be appropriate depending on the [15] price of fuel.

For example, the price of kerosene could become very low, but the possibility of accident of burn and the danger of pollution is critical; ethanol could become much cheaper and available, but the production of biofuel can be the challenge due to scarcity of land; and electricity could become more stable and less expensive, but the challenge of grid connection within rural poor areas can be next to impossible. It is a matter of policy and

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[15] 1 barrel contains158.987 Litres

priority, but as for the status quo and given the available opportunity of exploring crude oil, LPG is the promising option.

Table 7-4: Uganda gas price comparison chart 2015, Quarter 1

	Total Gas		**Shell Gas**		**Oryx Gas**	
	6 kg	**12.5 kg**	**6 kg**	**5 kg**	**6 kg**	**13 kg**
Cylinder	100,000	150,000	100,000	150,000	86,000	126,000
Gas/refill	57,000	118,000	59,000	142,000	59,000	118,000
Grill	26,000		26,000		26,000	
Burner	28,000		28,000		28,000	
Hose pipe		15,000		15,000		15,000
Regulator		40,000		5,000		30,000
TOTAL	**211,000**	**323,000**	**213,000**	**352,000**	**199,000**	**289,000**
	Mpishi Gas		**Hashi Gas**		**Kobil Gas**	
	6 kg	**13 kg**	**6 kg**	**13 kg**	**6 kg**	**12 kg**
Cylinder	70,000	80,000	100,000	139,000	125,000	155,000
Gas/refill	59,000	118,000	59,000	118,000	58,000	113,000
Grill	26,000		26,000		26,000	
Burner	28,000		28,000		28,000	
Hose pipe		15,000		15,000		15,000
Regulator		35,000		27,000		40,000
TOTAL	**183,000**	**248,000**	**213,000**	**299,000**	**237,000**	**323,000**

(Dignited, 2017).

Consequently, gas being a substitute for cooking in commercial sector. Of all the drivers, the population growth rate poses the greatest threat. It is 3.03% which means, the population almost doubles after every two decades, and doubling demand too as shown in **Figure 7.2** and **Figure 7.3**. With such population growth rate, the population which estimated at 38 million by 2017 will reach 102 million by 2050. Without population control it would mean that household sector alone is enough to deplete all the wood available in the country without the effect from the commercial. Therefore by 2050, the woodfuel demand for the household will be more than three times (31,024,818 to 101,995,165) in response to the population growth.

7.6. Substitution of LPG for Woodfuel to Replace Partial Demand for Household and the Commercial Sector

It is assumed that LPG plays a role in not only the commercial sector, but also in household sector. The households that categorized as mid-class (37%) should be eligible for the LPG substitution. But it is important to explain the middle class within the Ugandan concept. First, there is no single theoretical or imperial definition in literature of who the middle class are. It is generally agreed that using income and consumption levels might define the middle class (Frank Robert, 2007), for example absolute income and consumption levels in relation to poverty line, income levels in comparison to income of the median household, definite income proportion of the income distribution, consumption value or relative to the percentiles. The Ugandan the Ministry of Finance Planning and Economic (MFPED), attempts to draw the poverty line, which ends up with a misleading message. For example, it says that a person who has an expenditure that is twice the poverty line is in the middle class. That would mean that those spending about US$ 110 per month or US$ 4 per day fall within the middle class. The Kenya National Bureau of Statistics defines the middle class as one having incomes that lie between KSh 8,000 and KSh 25,000, that is USD 100—314) per month.

The African Development Bank (AfDB), 2011 applies per capita daily consumption of USD 2 – 20 to define the middle class in Africa, and he puts them in 3 categories: 1) “the floating” class with a daily consumption of 2 – 4 USD per day. This group is unstable and is vulnerable to different external forces that could easily push it back into poverty, therefore they cannot be in category of middle class. 2) the “lower middle class” with a per capita daily expenditure of USD 4 – 10 and it is assumed but not proven to have enough money to save and to spend on non-essential items. 3) the “upper middle class” with a per capita daily expenditure of USD 10 – 20 (AfDB, 2011).

But the AfDB definition fails in its characterization of the middle class in Uganda for two reasons: First, the per capita consumption levels do not reflect the modest cost of living based in Uganda (housing, meals, electricity, transport, medical, children, schooling, etc.). Second, the classification of per capita daily consumption of USD 4 – 10 and USD 10 – 20 seems to put the population in a wealthy category (Milton, 2012). Middle income countries have an annual gross per capita income between USD 1,025 and USD12,615. Therefore, to become a middle income status Uganda one has to have USD 1,025 and USD12,615 (Baguma, 2016). **Figure 7.10** shows the reduction in overall quantity of wood after switching to gas for commercial sub-sector and middle class.

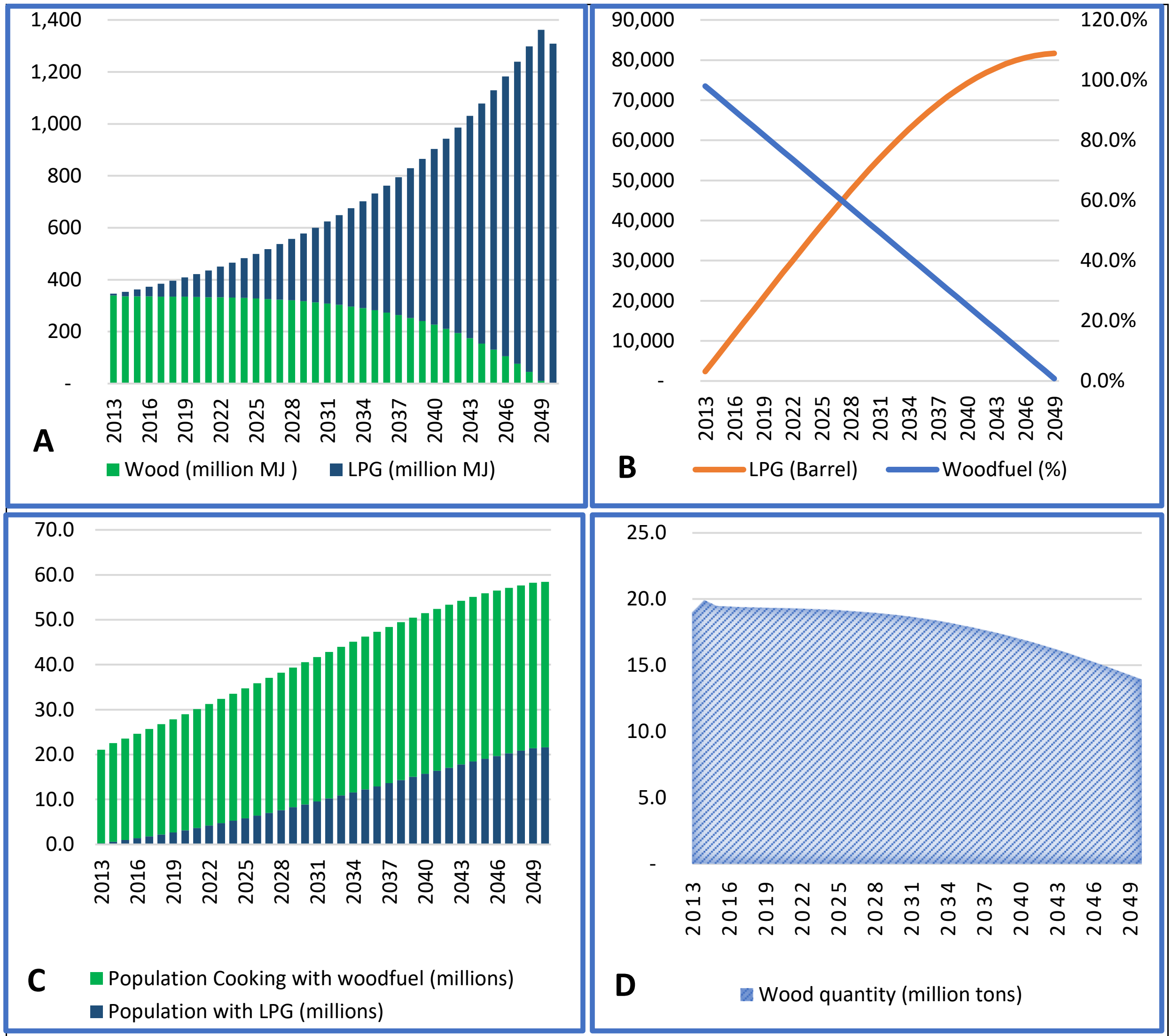

Figure 7.10: Commercial Sector and a Third of Middle-Class Substitutes Wood with LPG

Switching to LPG (A) reduces the proportion of wood as the barrel of LPG increases (B). Switching to LPG by the Middle Class (C): 37%, reduces the total wood demanded (D): 63%. **Appendix C.5**

When the commercial sector substitutes wood with LPG, as mentioned before, **Figure 7.10 A**, but this time the population of middle class takes up LPG as a cooking fuel. As the number of barrels of LPG supplied for commercial use increases in quantity, the amount or proportion of wood consumed decreases (**Figure 7.10 B)**. The same applies to the middle-class consumption: it increases up to the percentage approximately 37% (**Figure 7.10** C).

The wood assumed to remain to meet the demand decreases from about 20 million tons to 12.5 million tons per annum (**Figure 7.10** D). However, these assumptions might be challenged. On the one hand it might be an under-estimate to take the middle class of 37%, whereas Uganda is projected to reach a middle class society by 2020 (Ggoobi, 2016, p. 2) there is doubt that it can happen in the remaining years. On the other hand, it is a real fact that Uganda is pursuing the goal to become a middle income country. It might happen between a few years to come before 2050, in this case it might be an under-estimate to postulate that the 63% has no capacity to afford LPG.

Another point is that having LPG for the middle class is likely to induce the rest of the population to be modern and this has an acceleration effect on the adoption of the technology. However, there are also negative aspects: most of the foods cooked in Uganda are conditioned to biomass utilization. This becomes a drawback towards the new cooking technology.

7.7. Brick Making and Other Biomass Application

The main industrial sub-sector that consumes woodfuel is baking of bricks and bread. Bricks are the main construction materials for every building wall. The construction industry includes all the companies dealing in building, renovation and maintenance of residential, commercial and industrial structures. A list of subsectors includes following: general construction, clearing of the site, and the demolition or wreckage of buildings. The construction materials include among others sawn timber, burnt clay bricks and tiles, (UBOS, 2007, p. 44). Burnt clay bricks and tiles are the only ones that consume woodfuel. For example, residential houses that were constructed using brick wall in Uganda were

50.7 in 2002 and 55% in 2014. As the residential houses with bricks keep on increasing, the commercial buildings too increase.

Generally, construction generates between 10% and 16% towards GDP since 2000. The construction subsector contributed 13% to industrial GDP for instance. The contribution of the construction subsector to GDP in the recent past that has grown at an annual rate of 12 per cent from an average of 5 per cent in the 1990s and early 2000s (The World Bank; Marios Obwona). Because the construction subsector is rapidly expanding, it threatens the cooking subsector because of stiff competition with it and it is commercial. Other subsectors using biomass include the following in **Table 7-5**.

Table 7-5: Specific Energy Consumption in other Industries Using Biomass

Industry	**Specific Energy Kg of wood/Kg of product**	**Total wood consumption by the industry tons**
Artisanal brick making	0.6	6 mill
Tea	1.5	71,000
Small scale lime production	1.5	270,000
Tobacco	8	200,000
Jaggeries		500 tons of wood and 2,000 tons of bagasse
Vegetable oil		170,000 tons of agro residues 75,000 tons of wood
Fish smoking		
Pit kilns	1.2	22,000
Improved kiln	0.4	
Cement (Hima)		80,000 tons of agro residues
Textile		17,000 –agro residues
Bakeries	2	313,000
Local distilleries	1.25 -6.0 Kg of wood/litre	180,000

(MEMD, 2014 , p. 18)

7.8. Summary of Chapter 7

Having analyzed biomass scarcity (chapter 4) and confirming it by detailed investigation of biomass stock (chapter 5), the author made an inquiry into several cooking options (chapter 6) and decided to choose LPG (gas) to be the necessary substitute for biomass. Chapter 7 tells us that the future for biomass is questionable. Biomass demand is going to increasingly become a very serious issue for Ugandans. At local level in particular the scarcity of fuelwood will become even more critical. This is the core essence of unsustainability. The main drivers of biomass decline are pointed out: population growth – everyone requires biomass for cooking, agricultural expansion – every one requires food for survival: hence more land is put under cultivation, and deforestation: because of woodfuel and agricultural expansion. Then the projections of different scenarios will be described: first, business as usual scenario – what happens when no action is done; second, efficiency scenario for households, reduced population growth and gas for commercial subsector; and scenario of reduced population growth, switching to gas for commercial sub-sector and middle class and the remaining wood balance.

CHAPTER 8 **RECOMMENDATIONS AND CONCLUSION**

8.1. Recommendation

The most urgent and easiest step is to control the population growth with the aim of driving it back to 0. Next is the dissemination of gas for household and institution for which the strategic framework and infrastructure is critical. It is also necessary that the Ugandan population learns to cook more with less fuel, this needs more aggressive training, information exchange and adopting alternative foods from other regions to reduce cooking time. It is also vital to adopt proper land management practices in order to to increase biomass supply through tree planting and adoption of intensive agroforestry. In addition, it is vital to strengthening framework of wood energy institution and wood energy policy enablement.

8.1.1. Population

There urgency to have a controlled population growth with deliberate policy is critical. There is need to implement the population control recommendation. First, there need to invest in the provision of family planning and reproductive health, including systemmatic planning, training, monitoring and improvement of infrastructure to enable access to the reproductive health supplies. Secondly, supporting programmes that target the youth, particularly in education, vocational training and job creation; with emphasis on girls. Third, integrate broader age profile to address issues that partain to policies, including the challenge of land, and issues like education in order to ensure stability and security. Fourth, increased support of programs that enhance gender equity and equality, which aim at engaging men at community level to address their reproductive needs and also reduce violence against women. Fifth, development and funding of program that promote integration of climate change with family planning: bigger family gets hit hard by the climate change effects. Sixth, strengthen the integration of family planning within the broader context of maternal health care and HIV/AIDS. The risk of maternity death is high when the mother gives birth to children at a young age or too frequently (Madsen, 2010).

8.1.1. Framework for disseminating gas for household cooking

There is need to build infrastructure to make gas accessible and affordable. To do this it is recommended that gas should become cheaper and available. It is through these attributes that it can become an alternative by competing with wood.

8.1.2. Cooking more with less fuel

In Uganda the average cooking time is about three hours, and it takes a lot of energy to cook a typical meal. The author recommends that food should be cooked in than less than one hour. So research is necessary to this effect.

8.1.3. Land Fragmentation

One of the problems facing land in Uganda is land fragmentation. Land is divided into small pieces that cannot be used economically. There is no planning regarding the land: everyone can tear off any piece of his land from any part of his land (J. Olson, 2003, p. 5). As long as it it is private land anybody can use it, or sell it to anyone. This is the problem that creates slums. Such a practice should be stopped or discouraged. There is need for policy to consolidate land and to plan land in accordance to the gazetted areas. However, policy itself is not what affects change, but the policy actions implemented.

8.1.4. Tree Planting

The same strategy to have trees planted for timber could be used for firewood by making it a national priority. Fast growing trees could planted putting into account the ecological and environmental conditions to ensure productivity. There is an urgent need to plant trees and to save those trees that are essential for environment protection. Trees are not only used for woodfuel but they are essential for stimulation of rainfall, prevention of soil erosion, water retention and as source of income. There are however many challenges regarding the establishment of a tree forest. One of the challenges is the climate change which affects tree establishment: rains are unpredictable and it is risky to put seedlings in the soil when one is not sure of the patterns of rain.

Labour is expensive and the the price to buy the seedlings is high. This makes the establishment of trees very expensive. When this is coupled with land scarcity tree establishment becomes a very costly if not an impossible venture: being left for the rich category of the society. Since this is composed of a very few people, whose priority may not necessarily be tree planting this activity suffers neglect.

Lack of sufficient knowledge regarding tree planting. People are used to collect firewood from natural forest rather than growing it on the farm. Therefore they don’t know how to plant trees or protect them. They lack knowledge relating to selection of seedlings and the agronomic practices. Another challenge is an economic challenge. Woodfuel is the one that takes the least price among the different crops. This gives it the least economic advantage or a low opportunity cost.

8.1.5. Intensify Agroforestry

Woodlots are a very convinient way of tree management. Trees that are planted for woodlots can be cut and sold, or they can be as a source of woodfuel. Yet depending on the type of tree, they could be used for timber or poles. One can plant any tree for woodlot because the trees are not intercropped with crops. The major constraint of woodlot is the small holder farmer who does not have enough land to plant his crop.

This is a strategic planting of crops with trees with the aim of wood production. To optimize this integration trees that compete with crops should be avoided. This is an alternative for land which has unsustainable agricultural system. It is also a good strategy for crops like coffee, whose branches can be used for firewood. Its challenge is, the small holder farms who are already constrained by very tiny piece of land which cannot be used for raising trees with crops.

8.1.6. Strengthening Framework of Wood Energy Institution

Wood energy requires a consortium of expert to maximize efficiency of operation. First agriculturalists are needed to be able to have a selection of crops that match with certain trees; second, the foresters are needed to be able to deal with the trees and their management; and thirdly, the industrialists are important to deal with the finished crop.

Similarly, the Uganda Ministry of Lands, Housing and Urban Devepment, Ministry of Agriculture Animal Industry and Fisheries and Ministry of Energy and Mineral Development need to be coupled in order to utilize their synagies. The link among those experts and the related ministries is still weak and needs strengthening of not re-establishing.

8.1.7. Wood energy policy and planning enablement

Woodfuel planning should follow a decentralized path just as consumption of wood energy is localized. It must be site specific depending on the problems. It is not possible to carry wood through a certain distance and still maintain its value. This is because the economic viability of wood is dependent upon use in a short distance. Self-sufficiency is the goal. Wood energy data improvement relating to consumption and production. To improve wood energy database requires the concerted effort of all stakeholders regionally and nationally. It requires the establishment of data about demand and supply of wood through surveys and regular monitoring to evaluate the changes that have occurred over time.

8.2. Key findings

1. Biomass remains the source of energy for Ugandan population contributing over 90% due to its cheapness, cultural practices and poverty.
2. The main fuel transition is from fuelwood to charcoal, which doubles the primary wood depletion, due to carbonization (kiln) and burning (stove).
3. The transition to alternative is too slow and the depletion is too fast.
4. The woodfuel gap is a reality but it happens in certain irrefutable hotspots.

5. Because land scarcity increases as the population density shoots up, the option to plant trees is not viable.
6. Taking the mean size of the 10 main charcoal producing districts of only 540,000 ha the area required to generate lost biomass in 15 years is equivalent to 3 districts: one district for every five years.
7. Though there is a growth of the middle class and a reduction in the percentage of those below the line, poverty the curve for the percentage population using biomass for cooking is flat for the 22 years, signifying that there is no change.
8. There is a linear relationship between the percentage using biomass and the percentage of those below poverty line.
9. The total population and population using biomass increase increase in tandem.
10. There is a positive linear relationship between the percentage using charcoal and the percentage of the middle class; yet there is a negative relationship between the percentage of those who are below poverty line and those using charcoal.

8.3. Recommendation topics for further research

1. The health dangers of cooking with an Improved Cookstove which emits less IAP emissions than the three stone fire.
2. The time that would be required for the ICS warm up and catch up with the three stone fire.
3. The proportion charcoal production contributes to deforestation.
4. Proportion of deforestation that is due to brick-burning.
5. The optimum population growth that is appropriate for every Ugandan to find a job.
6. The comparison of the environmental impact of total biomass depletion with adoption of LPG gas.
7. The sustainability in relation to climate change due to deforestation
8. The sustainability in relation to IAP and its effects.

9. How Ugandan food can be processed so that it is easily cooked.
10. More updated data is needed for assessment of supply.

8.4. Conclusion

The cooking energy needs of the Ugandan population cannot be sustainably met by biomass because the biomass resource base, which provides the major share of the cooking fuel, is subjected to continuous depletion levels. Firewood is the main fuel for rural area, while charcoal is most popular for urban because of higher energy content, ease of storage and transport, and lower emission. Nevertheless, the emission levels are serious and a number of people die due to lack of ventilation, while using charcoal. The effort to plant trees is questionable given the small size of land, which in addition to the overwhelming cases of conflicts, is too small even to supply the food requirement.

It is impossible to extend the electric grid to rural households in developing countries for three reasons: first, the households are few; secondly, they are scattered; and thirdly their ability to pay is low. Therefore, it does not make economic sense to extend the grid in these rural areas. As a result, the costs of rural electrification can go up to sevenfold compared to the amount required to electrify the urban area. That means a decentralized source of cooking energy is the best alternative.

In some parts of Uganda inferior fuels used including plastics and agricultural residues. This indicates that the woodfuel gap is real but it does not extend to the entire country. The fact that the rural poor gather wood from 7 km distance and spend 8 hours in collection of the wood is in itself a crisis. This indicates that the woodfuel gap created when the poor lacks the fuelwood and cannot afford the alternative carry out cooking.

On the other hand, there is a negative relationship between the fuel transition and the family size. Women headed households are likely to adopt modern fuels. The most no-biomass fuels that are likely to be adopted are kerosene and LPG. But the author prefers LPG. Electricity would be the best option but because of the costs of extending the grid, and the prices and unreliability of electricity makes electricity not feasible.

The rate of urbanization is stimulating the depleting of forests due to demand of charcoal. Charcoal consumption is a way of wastage of energy because the overall efficiency involves both charcoal making which is wasteful and the charcoal burning. Though the share of firewood is higher than that of charcoal, and the rate of consumption of firewood is increasing due to population, still the rate of charcoal consumption is increasing even more due to urbanization and poor conversion of charcoal. On the other hand woodfuel is too precious to be used for cooking. If wood is used to make furniture it would generate more revenues and perhaps foreign exchange. The situation is worse in regards to charcoal: many trees including fruit trees and high quality furniture trees are cut in order to meet the need for charcoal. Yet charcoal does not put into account the whole production chain relating to the growing of the tree.

Taking the business as usual scenario, the fuel substitution is relatively slow. In fact the main substitution is from wood to wood, that is from firewood to charcoal. The contribution of the alternatives is very low in quantity as well as proportion.

Woodfuel gap happens when poverty and scarcity of cooking fuel takes place. Wood use primarily used by the poor because it is free and it meets the needs of the poor. You can have as much fire as possible and it cooks food allegedly with the “test” which has not been proven. This study looked at the emerging middle class and investigated its impact on substitution. Results still indicated that the middle class does not substitute but stacks the fuels. This means with increased incomes the household tends to add on more categories of fuels in which firewood or charcoal becomes assigned to the main meal, which consumes the huge proportion of energy.

Charcoal consumption is primarily driven by the urbanization rate which increases at the rate of 6% and firewood consumption increases at the rate of population growth. If the accounting is done with respect to the feedstock used for charcoal production, the Ugandan conversion factor of 10 times the wood to make charcoal would be 40 kg and 1200 kg for rural and urban household respectively. When firewood is added, the aggregate wood for the total primary energy consumption for rural and urban households would be 720 kg and 1,440 kg respectively. So the urban households that predominantly use charcoal for cooking require twice as much primary energy from wood as their rural counterpart. So every Ugandan making a transition from using firewood to charcoal for cooking requires twice as much quantity of wood harvest.

The study underlines the reality that universal access to electricity is part but not the whole parcel of universal access to modern energy in developing countries. It plays a very significant role for lighting, referigeration, TV, radio operation and mobile phone charging. Though indispensable it is insufficient due to the diverse socio-economic context. Apart from the socio-cultural background, the rate of transition to modern energy depends on the economic environment.

Woodfuel consumed in households takes the biggest share of round wood; the rest, including commercial and industrial use and the non-energy application, including poles and timber, have a minor share. This means that the bigger the number of the poor the greater the pressure and dependence on natural resources, and the lower the monetary value of the latter. An economy relying on natural resources for its survival frustrates most of the business models or commercialized approaches for consumption. Attempts to introduce commercial fuel alternatives are hindered by the availability of what is perceived to be "free" fuel, provided by nature. Because of consumption of resources without price signals, such an economy is far from sustainability.

There was a linear relationship between percent of population below poverty line and the percentage of the population using biomass energy for meeting their cooking needs. On the other hand, the total population and the population using biomass increase in tandem, though there is a decline in poverty levels in that percentage of people living in poverty fell from 56% to 19.7% and the growth in the middle class from 10.2% to 37.0%.

The economic environment, which among other things sets the price of the substitutes like LPG, electricity and kerosene is critically vital for the consumer's choice of cooking fuel. As long as biomass remains very cheap or even free while the alternatives retain their normal prices, the assumption that income enhancement will automatically influence substitution will always be invalidated.

There was a positive linear relationship between the population of the middle class and the population using charcoal but there was also a negative linear relationship between people below poverty line and population using charcoal for cooking.

Concerning the supply side, the change in the share of the biomass quantity and size of land area shows a variation between 1990 and 2005, with some dropping as others rising; and with some changing slightly while others vary considerably. In particular, the biomass in land cover classes as a percentage of the total biomass declined between 1990 and 2005 in woodland, grassland and SSF while it increased in tropical high forests and bushland. The share of land cover size as a percentage of the total national area declined in tropical high forest, woodland and grassland while it increased in bushland, wetland and SSF. Percentage change in biomass stock increased for bushland while it declined for SSF. Similarly, land cover size increased in BUA, while it declined in the Bushland. The mean stock between 1990 and 2005 increased mainly in the tropical high forests.

Land size in private areas reduced for woodland and grassland, while it increased for grassland, wetland and SSF; but the biomass stock takes another pattern: it increased only in THFls and Bushland, the rest registered a decline. Yet looking at the total biomass yield THFws, THFls and Bush increased while the rest registered a decline. Considering biomass yield in private areas only THFls and Bushland registered an increase; the rest underwent a decline. THFws got the highest gain of biomass, while woodland was the greatest contributor for demand needs while SSF was the greatest loser. There is no standard size for the districts but the main use in all districts is the subsistence farmland. Because the SSF is most available throughout all the districts, the abundance, scarcity or fluctuation of biomass within it is essential in answering the question of sustainability of cooking energy in Uganda. 28% (or 31%) of the districts had a deficit in biomass whereas 20% of the districts had 5 times the biomass and 4% of the districts have over 10 times their demand hence the distribution is positively skewed. Overall, there is a shift in the biomass supply curve to the right, which indicates a deficit, which is also indicated by 85% of the district having a reduction in biomass supply. If each district is divided into two segments – rural and urban it estimates indicate that though by 2005, 99% of the districts had enough biomass stock to yield sufficient wood for meeting the cooking needs of Ugandans, 61% of the district will face a declining biomass stock by 2040. Further, the biomass yield will even be smaller: by 2005 only 51% of the district had enough yield to replace the biomass stock, and by 2040, the districts having enough yield to replace the stock will be reduced to 29%

In regard to the land cover change in the 10 main charcoal supplying district, Masindi underwent the greatest change, while Kamuli district was the least unchanged. Regarding to change in land cover size it was the Bushland followed by SSF that had the biggest increase, while woodland and grassland underwent the greatest reduction respectively. In relation to biomass per land cover, there was an increase in Bushland and THF, yet there was a reduction in land cover biomass of 4 times for SSF and a reduction of nearly 3 times for woodland. Of the theoretically 70 land cover categories, 5 missing in some districts 65 remaining land cover subcategories 19 had an increase, 2 had no change and the rest (44) had a decline in biomass per ha. The reduction of biomass in the ten districts was a minimum of 1 tons/ha to a maximum of 58 tons/ha with a mean loss of 16 ton/ha.

A comparison of different cooking energy systems indicates that the three stone fire is the quickest device even when compared to the modern fuels. That makes fuel substitution complex. When it comes to the short meals or tea even those with ICS may prefer a firewood stove for its speed. Nevertheless, considering the fuel consumption (in terms of mass of fuel), it is the three stone fire that takes weight of fuel. An ICS is profitable when the cooking takes long time. Nevertheless, this needs research to determine how long it takes. In regard to the taste of food, ranking showed that electricity has the best taste rather than firewood. Concerning the amount of heat that is generated, traditional firewood stove releases the highest quantity of heat and it has the highest standard deviation. Electricity releases the least amount of heat and has the lowest standard deviation. However, a pairwise comparison shows that charcoal, ethanol, kerosene, LPG and Electricity are significantly different. Nevertheless, a Tukey group of means in homogeneous subsets shows 4 subsets which are highly overlapping with the exception of Electricity which is the first and the improved charcoal stove cold (last).

The annual cooking costs indicate that costs are highest with LPG and lowest with firewood. However, when the means arranged in the homogeneous subgroup are displayed, 5 subsets emerge showing tremendous overlaps. A multiplication of cost x time (the critical aspects in cooking) gives a traditional three stone fire the greatest preference and LPG which gives the least preference. But in comparison with biogas LPG becomes cheaper.

The population of Uganda has been growing at 3% and this has put pressure on the environment and the limited resources. Of the critical resources, land has become a source of conflict. Because of land wrangles and scarcity, and the population growth, tree planting on a major scale is far from being a solution.

On demand side, wood converted into tons for residential, commercial and industry is 32,067,706, 10,231,418 and 3,273,334, totaling up to 45,572458, and it is projected to increase to 61,634,397 by 2016; while the supply wood, under the most optimistic scenario (14%) from Sustainable Yield generated (annual accessible yield) would be a biomass stock deficit of 46,892,437 by 2016. This crisis is likely to be experienced in some parts of the country rather than in uniform pattern. One of the best alternative solutions is the promotion of LPG for the commercial sector, given the fact that the exploration of oil is going on in Uganda and prices are expected to be relatively low. This should be followed by ban on burnt bricks in the industrial sector. Then the household should have efficiency in the kiln, ICS (firewood and charcoal) and the control of population growth.

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A.1 Total production[16] of round-wood timber, 2003 – 2011 (‘000 tonnes)

Category	2003	2004	2005	2006	2007	2008	2009	2010	2011
Monetary									
For sawn timber	791	845	902	1,201	1,560	1,658	1,744	1847	1,957
For poles	234	243	253	278	290	302	323	338	709
For fuelwood - Household	747	774	802	830	858	887	917	948	981
For fuelwood - Commercial	645	660	676	692	709	725	743	760	779
For fuelwood- Industrial	1,496	1,529	1,562	1,596	1,631	1,667	1,703	1740	1,779
For charcoal	5,308	5,681	6,080	6,506	6,963	7,452	7,975	8535	9,134
Total wood production	**9,221**	**9,732**	**10,275**	**11,103**	**12,011**	**12,691**	**13,405**	**14,168**	**15,339**
Nonmonetary									
For poles	513	534	555	577	600	624	649	675	702
For fuelwood - Household	16,975	17,586	18,219	18,875	19,555	20,259	20,988	21,743	22,526
For fuelwood - Commercial	2,117	2,167	2,219	2,272	2,326	2,381	2,438	2,496	2,555
For fuelwood- Industrial	331	338	346	353	361	369	377	385	394
Total wood production	**19,936**	**20,625**	**21,339**	**22,077**	**22,842**	**23,633**	**24,452**	**25,299**	**26,177**
Total									
For sawn timber	791	845	902	1,201	1,560	1,658	1,744	1,847	1,957
For poles	747	777	808	855	890	926	972	1013	1411
For fuelwood - Household	17,722	18,360	19,021	19,705	20,413	21,146	21,905	22,691	23,507
For fuelwood - Commercial	2,762	2,827	2,895	2,964	3,035	3,106	3,181	3,256	3,334
For fuelwood- Industrial	1,827	1,867	1,908	1,949	1,992	2,036	2,080	2,125	2,173
For charcoal	5,308	5,681	6,080	6,506	6,963	7,452	7,975	8,535	9,134
Total wood production	**29,157**	**30,357**	**31,614**	**33,180**	**34,853**	**36,324**	**37,857**	**39,467**	**41,516**
Total Primary Woodfuel	**27,619**	**28,735**	**29,904**	**31,124**	**32,403**	**33,740**	**35,141**	**36,607**	**38,148**

Source: Figures are based on projections from the National Forestry Authority and Uganda Bureau of Statistics[17] (UBOS, 2009, p. 104; UBOS, 2011, p. 93; UBOS, 2012, p. 90)

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[16] The term production should be taken as “consumption” and wood fuel means here is termed as fuelwood or firewood.

[17] Data 2006 and 2007 from the two reports of UBOS (2009 and 2011) has some minor variation. Preference is given to the latest estimates of 2011 on assumption that it was updated. The greatest variation The greatest variation (25 – 52%), however is for sown timber but the real quantities are not very big. The other variations are not more than 8%.

A.2 Value of output of round-wood timber at current prices, 2003-2007(m shs)

Wood Type	2003	2004	2005	2006	2007	2008	2009	2010	2011
Monetary									
For sawn timber	33,062	35,280	37,648	56,880	71,266	95,837	101,696	132,677	173,097
For poles	4,399	4,575	4,758	7,196	10,010	13,069	16,782	29,250	50,981
Woodfuel- Household	5,398	5,592	5,794	6,637	6,863	7,096	7,338	7,587	7,845
Woodfuel- Commercial	4,660	4,771	4,884	6,922	7,086	7,255	7,428	7,604	7,785
Woodfuel- Industrial	10,812	11,048	11,290	15,963	16,311	16,668	17,032	17,405	17,785
For charcoal	31,908	34,148	36,545	39,038	41,779	44,712	47,851	51,210	54,805
Gross output	**90,239**	**95,414**	**100,919**	**132,636**	**153,315**	**184,637**	**198,127**	**245,733**	**312,298**
Non monetary									
For poles	9,633	10,018	10,419	10,835	11,269	11,269	11,719	12,188	12,676
Woodfuel-Household	98,159	101,664	105,323	109,115	113,043	113,043	117,113	121,329	125,697
Woodfuel-Commercial	15,299	15,668	16,041	16,423	16,814	16,814	17,214	17,624	18,043
Woodfuel-Industrial	2,393	2,446	2,499	2,554	2,610	2,610	2,667	2,725	2,785
Gross output	**125,484**	**129,796**	**134,282**	**138,927**	**143,736**	**143,736**	**148,713**	**153,866**	**159,201**
Total									
For sawn timber	33,062	35,280	37,648	56,880	71,266	95,837	101,696	132,677	173,097
For poles	14,032	14,593	15,177	18,031	21,279	24,338	28,501	41,438	63,657
Fuelwood - Household	103,557	107,256	111,117	115,752	119,906	120,139	124,451	128,916	133,542
Fuelwood-Commercial	19,959	20,439	20,925	23,345	23,900	24,069	24,642	25,228	25,828
Fuelwood- Industrial	13,205	13,494	13,789	18,517	18,921	19,278	19,699	20,130	20,570
For charcoal	31,908	34,148	36,545	39,038	41,779	44,712	47,851	51,210	54,805
Total Gross output	**215,723**	**225,210**	**235,201**	**271,563**	**297,051**	**328,373**	**346,840**	**399,599**	**471,499**

(25 – 52%), however is for sown timber but the real quantities are not very big. The other variations are not more than 8%.

A.3 Land cover Distribution, 2005, by District

REGION	DISTRICT	District Area (HA)	Broad leaved Plantation	Conifer Plantation	THF well stocked	THF low stocked	Woodland	Bush	Grassland	Wetland	Small scale farmland	Large scale farmland	Built up area	Open Water	Impediments
Central	KALANGALA	906,864			9,973	7,479	8,700	872	7,959	2,566	5,452	3,119	29	860,632	82
	KAMPALA	19,700	33				489	202	41	822	1,456		14,951	1,690	16
	KAYUNGA	170,240	139		433	277	26,831	16,051	9,199	20,300	84,095		631	12,284	
	KIBOGA	404,552		397		4,977	76,177	77,478	94,792	16,217	133,734	103	561	5	111
	LUWEERO	222,170	208		98		22,527	29,870	22,888	10,622	134,541	339	1,004	70	2
	LYANTONDE	87,361					66	39,771	14,864	278	32,191		142	50	
	MASAKA	469,174	292		6,289	10,895	13,858	20,833	68,374	27,775	206,160	70	1,841	112,424	365
	MITYANA	157,131	425		4,385	2,975	10,275	3,310	3,983	10,694	112,311	1,480	913	6,379	
	MPIGI	360,562	159		16,414	14,532	17,597	31,571	43,245	38,661	163,079	325	1,650	33,189	139
	MUBENDE	462,643	91	276	2,861	6,529	30,652	42,755	44,459	19,367	309,579	1,069	1,866	2,937	202
	MUKONO	1,265,581	498		34,310	29,667	31,667	7,541	18,539	23,906	165,820	20,035	6,236	927,207	155
	NAKASEKE	347,225	87				137,860	74,152	49,355	22,463	61,933	282	928	165	
	NAKASONGOLA	350,997		2,332			63,301	151,449	40,182	15,276	51,718	179	828	25,732	
	RAKAI	403,511	796		17,430	1,537	8,008	34,515	130,089	13,480	119,372	3,742	1,026	73,390	126
	SEMBABULE	231,917					5,561	49,352	65,331	2,814	108,476		271	112	
	WAKISO	280,775	663			3,782	16,620	1,614	3,427	19,934	126,929	3,412	14,933	89,451	11
Eastern	AMURIA	258,298						29,201	26,407	9,272	188,171	10	2,149		13
	BUDAKA	41,060	63							2,187	37,879	788	144		
	BUDUDA	27,390	72		7,884		1,440	3,288			14,689		17		
	BUGIRI	567,097		703	652	921	4,119	1,649	5,587	9,575	131,064	686	642	411,359	53
	BUKEDEA	105,466					124	6,945	21,314	6,070	70,807		163	33	11
	BUKWO	52,557	34	547	12,801	8	4,312	14,590	307		18,703	1,254			
	BUSIA	75,940	17		24	6	1,323	7,247	958	5,083	58,038	104	273	2,867	
	BUTALEJA	65,545					25	123	580	13,105	46,690	4,792	221	9	
	IGANGA	166,965					67	2,286		7,534	154,635	1,127	1,302		14
	JINJA	72,268	746	256			61	720	1,329	529	50,249	10,925	2,495	4,959	
	ABERAMAIDO	162,396					8,735	9,020	5,276	12,242	96,139		332	30,653	
	KALIRO	86,853						8,377	203	15,032	54,482		152	8,608	
	KAMULI	343,304	85				4,558	30,243	9,771	22,063	213,885	13	781	61,784	120
	KAPCHORWA	120,616		2,382	14,762	6	5,600	54,780	3,506	3,275	34,709	1,412	185		
	KATAKWI	243,152					6,215	12,264	87,353	25,129	103,559		231	8,225	177
	KUMI	179,351					741	9,619	10,741	30,092	118,062		302	9,793	
	MANAFWA	58,077	54		7,845		2,268	2,067	77		45,645		120		
	MAYUGE	463,859	565	2,365		451	6,847	666	2,590	5,648	85,940	2,006	1,301	355,450	30

	MBALE	51,816	266		1,504		1,638	630	316	975	43,402	1,251	1,835		
	NAMUTUMBA	81,268						3,392	999	13,438	63,206		87	147	
	PALLISA	158,114	34				96	793	147	35,523	115,044		258	6,220	
	SIRONKO	109,391			9,095	483	3,720	22,400	13,573	7,521	51,948	205	445		
	SOROTI	337,770		376			1,582	30,600	18,041	38,001	193,269		1,731	54,104	67
	TORORO	119,383	68				547	1,535	1,428	5,572	108,263	1,342	555	48	24
Nothern	ABIM	235,271					74,476	88,769	35,296		35,957		364	25	384
	ADJUMANI	308,703	375		1,262		149,950	44,035	22,011	13,697	70,449	51	666	6,148	59
	AMOLATAR	170,944					5,478	8,298	11,163	10,144	57,827		377	77,657	
	AMURU	842,700		6			307,997	101,189	310,878	6,388	103,698	37	1,137	11,353	17
	APAC	433,545	148				26,019	62,889	38,747	16,261	251,632	104	317	37,362	66
	ARUA	311,287	802	402			61,829	19,791	25,705	12,978	184,065		1,732	3,944	38
	DOKOLO	108,732		237			295	8,755	7,313	9,696	72,714		187	9,535	
	GULU	328,861	1,629	507			112,823	67,121	35,100	4,754	103,372	160	2,723	590	83
	KAABONG	726,372					61,462	214,749	373,028	455	75,808		134		735
	KITGUM	963,459				5	178,160	229,281	342,893	3,890	204,779	338	3,404	181	527
	KOBOKO	75,622	7				8,426	9,305	6,191		51,247		441		4
	KOTIDO	362,892					27,403	80,475	154,646	506	99,587		31	7	238
	LIRA	440,405	143				16,312	40,231	26,024	4,497	348,284		3,689	1,116	109
	MOROTO	851,769					138,110	208,274	376,849		128,135		55		346
	MOYO	189,072	21				48,809	34,785	31,533	8,282	54,818		520	10,161	144
	NAKAPIRIPIRIT	583,388					85,480	114,881	353,293	2,613	26,716	34	343		26
	NEBBI	291,726	210	1,833		4	26,085	21,308	41,493	8,295	182,543	607	322	9,028	
	NYADRI	160,722	887				9,816	2,742	25,362	3,293	118,436		176	11	
	OYAM	220,586	519				4,202	8,953	10,240	20,500	175,498	139		534	
	PADER	692,934				210	172,271	109,349	172,088	834	230,365		6,071	453	1,294
	YUMBE	240,302					89,432	27,229	14,058	2,195	106,291		95	949	54
	BULIISA	188,484			15,917	74	2,192	47,553	23,592	4,217	18,370	84	90	76,397	
	BUNDIBUGYO	226,170			37,513		35,541	11,255	88,512	333	35,660		170	17,187	
	BUSHENYI	429,257	713		64,199	966	34,793	23,203	57,491	8,747	200,553	1,265	352	36,976	
	HOIMA	577,873	128		37,345	21,424	39,246	64,390	45,856	4,966	150,412	1,154	1,099	211,816	
	IBANDA	97,168	16		3,915	78	6,704	4,234	13,838	1,260	66,809		314		
	ISINGIRO	265,087	142				730	58,081	95,231	9,893	97,294		36	3,678	
	KABALE	172,964	330	1,468	8,745		418	1,069	9,138	1,392	144,488		834	5,045	
	KABAROLE	182,446	1,838	161	34,498	1,455	18,950	15,150	7,360	1,309	94,772	5,479	604	870	
	KAMWENGE	243,944			25,519	571	27,022	9,704	15,365	7,602	151,559		168	6,435	
	KANUNGU	129,214	472	1,253	19,170		4,409	4,029	17,360	390	79,897	220	252	1,760	
	KASESE	338,962	28		38,086	56	39,044	30,196	67,784	15,478	85,867	18,714	1,921	41,088	
	KIBAALE	440,020	21		27,945	33,145	45,221	22,043	17,162	8,780	267,870	711	594	15,381	
	KIRUHURA	460,266				28	45,412	169,931	74,978	9,232	158,549	211	152	1,772	
	KISORO	72,967	270		7,677		3,763	1,459	269	334	55,885	309	193	2,809	
	KYENJOJO	405,440	253	1,102	29,226	54,582	57,495	25,089	21,482	7,846	204,428	3,632	249	40	
	MASINDI	755,829	20	73	27,410	4,523	309,612	123,480	88,378	9,847	174,883	12,632	870	4,092	

MBARARA	179,395	449	1,354			2,700	9,488	69,938	9,843	83,014	669	1,876	64
NTUNGAMO	205,551	28	729			2,283	9,576	88,101	8,955	94,591	11	814	447
RUKUNGIRI	156,678		7	17,601		8,766	4,212	21,353	302	92,224		366	11,848
TOTAL	**24,155,348**	**14,841**	**18,767**	**542,787**	**201,644**	**2,816,423**	**2,970,318**	**4,064,332**	**753,041**	**8,854,671**	**106,630**	**97,270**	**3,706,732**
National share or Size	0.10%	0.10%	0.20%	0.80%	11.70%	12.30%	16.80%	3.10%	36.70%	0.40%	0.40%	15.30%	0%
District distribution	58%	28%	41%	38%	96%	99%	96%	93%	100%	59%	98%	83%	53%

Source: Diisi (2009, p. 33); national share and district coverage added by author

A.4 Protected and Private Areas

Class	Protected	Private	Area (ha) 2005
HWP	5,266	9,575	14,841
CP	16,541	2,226	18,767
THFws	473,376	66,913	540,289
THFls	45,534	156,110	201,644
Woodland	760,278	2,058,644	2,818,922
Bushland	518,361	2,451,957	2,970,318
Grassland	990,098	3,074,234	4,064,332
Wetland	45,530	707,511	753,041
SSF	226,154	8,628,517	8,854,671
LSF	3,968	102,662	106,630
BUA	3,463	93,807	97,270
Water	15,805	3,690,927	3,706,732
Impediments	1,990	5,814	7,804

A.5 Biomass and Population by District

REGION	**DISTRICT**	**OPEN WATER**	**LAND AREA**	**DISTRICT AREA**	**Tons_Ha 1990**	**Tons_Ha 2004**	**Area Ha**	**Biomass Difference**	**Biomass change/ ha**	**Biomass growth rate (%)**	**Yield/ Stock (%)**	**Pop 1991**	**Pop 2002**	**Pop growth Rate (%)**
Central	KALANGALA	860,632	46,232	906,864	4,944,206	4,628,362	906,864	-315,844	-0.3	-0.40%	6.30%	16,371	34,766	6%
Central	KAMPALA	1,690	18,011	19,700	145,713	30,178	19,700	-115,535	-5.9	-5.30%	20.10%	774,241	1,189,142	4%
Central	KAYUNGA	12,284	157,956	170,240	2,771,430	1,544,202	170,240	-1,227,228	-7.2	-3.00%	16.60%	236,177	294,613	2%
Central	KIBOGA	5	404,547	404,552	10,605,033	4,876,714	404,552	-5,728,319	-14.2	-3.60%	15.20%	141,607	229,472	4%
Central	LUWEERO	70	222,100	222,170	6,183,295	1,830,409	222,170	-4,352,886	-19.6	-4.70%	16.80%	255,390	341,317	2%
Central	LYANTONDE	50	87,311	87,361	958,976	625,011	87,361	-333,965	-3.8	-2.30%	14.00%	53,100	66,039	2%
Central	MASAKA	112,424	356,750	469,174	3,485,663	4,898,366	469,174	1,412,703	3	2.70%	12.00%	694,697	770,662	1%
Central	MITYANA	6,379	150,752	157,131	4,538,952	3,031,339	157,131	-1,507,613	-9.6	-2.20%	9.20%	223,527	266,108	1%
Central	MPIGI	33,189	327,373	360,562	11,353,568	7,870,293	360,562	-3,483,275	-9.7	-2.00%	9.40%	350,980	407,790	1%
Central	MUBENDE	2,937	459,706	462,643	11,539,635	5,529,190	462,643	-6,010,445	-13	-3.50%	12.10%	277,449	423,422	4%
Central	MUKONO	927,207	338,374	1,265,581	21,761,689	17,684,324	1,265,581	-4,077,365	-3.2	-1.20%	6.90%	588,427	795,393	3%
Central	NAKASEKE	165	347,060	347,225	9,830,898	5,013,632	347,225	-4,817,266	-13.9	-3.30%	17.50%	93,804	137,278	3%
Central	NAKASONGOLA	25,732	325,265	350,997	4,836,317	3,486,007	350,997	-1,350,310	-3.8	-1.90%	16.10%	100,497	127,064	2%
Central	RAKAI	73,390	330,121	403,511	4,868,809	5,940,876	403,511	1,072,067	2.7	1.50%	10.40%	330,401	404,326	2%
Central	SEMBABULE	112	231,804	231,917	2,950,193	1,555,673	231,917	-1,394,520	-6	-3.20%	16.20%	144,039	180,045	2%
Central	WAKISO	89,451	191,324	280,775	6,308,391	2,265,161	280,775	-4,043,230	-14.4	-4.30%	13.70%	562,887	907,988	4%
Eastern	AMURIA		258,298	258,298	5,254,967	1,431,176	258,298	-3,823,791	-14.8	-4.90%	18.60%	69,353	180,022	8%
Eastern	BUDAKA		41,060	41,060	615,832	194,201	41,060	-421,631	-10.3	-4.60%	20.10%	100,348	136,489	3%
Eastern	BUDUDA		27,390	27,390	664,414	1,737,593	27,390	1,073,179	39.2	10.80%	8.30%	79,218	123,103	4%
Eastern	BUGIRI	411,359	155,739	567,097	3,151,792	1,486,520	567,097	-1,665,272	-2.9	-3.50%	12.20%	239,307	412,395	5%
Eastern	BUKEDEA	33	105,434	105,466	1,565,764	459,440	105,466	-1,106,324	-10.5	-4.70%	21.80%	75,272	122,433	4%
Eastern	BUKWO		52,557	52,557	2,185,658	2,717,878	52,557	532,220	10.1	1.60%	9.10%	30,692	48,952	4%
Eastern	BUSIA	2,867	73,074	75,940	1,157,392	513,191	75,940	-644,201	-8.5	-3.70%	14.50%	163,597	225,008	3%
Eastern	BUTALEJA	9	65,536	65,545	1,146,605	234,331	65,545	-912,274	-13.9	-5.30%	20.60%	106,678	157,489	3%
Eastern	IGANGA		166,965	166,965	4,498,371	1,112,824	166,965	-3,385,547	-20.3	-5.00%	14.50%	365,756	540,999	3%
Eastern	JINJA	4,959	67,309	72,268	940,845	394,842	72,268	-546,003	-7.6	-3.90%	17.70%	289,476	387,573	2%
Eastern	KABERAMAIDO	30,653	131,743	162,396	2,774,282	889,663	162,396	-1,884,619	-11.6	-4.50%	17.40%	81,535	131,650	4%
Eastern	KALIRO	8,608	78,245	86,853	2,287,119	337,357	86,853	-1,949,762	-22.4	-5.70%	18.80%	105,122	154,667	3%
Eastern	KAMULI	61,784	281,519	343,304	5,498,013	2,271,001	343,304	-3,227,012	-9.4	-3.90%	12.30%	380,092	552,665	3%
Eastern	KAPCHORWA		120,616	120,616	3,813,276	3,472,133	120,616	-341,143	-2.8	-0.60%	9.90%	86,010	141,439	4%
Eastern	KATAKWI	8,225	234,927	243,152	3,778,151	1,619,598	243,152	-2,158,553	-8.9	-3.80%	14.50%	75,244	118,928	4%
Eastern	KUMI	9,793	169,558	179,351	2,579,714	710,743	179,351	-1,868,971	-10.4	-4.80%	20.10%	161,422	267,232	4%
Eastern	MANAFWA		58,077	58,077	1,170,768	2,681,152	58,077	1,510,384	26	8.60%	6.60%	178,528	262,566	3%
Eastern	MAYUGE	355,450	108,409	463,859	3,242,579	953,316	463,859	-2,289,263	-4.9	-4.70%	14.60%	216,849	324,674	3%
Eastern	MBALE		51,816	51,816	578,802	839,868	51,816	261,066	5	3.00%	10.00%	240,929	332,571	3%
Eastern	NAMUTUMBA	147	81,122	81,268	1,801,784	340,928	81,268	-1,460,856	-18	-5.40%	19.90%	123,871	167,691	3%
Eastern	PALLISA	6,220	151,894	158,114	2,173,847	582,833	158,114	-1,591,014	-10.1	-4.90%	20.20%	257,308	384,089	3%
Eastern	SIRONKO		109,391	109,391	2,314,059	2,383,855	109,391	69,796	0.6	0.20%	10.50%	212,305	283,092	2%

Eastern	SOROTI	54,104	283,666	337,770	4,183,276	1,267,045	337,770	-2,916,231	-8.6	-4.60%	20.10%	204,258	369,789	5%
Eastern	TORORO	48	119,336	119,383	1,290,693	586,646	119,383	-704,047	-5.9	-3.60%	19.90%	285,299	379,399	2%
Northern	ABIM	25	235,246	235,271	4,695,338	3,096,325	235,271	-1,599,013	-6.8	-2.30%	17.20%	47,572	51,803	1%
Northern	ADJUMANI	6,148	302,555	308,703	6,337,364	8,200,196	308,703	1,862,832	6	2.00%	11.10%	96,264	202,290	6%
Northern	AMOLATAR	77,657	93,288	170,944	1,322,179	509,064	170,944	-813,115	-4.8	-4.10%	20.80%	68,473	96,189	3%
Northern	AMURU	11,353	831,347	842,700	16,150,838	14,668,018	842,700	-1,482,820	-1.8	-0.60%	14.00%	126,639	176,733	3%
Northern	APAC	37,362	396,182	433,545	5,758,126	2,635,082	433,545	-3,123,044	-7.2	-3.60%	18.50%	277,451	415,578	3%
Northern	ARUA	3,944	307,343	311,287	5,792,205	3,038,318	311,287	-2,753,887	-8.8	-3.20%	18.20%	368,214	559,075	4%
Northern	DOKOLO	9,535	99,196	108,732	1,523,867	457,289	108,732	-1,066,578	-9.8	-4.70%	19.90%	84,978	129,385	4%
Northern	GULU	590	328,272	328,861	5,913,795	4,818,170	328,861	-1,095,625	-3.3	-1.20%	16.60%	211,788	298,527	3%
Northern	KAABONG		726,372	726,372	6,433,570	6,566,888	726,372	133,318	0.2	0.10%	14.80%	91,236	202,758	7%
Northern	KITGUM	181	963,278	963,459	20,007,441	10,337,713	963,459	-9,669,728	-10	-3.20%	16.20%	175,587	282,375	4%
Northern	KOBOKO		75,622	75,622	1,963,155	778,210	75,622	-1,184,945	-15.7	-4.00%	14.20%	62,337	129,148	6%
Northern	KOTIDO	7	362,885	362,892	2,966,702	2,790,019	362,892	-176,683	-0.5	-0.40%	16.90%	57,198	122,541	7%
Northern	LIRA	1,116	439,289	440,405	7,720,484	2,629,472	440,405	-5,091,012	-11.6	-4.40%	19.40%	347,514	515,666	3%
Northern	MOROTO		851,769	851,769	6,974,067	8,661,415	851,769	1,687,348	2	1.60%	16.20%	96,833	189,940	6%
Northern	MOYO	10,161	178,912	189,072	3,921,171	1,901,158	189,072	-2,020,013	-10.7	-3.40%	19.30%	79,381	194,778	8%
Northern	NAKAPIRIPIRIT		583,388	583,388	6,503,214	5,960,484	583,388	-542,730	-0.9	-0.60%	15.50%	77,584	154,494	6%
Northern	NEBBI	9,028	282,699	291,726	4,038,710	2,245,584	291,726	-1,793,126	-6.1	-3.00%	16.90%	316,866	435,360	3%
Northern	NYADRI	11	160,711	160,722	2,670,381	1,489,424	160,722	-1,180,957	-7.3	-2.90%	13.90%	107,596	145,705	3%
Northern	OYAM	534	220,052	220,586	2,760,745	1,267,505	220,586	-1,493,240	-6.8	-3.60%	17.60%	177,053	268,415	4%
Northern	PADER	453	692,481	692,934	15,764,262	7,995,249	692,934	-7,769,013	-11.2	-3.30%	17.40%	181,597	326,338	5%
Northern	YUMBE	949	239,353	240,302	6,121,393	3,302,238	240,302	-2,819,155	-11.7	-3.10%	18.00%	99,794	251,784	8%
Western	BULIISA	76,397	112,087	188,484	4,826,010	6,078,944	188,484	1,252,934	6.6	1.70%	5.60%	47,709	63,363	2%
Western	BUNDIBUGYO	17,187	208,983	226,170	12,026,151	14,614,052	226,170	2,587,901	11.4	1.40%	6.00%	116,566	209,978	5%
Western	BUSHENYI	36,976	392,282	429,257	14,951,200	24,500,662	429,257	9,549,462	22.2	4.30%	5.90%	579,137	731,392	2%
Western	HOIMA	211,816	366,057	577,873	19,631,097	19,067,634	577,873	-563,463	-1	-0.20%	6.60%	197,851	343,618	5%
Western	IBANDA		97,168	97,168	1,288,885	1,962,798	97,168	673,913	6.9	3.50%	9.10%	148,029	198,635	3%
Western	ISINGIRO	3,678	261,408	265,087	1,654,883	1,695,768	265,087	40,885	0.2	0.20%	15.10%	226,365	316,025	3%
Western	KABALE	5,045	167,919	172,964	2,291,103	3,244,393	172,964	953,290	5.5	2.80%	9.10%	417,218	458,318	1%
Western	KABAROLE	870	181,576	182,446	8,155,276	13,165,267	182,446	5,009,991	27.5	4.10%	5.90%	299,573	356,914	1%
Western	KAMWENGE	6,435	237,509	243,944	7,848,612	10,362,078	243,944	2,513,466	10.3	2.10%	6.80%	201,654	263,730	2%
Western	KANUNGU	1,760	127,454	129,214	4,886,682	7,419,189	129,214	2,532,507	19.6	3.50%	5.60%	160,708	204,732	2%
Western	KASESE	41,088	297,874	338,962	9,401,727	14,914,835	338,962	5,513,108	16.3	3.90%	6.40%	343,601	523,033	4%
Western	KIBAALE	15,381	424,639	440,020	23,527,336	18,157,621	440,020	-5,369,715	-12.2	-1.50%	7.30%	220,261	405,882	5%
Western	KIRUHURA	1,772	458,494	460,266	4,516,393	3,883,838	460,266	-632,555	-1.4	-0.90%	16.30%	140,946	212,219	4%
Western	KISORO	2,809	70,158	72,967	2,166,202	2,932,258	72,967	766,056	10.5	2.40%	6.70%	186,681	220,312	1%
Western	KYENJOJO	40	405,401	405,440	16,882,705	20,813,693	405,440	3,930,988	9.7	1.60%	7.60%	245,573	377,171	4%
Western	MASINDI	4,092	751,737	755,829	24,048,438	24,824,503	755,829	776,065	1	0.20%	9.70%	213,087	396,127	5%
Western	MBARARA	64	179,331	179,395	647,185	1,140,273	179,395	493,088	2.7	5.10%	16.40%	267,457	361,477	3%
Western	NTUNGAMO	447	205,104	205,551	467,634	949,284	205,551	481,650	2.3	6.90%	21.80%	305,199	379,987	2%
Western	RUKUNGIRI	11,848	144,829	156,678	4,044,877	6,993,094	156,678	2,948,217	18.8	4.90%	6.10%	230,072	275,162	2%
	TOTAL	3,706,732	20,448,616	24,155,348	464,352,174	390,095,878	24,155,348	-74,256,298	-3.1	-1.10%	10.50%	16,671,705	24,227,297	3%

Source: Diisi (2009, p. 72); UBOS (2009, pp. 107-108); Biomass change/ha, biomass growth rate (%), yield as a percentage of stock and population growth rate are author's calculations.

A.6 Biomass Current Annual Increment (yield), demand, balance and yield to demand ratio by land cover[18] types in each district 2005 (tonnes per year)

REGION	DISTRICT	Broad leaved Plantation	THF well stocked	THF low stocked	Woodland	Bush	Grassland	Small scale farmland	Built up area	Yield	Demand	Balance	Yield/ Demand
Central	KALANGALA	-	149,595	82,269	43,500	872	7,959	5,452	87	289,734	28,515	261,219	10.2
	KAMPALA	429	-	-	2,445	202	41	1,456	1,495	6,068	901,057	(894,989)	0.0
	KAYUNGA	1,807	6,495	3,047	134,155	16,051	9,199	84,095	1,893	256,742	211,930	44,812	1.2
	KIBOGA	-	-	54,747	380,885	77,478	94,792	133,734	1,683	743,319	176,200	567,119	4.2
	LUWEERO	2,704	1,470	-	112,635	29,870	22,888	134,541	3,012	307,120	249,818	57,302	1.2
	LYANTONDE	-	-	-	330	39,771	14,864	32,191	426	87,582	47,469	40,113	1.8
	MASAKA	3,796	94,335	119,845	69,290	20,833	68,374	206,160	5,523	588,156	538,143	50,013	1.1
	MITYANA	5,525	65,775	32,725	51,375	3,310	3,983	112,311	2,739	277,743	189,180	88,563	1.5
	MPIGI	2,067	246,210	159,852	87,985	31,571	43,245	163,079	4,950	738,959	288,121	450,838	2.6
	MUBENDE	1,183	42,915	71,819	153,260	42,755	44,459	309,579	5,598	671,568	320,336	351,232	2.1
	MUKONO	6,474	514,650	326,337	158,335	7,541	18,539	165,820	18,708	1,216,404	583,827	632,577	2.1
	NAKASEKE	1,131	-	-	689,300	74,152	49,355	61,933	2,784	878,655	102,781	775,874	8.5
	NAKASONGOLA	-	-	-	316,505	151,449	40,182	51,718	2,484	562,338	91,715	470,623	6.1
	RAKAI	10,348	261,450	16,907	40,040	34,515	130,089	119,372	3,078	615,799	289,449	326,350	2.1
	SEMBABULE	-	-	-	27,805	49,352	65,331	108,476	813	251,777	129,582	122,195	1.9

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[18] Land cover types with insignificant or no biomass increment are excluded

	WAKISO	8,619	-	41,602	83,100	1,614	3,427	126,929	44,799	310,090	696,411	(386,321)	0.4
Eastern	AMURIA	-	-	-	15,375	29,201	26,407	188,171	6,447	265,601	154,924	110,677	1.7
	BUDAKA	819	-	-	-	-	-	37,879	432	39,130	100,340	(61,210)	0.4
	BUDUDA	936	118,260	-	7,200	3,288	-	14,689	51	144,424	93,551	50,873	1.5
	BUGIRI	-	9,780	10,131	20,595	1,649	5,587	131,064	1,926	180,732	321,485	(140,753)	0.6
	BUKEDEA	-	-	-	620	6,945	21,314	70,807	489	100,175	94,096	6,079	1.1
	BUKWO	442	192,015	88	21,560	14,590	307	18,703	-	247,705	37,441	210,264	6.6
	BUSIA	221	360	66	6,615	7,247	958	58,038	819	74,324	165,877	(91,553)	0.4
	BUTALEJA	-	-	-	125	123	580	46,690	663	48,181	118,169	(69,988)	0.4
	IGANGA	-	-	-	335	2,286	-	154,635	3,906	161,162	406,123	(244,961)	0.4
	JINJA	9,698	-	-	305	720	1,329	50,249	7,485	69,786	283,803	(214,017)	0.2
	KABERAMAIDO	-	-	-	43,675	9,020	5,276	96,139	996	155,106	100,997	54,109	1.5
	KALIRO	-	-	-	-	8,377	203	54,482	456	63,518	115,954	(52,436)	0.5
	KAMULI	1,105	-	-	22,790	30,243	9,771	213,885	2,343	280,137	413,118	(132,981)	0.7
	KAPCHORWA	-	221,430	66	28,000	54,780	3,506	34,709	555	343,046	108,997	234,049	3.1
	KATAKWI	-	-	-	31,075	12,264	87,353	103,559	693	234,944	90,758	144,186	2.6
	KUMI	-	-	-	3,705	9,619	10,741	118,062	906	143,033	206,277	(63,244)	0.7
	MANAFWA	702	117,675	-	11,340	2,067	77	45,645	360	177,866	196,827	(18,961)	0.9
	MAYUGE	7,345	-	4,961	34,235	666	2,590	85,940	3,903	139,640	244,467	(104,827)	0.6
	MBALE	3,458	22,560	-	8,190	630	316	43,402	5,505	84,061	245,395	(161,334)	0.3

	NAMUTUMBA	-	-	-	-	3,392	999	63,206	261	67,858	123,133	(55,275)	0.6
	PALLISA	442	-	-	480	793	147	115,044	774	117,680	288,988	(171,308)	0.4
	SIRONKO	-	136,425	5,313	18,600	22,400	13,573	51,948	1,335	249,594	207,084	42,510	1.2
Eastern	SOROTI	-	-	-	7,910	30,600	18,041	193,269	5,193	255,013	291,775	(36,762)	0.9
	TORORO	884	-	-	2,735	1,535	1,428	108,263	1,665	116,510	277,346	(160,836)	0.4
Northern	ABIM	-	-	-	372,380	88,769	35,296	35,957	1,092	533,494	36,003	497,491	14.8
	ADJUMANI	4,875	18,930	-	749,750	44,035	22,011	70,449	1,998	912,048	165,499	746,549	5.5
	AMOLATAR	-	-	-	27,390	8,298	11,163	57,827	1,131	105,809	71,286	34,523	1.5
	AMURU	-	-	-	1,539,985	101,189	310,878	103,698	3,411	2,059,161	130,763	1,928,398	15.7
	APAC	1,924	-	-	130,095	62,889	38,747	251,632	951	486,238	312,946	173,292	1.6
	ARUA	10,426	-	-	309,145	19,791	25,705	184,065	5,196	554,328	422,427	131,901	1.3
	DOKOLO	-	-	-	1,475	8,755	7,313	72,714	561	90,818	97,829	(7,011)	0.9
	GULU	21,177	-	-	564,115	67,121	35,100	103,372	8,169	799,054	221,429	577,625	3.6
	KAABONG	-	-	-	307,310	214,749	373,028	75,808	402	971,297	168,134	803,163	5.8
	KITGUM	-	-	55	890,800	229,281	342,893	204,779	10,212	1,678,020	216,414	1,461,606	7.8
	KOBOKO	91	-	-	42,130	9,305	6,191	51,247	1,323	110,287	105,298	4,989	1.0
	KOTIDO	-	-	-	137,015	80,475	154,646	99,587	93	471,816	100,723	371,093	4.7
	LIRA	1,859	-	-	81,560	40,231	26,024	348,284	11,067	509,025	387,414	121,611	1.3
	MOROTO	-	-	-	690,550	208,274	376,849	128,135	165	1,403,973	152,825	1,251,148	9.2
	MOYO	273	-	-	244,045	34,785	31,533	54,818	1,560	367,014	165,393	201,621	2.2

	NAKAPIRIPIRIT	-	-	-	427,400	114,881	353,293	26,716	1,029	923,319	124,761	798,558	7.4
	NEBBI	2,730	-	44	130,425	21,308	41,493	182,543	966	379,509	320,866	58,643	1.2
	NYADRI	11,531	-	-	49,080	2,742	25,362	118,436	528	207,679	106,998	100,681	1.9
	OYAM	6,747	-	-	21,010	8,953	10,240	175,498	-	22,448	202,733	19,715	1.1
	PADER	-	-	2,310	861,355	109,349	172,088	230,365	18,213	1,393,680	257,025	1,136,655	5.4
	YUMBE	-	-	-	447,160	27,229	14,058	106,291	285	595,023	215,223	379,800	2.8
Western	BULIISA	-	238,755	814	10,960	47,553	23,592	18,370	270	340,314	46,304	294,010	7.3
	BUNDIBUGYO	-	562,695	-	177,705	11,255	88,512	35,660	510	876,337	165,476	710,861	5.3
	BUSHENYI	9,269	962,985	10,626	173,965	23,203	57,491	200,553	1,056	1,439,148	527,764	911,384	2.7
	HOIMA	1,664	560,175	235,664	196,230	64,390	45,856	150,412	3,297	1,257,688	268,382	989,306	4.7
	IBANDA	208	58,725	858	33,520	4,234	13,838	66,809	942	179,134	145,533	33,601	1.2
	ISINGIRO	1,846	-	-	3,650	58,081	95,231	97,294	108	256,210	233,846	22,364	1.1
	KABALE	4,290	131,175	-	2,090	1,069	9,138	144,488	2,502	294,752	319,238	(24,486)	0.9
	KABAROLE	23,894	517,470	16,005	94,750	15,150	7,360	94,772	1,812	771,213	253,784	517,429	3.0
	KAMWENGE	-	382,785	6,281	135,110	9,704	15,365	151,559	504	701,308	191,985	509,323	3.7
	KANUNGU	6,136	287,550	-	22,045	4,029	17,360	79,897	756	417,773	148,056	269,717	2.8
	KASESE	364	571,290	616	195,220	30,196	67,784	85,867	5,763	957,100	395,444	561,656	2.4
	KIBAALE	273	419,175	364,595	226,105	22,043	17,162	267,870	1,782	1,319,005	321,641	997,364	4.1
	KIRUHURA	-	-	308	227,060	169,931	74,978	158,549	456	631,282	160,016	471,266	3.9
	KISORO	3,510	115,155	-	18,815	1,459	269	55,885	579	195,672	156,277	39,395	1.3

	KYENJOJO	3,289	438,390	600,402	287,475	25,089	21,482	204,428	747	1,581,302	285,796	1,295,506	5.5
	MASINDI	260	411,150	49,753	1,548,060	123,480	88,378	174,883	2,610	2,398,574	314,584	2,083,990	7.6
	MBARARA	5,837	-	-	13,500	9,488	69,938	83,014	5,628	187,405	265,319	(77,914)	0.7
	NTUNGAMO	364	-	-	11,415	9,576	88,101	94,591	2,442	206,489	273,212	(66,723)	0.8
	RUKUNGIRI	-	264,015	-	43,830	4,212	21,353	92,224	1,098	426,732	195,844	230,888	2.2
	TOTAL	192,933	8,141,805	2,218,084	14,082,115	2,970,318	4,064,332	8,854,671	291,810	40,816,068	18,107,373	22,708,695	2.3

Source: Author based on Diisi (2009, p. 33);

A.7 Comparison of Biomass per Capita for 2005 and 1990 by District

DISTRICT	Tons_ 1990	Tons_ 2004	Pop1991	Pop2002	PopPR	Pop 2005	BPC1990	BPC2005	BPC Ratio (2005/1990)
KALANGALA	4,944,206	4,628,362	16,371	34,766	4%	38,632	302	119.8	0.4
KAMPALA	145,713	30,178	774,241	1,189,142	2%	1,262,849	0.2	0	0.13
KAYUNGA	2,771,430	1,544,202	236,177	294,613	2%	311,758	11.7	5	0.42
KIBOGA	10,605,033	4,876,714	141,607	229,472	4%	256,743	74.9	19	0.25
LUWEERO	6,183,295	1,830,409	255,390	341,317	2%	367,059	24.2	5	0.21
LYANTONDE	958,976	625,011	53,100	66,039	3%	72,147	18.1	8.7	0.48
MASAKA	3,485,663	4,898,366	694,697	770,662	1%	802,540	5	6.1	1.22
MITYANA	4,538,952	3,031,339	223,527	266,108	2%	280,946	20.3	10.8	0.53

MPIGI	11,353,568	7,870,293	350,980	407,790	2%	431,445	32.3	18.2	0.56
MUBENDE	11,539,635	5,529,190	277,449	423,422	4%	477,049	41.6	11.6	0.28
MUKONO	21,761,689	17,684,324	588,427	795,393	3%	866,566	37	20.4	0.55
NAKASEKE	9,830,898	5,013,632	93,804	137,278	3%	150,181	104.8	33.4	0.32
NAKASONGOLA	4,836,317	3,486,007	100,497	127,064	3%	138,798	48.1	25.1	0.52
RAKAI	4,868,809	5,940,876	330,401	404,326	2%	429,892	14.7	13.8	0.94
SEMBABULE	2,950,193	1,555,673	144,039	180,045	3%	195,794	20.5	7.9	0.39
WAKISO	6,308,391	2,265,161	562,887	907,988	7%	1,100,287	11.2	2.1	0.18
AMURIA	5,254,967	1,431,176	69,353	180,022	3%	198,995	75.8	7.2	0.09
BUDAKA	615,832	194,201	100,348	136,489	4%	151,452	6.1	1.3	0.21
BUDUDA	664,414	1,737,593	79,218	123,103	5%	140,551	8.4	12.4	1.47
BUGIRI	3,151,792	1,486,520	239,307	412,395	3%	454,681	13.2	3.3	0.25
BUKEDEA	1,565,764	459,440	75,272	122,433	4%	136,195	20.8	3.4	0.16
BUKWO	2,185,658	2,717,878	30,692	48,952	5%	56,677	71.2	48	0.67
BUSIA	1,157,392	513,191	163,597	225,008	3%	246,428	7.1	2.1	0.29
BUTALEJA	1,146,605	234,331	106,678	157,489	4%	175,687	10.7	1.3	0.12
IGANGA	4,498,371	1,112,824	365,756	540,999	3%	585,981	12.3	1.9	0.15
JINJA	940,845	394,842	289,476	387,573	2%	406,187	3.3	1	0.3
KABERAMAIDO	2,774,282	889,663	81,535	131,650	4%	148,192	34	6	0.18
KALIRO	2,287,119	337,357	105,122	154,667	4%	171,751	21.8	2	0.09
KAMULI	5,498,013	2,271,001	380,092	552,665	3%	607,315	14.5	3.7	0.26
KAPCHORWA	3,813,276	3,472,133	86,010	141,439	3%	154,084	44.3	22.5	0.51
KATAKWI	3,778,151	1,619,598	75,244	118,928	3%	129,036	50.2	12.6	0.25
KUMI	2,579,714	710,743	161,422	267,232	3%	295,195	16	2.4	0.15
MANAFWA	1,170,768	2,681,152	178,528	262,566	2%	282,450	6.6	9.5	1.45
MAYUGE	3,242,579	953,316	216,849	324,674	3%	357,304	15	2.7	0.18

MBALE	578,802	839,868	240,929	332,571	3%	366,351	2.4	2.3	0.95
NAMUTUMBA	1,801,784	340,928	123,871	167,691	3%	185,576	14.5	1.8	0.13
PALLISA	2,173,847	582,833	257,308	384,089	4%	426,572	8.4	1.4	0.16
SIRONKO	2,314,059	2,383,855	212,305	283,092	3%	312,647	10.9	7.6	0.7
SOROTI	4,183,276	1,267,045	204,258	369,789	4%	413,114	20.5	3.1	0.15
TORORO	1,290,693	586,646	285,299	379,399	3%	411,311	4.5	1.4	0.32
ABIM	4,695,338	3,096,325	47,572	51,803	6%	62,052	98.7	49.9	0.51
ADJUMANI	6,337,364	8,200,196	96,264	202,290	1%	209,481	65.8	39.1	0.59
AMOLATAR	1,322,179	509,064	68,473	96,189	4%	106,736	19.3	4.8	0.25
AMURU	16,150,838	14,668,018	126,639	176,733	5%	204,071	127.5	71.9	0.56
APAC	5,758,126	2,635,082	277,451	415,578	3%	456,861	20.8	5.8	0.28
ARUA	5,792,205	3,038,318	368,214	559,075	3%	607,902	15.7	5	0.32
DOKOLO	1,523,867	457,289	84,978	129,385	3%	140,848	17.9	3.2	0.18
GULU	5,913,795	4,818,170	211,788	298,527	3%	329,096	27.9	14.6	0.52
KAABONG	6,433,570	6,566,888	91,236	202,758	-2%	193,746	70.5	33.9	0.48
KITGUM	20,007,441	10,337,713	175,587	282,375	1%	295,273	113.9	35	0.31
KOBOKO	1,963,155	778,210	62,337	129,148	4%	145,182	31.5	5.4	0.17
KOTIDO	2,966,702	2,790,019	57,198	122,541	3%	134,504	51.9	20.7	0.4
LIRA	7,720,484	2,629,472	347,514	515,666	3%	563,915	22.2	4.7	0.21
MOROTO	6,974,067	8,661,415	96,833	189,940	2%	203,240	72	42.6	0.59
MOYO	3,921,171	1,901,158	79,381	194,778	-3%	178,304	49.4	10.7	0.22
NAKAPIRIPIRIT	6,503,214	5,960,484	77,584	154,494	5%	178,837	83.8	33.3	0.4
NEBBI	4,038,710	2,245,584	316,866	435,360	3%	476,021	12.7	4.7	0.37
NYADRI	2,670,381	1,489,424	107,596	145,705	2%	154,817	24.8	9.6	0.39
OYAM	2,760,745	1,267,505	177,053	268,415	3%	293,910	15.6	4.3	0.28
PADER	15,764,262	7,995,249	181,597	326,338	2%	345,563	86.8	23.1	0.27

YUMBE	6,121,393	3,302,238	99,794	251,784	5%	295,429	61.3	11.2	0.18
BULIISA	4,826,010	6,078,944	47,709	63,363	5%	73,063	101.2	83.2	0.82
BUNDIBUGYO	12,026,151	14,614,052	116,566	209,978	3%	227,496	103.2	64.2	0.62
BUSHENYI	14,951,200	24,500,662	579,137	731,392	2%	767,059	25.8	31.9	1.24
HOIMA	19,631,097	19,067,634	197,851	343,618	4%	389,591	99.2	48.9	0.49
IBANDA	1,288,885	1,962,798	148,029	198,635	2%	209,880	8.7	9.4	1.07
ISINGIRO	1,654,883	1,695,768	226,365	316,025	4%	352,324	7.3	4.8	0.66
KABALE	2,291,103	3,244,393	417,218	458,318	1%	476,089	5.5	6.8	1.24
KABAROLE	8,155,276	13,165,267	299,573	356,914	2%	382,875	27.2	34.4	1.26
KAMWENGE	7,848,612	10,362,078	201,654	263,730	4%	295,864	38.9	35	0.9
KANUNGU	4,886,682	7,419,189	160,708	204,732	2%	215,565	30.4	34.4	1.13
KASESE	9,401,727	14,914,835	343,601	523,033	2%	562,471	27.4	26.5	0.97
KIBAALE	23,527,336	18,157,621	220,261	405,882	6%	477,094	106.8	38.1	0.36
KIRUHURA	4,516,393	3,883,838	140,946	212,219	4%	236,261	32	16.4	0.51
KISORO	2,166,202	2,932,258	186,681	220,312	2%	235,236	11.6	12.5	1.07
KYENJOJO	16,882,705	20,813,693	245,573	377,171	5%	438,740	68.7	47.4	0.69
MASINDI	24,048,438	24,824,503	213,087	396,127	3%	431,624	112.9	57.5	0.51
MBARARA	647,185	1,140,273	267,457	361,477	2%	386,554	2.4	2.9	1.22
NTUNGAMO	467,634	949,284	305,199	379,987	2%	404,520	1.5	2.3	1.53
RUKUNGIRI	4,044,877	6,993,094	230,072	275,162	1%	285,803	17.6	24.5	1.39
TOTAL	464,352,174	390,095,878	16,671,705	24,227,297	3%	26,495,699	27.9	14.7	0.53

A.8 Land cover distribution by district, 1990, for the 10 main producers of charcoal sold in capital Kampala

DISTRICT	District Area (HA) 1990	Hardwood Plantation	Coniferous Plantations	Tropical High Forest (THF) well stocked	Tropical High Forest (THF) low stocked	Woodland	Bush land	Grassland	Wetland	Subsistence farmland	Large scale farmland	Built up area	Open water	Impediments
KAMULI	430,151	286	21	-	-	27,601	10,442	33,783	39,682	252,490	242	586	64,916	102
KAYUNGA	170,238	593	142	61	433	13,916	13,579	28,150	18,407	82,898	326	280	11,453	
KIBOGA	404,549	2	491	3,148	3,826	161,213	10,816	90,703	12,276	121,825	111	118	20	
LUWEERO	569,390	76	32	137	5,565	231,639	6,665	123,071	24,007	177,173	388	508	126	3
MASINDI	944,301	281	112	50,966	1,980	393,058	27,089	201,460	13,042	164,511	10,892	942	79,956	12
MPIGI	360,558	93		20,839	19,462	31,556	10,767	83,464	8,274	150,863	1,056	383	33,801	
MUBENDE	619,768	707	137	4,917	23,950	94,446	26,046	99,109	6,002	335,634	2,884	473	15,428	35
MUKONO	1,265,572	497	216	54,673	45,953	6,641	12,919	32,120	17,232	149,693	15,137	1,441	928,966	84
NAKASONGOLA	350,995	1	1707			127,051	48,865	78,091	5,806	54,729	67	793	23,884	1
WAKISO	280,774	322	16	6,823	21,638	9,229	4,620	20,910	6,474	115,086	2,401	3,085	90,109	61

A.9 Biomass in the different land cover types in the 10 main charcoal producing districts in 1990 and 2005 in 000 tons

Land Cover	Year	KAMULI	KAYUNGA	KIBOGA	LUWEERO	MASINDI	MPIGI	MUBENDE	MUKONO	NAKASON GOLA	WAKISO
District total	1990	7,826	2,802	10,748	16,042	28,565	11,525	16,028	21,788	5,134	6,472
	2005	2,608	1,544	4,877	6,844	30,904	7,870	8,560	17,679	3,486	2,265
Hardwood	1990	30	56	-	7	27	10	69	50	-	33
	2005	8	13		28	2	15	50	48		64
THF well stocked	1990		16	515	21	12,722	4,337	870	12,830	-	1,484
	2005		142		18	14,250	3,515	2,319	10,274		
THF low stocked	1990		43	180	694	184	2,391	2,902	4,703		2,184
	2005		43	773		714	2,010	1,474	4,570		588
Woodland	1990	993	259	6,241	7,959	11,772	1,386	3,918	224	2,694	369
	2005	117	669	1,971	4,308	12,437	782	1,545	1,080	1,305	555
Bushland	1990	167	211	172	87	351	120	561	178	842	66
	2005	327	146	912	895	1,824	225	354	81	1,510	18
Grassland	1990	508	345	1,223	1,103	2,317	1,072	1,508	260	783	161
	2005	26	25	350	260	714	310	325	192	217	11
Subsistence	1990	6,081	1,834	2,332	6,140	1,111	2,198	6,157	3,476	527	2,100
	2005	2,130	506	871	1,333	964	1,012	2,494	1,434	455	1,030

Source: (Drichi, 2003), (Diisi, 2009, p. 58)

A.10 Current annual increment and annual firewood consumption for 10 major charcoal producing district

DISTRICT	**Available CAI (t/yr)**	**Bags/ Week**	**Wood Equivalent t/yr**	**%**	**Population**	**Annual firewood consumption (t/yr)**	**Total wood (t/yr)**	**Balance (t/yr)**	**Pop GR%**
Kamuli	404,626	5,709	178,121	6	485,214	329,946	508,066	(103,440)	3%
Kayunga	152,844	5,442	169,790	6	296,094	201,344	371,134	(218,290)	2%
Kiboga	868,550	14,188	442,666	15	231,231	157,237	599,903	268,647	4%
Luwero	1,313,455	25,962	810,014	27	479,922	326,347	136,361	177,094	2%
Masindi	2,014,309	6,393	199,462	7	466,204	317,019	516,480	1,497,829	3%
Mpigi	582,402	9,562	298,334	10	414,529	281,880	580,214	2,188	2%
Mubende	1,053,537	5,254	163,925	5	696,933	473,914	637,839	415,698	4%
Mukono	906,137	2,612	81,494	3	788,332	536,066	617,560	288,577	3%
Nakasongola	680,857	14,432	450,278	15	128,126	87,126	537,404	143,453	3%
Wakiso	459,194	2,461	76,783	3	914,111	621,595	698,379	(239,185)	7%
Other		4,622	144,206	5					
			3,015,074	100					

Source: Data based on Kisakye (2004, pp. 26-27), tables 4.2, 4.3 and 4.4 with adjustments

A.11 National woody Biomass and area size by land cover class including the yield in private area by 1990 and 2005

Class	Total Biomass (Tons) 1990	Total Biomass (Tons) 2005	Total Area(ha) 1990	Total Area (ha) 2005	Private Area (ha) 1990	Private Area (ha) 2005	Stock (tons) Private 1990	Stock (tons) Private 2005	yield tons) Private 1990	yield (tons) Private 2005
Broad leaved plantations	1,702,827	1,438,177	18,682	14,841	12,044	9,575	1,059,600	927,872	156,308	124,475
Coniferous plantations			16,384	18,767	701	2226				
THF well stocked	129,591,090	162,126,739	651,110	540,289	174,055	66913	31,843,300	20,078,859	2,596,244	1,513,246
THF low stocked	25,906,891	30,882,558	273,062	201,644	176,428	156,110	18,050,200	23,908,850	1,947,514	2,772,026
Woodland	132,468,709	86,044,859	3,974,508	2,818,922	3,099,269	2,058,644	101,071,700	62,838,111	16,420,714	10,910,813
Bushland	17,865,384	26,883,367	1,422,193	2,970,318	1,126,650	2,451,957	11,413,300	22,191,853	957,342	2,451,957
Grassland	44,247,586	29,559,256	5,115,426	4,064,332	3,964,325	3,074,234	36,994,300	22,358,427	5,154,888	3,996,381
Wetland			484,030	753,041	451,738	707,511				
Small scale farmland	112,569,687	53,160,922	8,400,790	8,854,671	8,263,175	8,628,517	112,569,687	53,160,922	8,263,068	3,982,392
Large scale farmland			68,447	106,630	67,159	102,662	150,500	-		307,986
Built up area			36,572	97,270	34,600	93,807				
Open Water			3,689,603	3,706,732	3,675,082	3,690,927				
Impediments			3,741	7,804	2,996	5,814				
	464,352,174	390,095,878	24,154,548	24,155,261	21,048,222	21,048,897	313,152,587	205,464,893	35,496,078	26,059,277

Source: National Biomass Study Technical Report 2005, table 2-12 adjusted (Diisi, 2009, pp. 37,57) and National Biomass Study 2003, table 5-9 (Drichi, 2003, p. 67)

APPENDIX B

B.1 Cook 1: Mrs Dorothy Kakande - Three Stone Fire

	Percentage moisture content (%MCw) = **25**%						
	Charcoal GCV = 29.6 MJ/kg						
	Firewood						
		Traditional		*Improved cold*		*Improved hot*	
Initial mass	Wood	2.14	kg	1.22	kg	2.06	kg
Final mass	Wood	1.04	kg	0.2	kg	1.42	kg
	Wood used	1.1	kg	1.02	kg	0.64	kg
	Charcoal left	0.38	kg	0.04	kg	0.04	kg
Fire preparation (min)		1		3		1	
Pot warming (min)		4		3		1	
Ingredients (min)		9		7		6	
Water (up to boiling)		10		11		6	
Rice		19		31		24	
Total cooking time		**43**		**55**		**38**	
Energy in the Initial mass (MJ)		**28.70**		**16.36**		**27.62**	
Energy in firewood converted (MJ)		**14.75**		**13.68**		**8.58**	
Energy in charcoal left (MJ)		**11.25**		**1.18**		**1.18**	
Energy used		**3.50**		**12.49**		**7.40**	
Unit Price (UGX/kg)		163		163		163	
Cooking Cost		179		166		104	

Cook 1: Mrs Dorothy Kakande – Comparison of Multiple Cooking Fuels

	Charcoal	**Charcoal**	**Charcoal**	**Ethanol**	**Kerosene**	**LPG**	**Electricity**	**Electricity**

	Traditional	*Improved (cold)*	Improved (hot)		*(Paraffin)*	*(Butane)*		
Initial Fuel mass	0.88 kg	0.74 kg	0.46 kg	0.58 kg	0.42 kg	0.48 kg	0.8 kWh	5.5 kWh
Final Fuel mass	0.61 kg	0.42 kg	0.24 kg	0.46 kg	0.36 kg	0.42 kg	1.5 kWh	6.1 kWh
Used Fuel mass	0.27 kg	0.32 kg	0.22 kg	0.12 kg	0.06	0.06	0.7 kWh	0.6 kWh
Fire preparation (min)	25	16	3	0.5	0.5	0.5	5	1
Pot warming (min)	1	4	1	1	2	1	6	1
Ingredients (min)	6	33	4	5	12	7	25	7
Water (up to boiling)	11	27	10	21	9	32	42	17
Rice	21	28	14	16	23	26	60	23
Total cooking time	**64**	**108**	25	**43.5**	**46.5**	**66.5**	**138**	**49**
Final Energy (MJ)	**8.0**	**9.5**	**6.5**	**3.2**	**2.7**	2.8	**2.5**	**2.2**
Unit Quantity Price	850 UGX/kg	850 UGX/kg	850	2000 UGX/kg	3200 UGX/kg	8000 UGX/kg	500 UGX/kWh	500 UGX/kWh
Cooking cost	230 UGX	272	187	240	192	480	350	300

B.2 Cook 2: Mrs Nsamba – Three Stone Fire

	Percentage Moisture Content (MCw)	= **25**	%			

	Charcoal GCV	= 29.6	MJ/kg	
	Firewood			
		Traditional	*Improved cold*	*Improved hot*
Initial mass	Wood	2.28 kg	1.7 kg	1.46 kg
Final mass	Wood	1.46 kg	0.7 kg	0.6 kg
	Wood used	0.82 kg	1 kg	0.86 kg
	Charcoal left	0.04 kg	0.04 kg	0.34 kg
Fire preparation (min)		2	4	1
Pot warming (min)		1	1	1
Ingredients (min)		8	5	4
Water (up to boiling)		10	12	9

Rice		19	23	19
Total cooking time		40	**45**	**34**
Energy in the Initial mass (MJ)		**30.57**	**22.80**	**19.58**
Energy in firewood converted (MJ)		**11.00**	**13.41**	**11.53**
Energy in charcoal left (MJ)		**1.18**	**1.18**	**10.06**
Energy used		**9.81**	**12.23**	**1.47**
Unit price UGX/kg		163	163	163
Cooking cost		134	163	140

Cook 2: Mrs Nsamba – Comparison of Multiple Cooking Fuels

	Charcoal	**Charcoal**	**Charcoal**	**Ethanol**	**Kerosene**	**LPG**	**Electricity**
	Traditional	*Improvedcold*	*Improvedhot*	Gel	*Paraffin*	*(Butane)*	Hot-plate
Initial Fuel mass	0.66 kg	0.72 kg	0.72	0.18 kg	0.54 kg	0.56 kg	0.1
Final Fuel mass	0.44 kg	0.46 kg	0.54	0.02 kg	0.42 kg	0.48 kg	0.8
Used Fuel mass	0.22 kg	0.26 kg	0.18	0.16 kg	0.12 kg	0.08 kg	0.7
Fire preparation (min)	24	26	10	1	1	0.5	4
Pot warming (min)	3	2	5	1	1	1	4
Ingredients (min)	8	11	12	7	13	13	17
Water (up to boiling)	17	19	13	23	8	19	8
Rice	19	23	19	20	21	25	29
Total cooking time	**71**	**81**	**59**	**52**	**44**	**58.5**	**62**
Final Energy (MJ)	6.5	7.7	5.3	**4.3**	**5.4**	3.8	2.5
Unit Quantity Price	850 UGX/ kg	850 UGX/ kg	850 UGX/ kg	2000 UGX/ kg	3200 UGX/ kg	8000 UGX/ kg	500
Cooking cost	187UGX	221	153	320	384	640	350

B.3 Cook 3: Miss Nayiga – Three Stone Fire

	Percentage Moisture Content (Wet basis) : MCw	= **25** %			

	Charcoal GCV	= 29.6 MJ/kg		
	Firewood			
		Traditional	*Improved cold*	*Improved hot*
Initial mass		2.1 kg	1.87 kg	1.23 kg
Final mass	Wood	0.72 kg	0.72 kg	0.28 kg
	Wood used	1.38 kg	1.15 kg	0.95 kg
	Charcoal left	0.08 kg	0.04 kg	0.04 kg
Fire preparation (min)		4	2	1
Pot warming (min)		2	3	1
Ingredients (min)		7	13	4
Water (up to boiling)		9	23	7
Rice		19	23	18
Total cooking time		41	**64**	**31**
Energy in the Initial mass (MJ)		**28.16**	**25.08**	**16.49**
Energy in firewood converted (MJ)		**18.51**	**15.42**	**12.74**
Energy in charcoal left (MJ)		**2.37**	**1.18**	**1.18**
Energy used		**16.14**	**14.24**	**11.56**
Unit price UGX/kg		163	163	163
Cooking cost		225	187.45	155

Cook 3: Miss Nayiga – Comparison of Multiple Cook Fuels

	Charcoal	**Charcoal**	**Charcoal**	**Ethanol**	**Kerosene**	**LPG**	**Electricity**
	Traditional	*Improvedcold*	*Improvedhot*	Gel	*Paraffin*	*(Butane)*	Infrared
Initial Fuel mass	1 kg	0.72 kg	0.84	0.26 kg	0.54 kg	0.56 kg	6.1 kWh
Final Fuel mass	0.7 kg	0.38 kg	0.52	0.1 kg	0.42 kg	0.48 kg	6.8 kWh

Used Fuel mass	0.3 kg	0.34 kg	0.32	0.16 kg	0.12 kg	0.08 kg	0.7 kWh
Fire preparation (min)	11	13	5	0	0	0	0
Pot warming (min)	4	6	8	3	5	2	3
Ingredients (min)	9	23	17	13	19	6	3
Water (up to boiling)	17	25	22	29	17	22	26
Rice	25	30	34	33	22	25	40
Total cooking time	**66**	**97**	**86**	**78**	**63**	**55**	**72**
Final Energy (MJ)	8.9	10.1	9.5	**4.3**	**5.4**	3.8	2.5
Unit Quantity Price	850 UGX/kg	850 UGX/kg	850 UGX/kg	2000 UGX/kg	3200 UGX/kg	8000 UGX/kg	500 UGX/kWh
Cooking cost	255 UGX	289	272	320	384	640	350

B.4 Cook 4: Anitakute – Three Stone Fire

		Firewood	**Firewood**	**Firewood**
		Traditional	*Improved cold*	*Improved hot*
Initial mass	Wood	3.28 kg	2.02 kg	0.89 kg
Final mass	Wood	1.9 kg	0.89 kg	0.07 kg
	Wood used	1.38 kg	1.13 kg	0.82 kg
	Charcoal left	0.15 kg	0.08 kg	0.04 kg

Fire preparation (min)		6	2	1
Pot warming (min)		2	1	1
Ingredients (min)		7	5	4
Water (up to boiling)		9	12	7
Rice		19	20	18
Total cooking time		43	**40**	**31**
Energy in the Initial mass (MJ)		**43.98**	**27.09**	**11.93**
Energy in firewood converted (MJ)		**18.51**	**15.15**	**11.00**
Energy in charcoal left (MJ)		**4.44**	**2.37**	**1.18**
Energy used		**14.07**	**12.79**	**9.81**
Unit price UGX/kg		163	163	163
Cooking cost		225	184.19	134

Cook 4: Miss Anitakute – Comparison of Multiple Cook Fuels

	Charcoal	**Charcoal**	**Charcoal**	**Ethanol**	**Kerosene**	**LPG**	**Electricity**
	Traditional	*Improvedcold*	*Improvedhot*	Gel	*Paraffin*	*(Butane)*	Infrared
Initial Fuel mass	0.76 kg	1 kg	0.72	0.32 kg	0.21 kg	0.48 kg	7.5 kWh
Final Fuel mass	0.49 kg	0.72 kg	0.48	0.16 kg	0.1 kg	0.41 kg	8.1 kWh
Used Fuel mass	0.27 kg	0.28 kg	0.24	0.16 kg	0.11 kg	0.07 kg	0.6 kWh
Fire preparation (min)	8	11	4	0	1	0	0
Pot warming (min)	4	8	2	1	2	1	3
Ingredients (min)	7	14	8	12	8	7	4

Water (up to boiling)	14	17	21	21	16	22	20
Rice	29	30	32	24	25	28	53
Total cooking time	**62**	**80**	**67**	**58**	**52**	**58**	**80**
Final Energy (MJ)	8.0	8.3	7.1	**4.3**	**4.9**	3.3	2.2
Unit Quantity Price	850 UGX/kg	850 UGX/kg	850 UGX/kg	2000 UGX/kg	3200 UGX/kg	8000 UGX/kg	500 UGX/kWh
Cooking cost	229.5 UGX	238	204	320	352	560	300

B.5 All Cooks Put Together – A Comparison of Firewood Consumption

Ka = Mrs. Kakande; Ns = Mrs. Nsamba; Na = Miss Nayinga; An = Anitakute

		Firewood						**Firewood**						**Firewood**				
		Traditional						*Improved cold*						*Improved hot*				
	Ka	Ns	Na	An	Mean	STDEV	*Ka*	Ns	Na	An	Mean	STDEV	*Ka*	Ns	Na	An	Mean	STDEV
Initial Fuel mass	2.14	2.28	2.1	3.28	**2.45**	**0.56**	1.22	1.7	1.87	2.02	**1.703**	**0.347**	2.06	1.46	1.23	0.89	**1.41**	**0.493**
Final Fuel mass	1.04	1.46	0.72	1.9	**1.28**	**0.51**	0.2	0.7	0.72	0.89	**0.628**	**0.297**	1.42	0.6	0.28	0.07	**0.593**	**0.593**
Converted Fuel Mass	1.1	0.82	1.38	1.38	**1.17**	**0.27**	1.02	1	1.15	1.13	**1.075**	**0.076**	0.64	0.86	0.95	0.82	**0.818**	**0.13**
Charcoal residue (kg)	0.38	0.04	0.08	0.15	**0.163**	**0.15**	0.04	0.04	0.04	0.08	**0.05**	**0.02**	0.04	0.34	0.04	0.04	**0.115**	**0.15**

Fire preparation (min)	1	2	4	6	**3.25**	**2.22**	3	4	2	2	**2.75**	**0.957**	1	1	1	1	**1**	**0**
Pot warming (min)	4	1	2	2	**2.25**	**1.26**	3	1	3	1	**2**	**1.155**	1	1	1	1	**1**	**0**
Ingredients (min)	9	8	7	7	**7.75**	**0.96**	7	5	13	5	**7.5**	**3.786**	6	4	4	4	**4.5**	**1**
Water (up to boiling)	10	10	9	9	**9.5**	**0.58**	11	12	23	12	**14.5**	**5.686**	6	9	7	7	**7.25**	**1.258**
Rice	19	19	19	19	**19**	**0.00**	31	23	23	20	**24.25**	**4.717**	24	19	18	18	**19.75**	**2.872**
Total cooking time	**43**	40	41	43	**41.75**	**1.50**	**55**	**45**	**64**	**40**	**51**	**10.68**	**38**	**34**	**31**	**31**	**33.5**	**3.317**
Energy in Converted Wood (MJ)	**14.75**	**11.00**	**18.51**	**18.51**	**15.69**	**3.59**	**13.68**	**13.41**	**15.42**	**15.15**	**14.42**	**1.018**	**8.58**	**11.53**	**12.74**	**11.00**	**10.96**	**1.746**
Energy in charcoal residues	**11.25**	**1.18**	**2.37**	**4.44**	**4.81**	**4.50**	**1.18**	**1.18**	**1.18**	**2.37**	**1.48**	**0.592**	**1.18**	**10.06**	**1.18**	**1.18**	**3.40**	**4.44**
Total heat energy input	***3.50***	***9.81***	***16.14***	***14.07***	***10.88***	**5.58**	***12.49***	***12.23***	***14.24***	***12.79***	***12.94***	**0.897**	***7.40***	***1.47***	***11.56***	***9.81***	***7.56***	**4.403**
Unit Quantity Price (UGX)	163	163	163	163	**163**		163	163	163	163	**163**	**0**	163	163	163	163	**163**	**0**
Cooking cost	179	134	225	225	**190.7**	**43.70**	166	163	187.5	184.2	**175.2**	**12.38**	104	140	155	134	**133.3**	**21.23**

B.6 All Cooks Put Together – A Comparison of Charcoal Consumption

Ka = Mrs. Kakande; Ns = Mrs. Nsamba; Na = Miss Nayinga; An = Anitakute

		Charcoal						**Charcoal**						**Charcoal**				
		Traditional						**Improved (cold)**						**Improved (hot)**				
	Ka	Ns	Na	An	**Av**	STDEV	Ka	Ns	Na	An	**Av**	STDEV	Ka	Ns	Na	An	**Av**	STDEV
Initial Fuel mass	0.9	0.7	1.0	0.8	**0.8**	**0.15**	0.74	0.72	0.72	1	**0.8**	**0.1**	0.46	0.72	0.84	0.72	**0.7**	**0.2**
Final Fuel mass	0.6	0.4	0.7	0.5	**0.6**	**0.12**	0.42	0.46	0.38	0.72	**0.5**	**0.2**	0.24	0.54	0.52	0.48	**0.4**	**0.1**
Used Fuel mass	0.3	0.2	0.3	0.3	**0.3**	**0.03**	0.32	0.26	0.34	0.28	**0.3**	**0.0**	0.22	0.18	0.32	0.24	**0.2**	**0.1**
Fire preparation (min)	25.0	24.0	11.0	8.0	**17.0**	**8.76**	16	26	13	11	**16.5**	**6.7**	3	10	5	4	**5.5**	**3.1**
Pot warming (min)	1.0	3.0	4.0	4.0	**3.0**	**1.41**	4	2	6	8	**5.0**	**2.6**	1	5	8	2	**4.0**	**3.2**
Ingredients (min)	6.0	8.0	9.0	7.0	**7.5**	**1.29**	33	11	23	14	**20.3**	**9.9**	4	12	17	8	**10.3**	**5.6**
Water (up to boiling)	11.0	17.0	17.0	14.0	**14.8**	**2.87**	27	19	25	17	**22.0**	**4.8**	10	13	22	21	**16.5**	**5.9**

Rice ready	21.0	19.0	25.0	29.0	**23.5**	**4.43**	28	23	30	30	**27.8**	**3.3**	14	19	34	32	**24.8**	**9.8**
Total cooking time	64.0	71.0	66.0	62.0	**65.8**	**3.86**	108	81	97	80	**91.5**	**13.5**	25	59	86	67	**59.3**	**25.5**
Final Energy (MJ)	8.0	6.5	8.9	8.0	**7.8**	**0.98**	9.5	7.7	10.1	8.3	**8.9**	**1.1**	6.5	5.3	9.5	7.1	**7.1**	**1.7**
Unit Quantity Price	850.0	850.0	850.0	850.0	**850.0**		850	850	850	850	**850.0**		850	850	850	850	**850.0**	
Cooking cost	229.5	187.0	255.0	229.5	**225.3**	**28.2**	272	221	289	238	**255.0**	**31.0**	187	153	272	204	**204.0**	**50.0**

B.7 All Cooks Put Together – A Comparison of Ethanol, Kerosene and LPG

Ka = Mrs. Kakande; Ns = Mrs. Nsamba; Na = Miss Nayinga; An = Anitakute

								Kerosene						**LPG**				
			Ethanol					**(Paraffin)**						**(Butane)**				
	Ka	Ns	Na	An	**Av**	STDEV	Ka	Ns	Na	An	**Av**	STDEV	Ka	Ns	Na	An	**Av**	STDEV
Initial Fuel mass	0.58	0.18	0.26	0.32	**0.3**	**0.17**	0.42	0.54	0.54	0.21	**0.4**	**0.16**	0.48	0.56	0.56	0.48	**0.5**	**0.05**
Final Fuel mass	0.46	0.02	0.1	0.16	**0.2**	**0.19**	0.36	0.42	0.42	0.1	**0.3**	**0.15**	0.42	0.48	0.48	0.41	**0.4**	**0.04**
Used Fuel mass	0.12	0.16	0.16	0.16	**0.2**	**0.02**	0.06	0.12	0.12	0.11	**0.1**	**0.03**	0.06	0.08	0.08	0.07	**0.1**	**0.01**
Fire preparation (min)	0.5	1	0	0	**0.4**	**0.48**	0.5	1	0	1	**0.6**	**0.48**	0.5	0.5	0	0	**0.3**	**0.29**
Pot warming (min)	1	1	3	1	**1.5**	**1.00**	2	1	5	2	**2.5**	**1.73**	1	1	2	1	**1.3**	**0.50**
Ingredients (min)	5	7	13	12	**9.3**	**3.86**	12	13	19	8	**13.0**	**4.55**	7	13	6	7	**8.3**	**3.20**
Water (up to boiling)	21	23	29	21	**23.5**	**3.79**	9	8	17	16	**12.5**	**4.65**	32	19	22	22	**23.8**	**5.68**

Rice ready	16	20	33	24	**23.3**	**7.27**	23	21	22	25	**22.8**	**1.71**	26	25	25	28	**26.0**	**1.41**
Total cooking time	43.5	52	78	58	**57.9**	**14.68**	46.5	44	63	52	**51.4**	**8.44**	66.5	58.5	55	58	**59.5**	**4.92**
Final Energy (MJ)	3.23	4.312	4.312	4.312	**4.0**	**0.54**	2.69	5.37	5.37	4.923	**4.6**	**1.29**	2.8	3.8	3.8	3.3	**3.4**	**0.45**
Unit Quantity Price	2000	2000	2000	2000	**2000.0**	**0.00**	3200	3200	3200	3200	**3200.0**	**0.00**	8000	8000	8000	8000	**8000.0**	**0.00**
Cooking cost	240	320	320	320	**300.0**	**40.00**	192	384	384	352	**328.0**	**91.91**	480	640	640	560	**580.0**	**76.59**

B.8 All Cooks Put Together – A Comparison of Electricity Consumption

Ka = Mrs. Kakande; Ns = Mrs. Nsamba; Na = Miss Nayinga; An = Anitakute

		Infrared/Redhot				
	Ka	Ns	Na	An	Av	STDEV
Initial Meter Reading	5.5	1.5	6.1	7.5	**5.2**	**2.574**
Final Meter Reading	6.1	2	6.8	8.1	**5.8**	**2.634**
Used Energy (kWh)	0.6	0.5	0.7	0.6	**0.6**	**0.082**
Fire preparation (min)	1	0.5	0	0	**0.4**	**0.479**
Pot warming (min)	1	1	3	3	**2.0**	**1.155**
Ingredients (min)	7	9	3	4	**5.8**	**2.754**
Water (up to boiling)	17	23	26	20	**21.5**	**3.873**
Rice ready	23	21	40	53	**34.3**	**15.13**
Total cooking time	49	54.5	72	80	**63.9**	**14.55**
Final Energy (MJ)	2.16	1.8	2.52	2.16	**2.2**	**0.294**

Unit Quantity Price	500	500	500	500	**500.0**	**0**
Cooking cost	300	250	350	300	**300.0**	**40.82**

B.9 **Standard Deviation of Firewood and Charcoal Stoves**

		Firewood						Charcoal				
	Trad	*Trad STDEV*	*ICS cold*	*ICS-STDEV-cold*	*ICS hot*	*ICS-STDEV-hot*	*Trad char*	*Trad-Char-STDEV*	*ICS cold*	*ICS-Char-STDEV*	*ICS-hot*	*ICS-STDEV-hot*
Fire preparation (min)	3.3	2.2	2.8	1.0	1.0	0.0	17.0	8.8	16.5	6.7	5.5	3.1
Pot warming (min)	2.3	1.3	2.0	1.2	1.0	0.0	3.0	1.4	5.0	2.6	4.0	3.2
Ingredients (min)	7.8	1.0	7.5	3.8	4.5	1.0	7.5	1.3	20.3	9.9	10.3	5.6
Water (up to boiling)	9.5	0.6	14.5	5.7	7.3	1.3	14.8	2.9	22.0	4.8	16.5	5.9
Rice ready	19.0	0.0	24.3	4.7	19.8	2.9	23.5	4.4	27.8	3.3	24.8	9.8
Total cooking time (min)	41.8	1.5	51.0	10.7	33.5	3.3	65.8	3.9	91.5	13.5	59.3	25.5
Used Fuel mass (kg)	1.17	0.27	1.08	0.0759	0.82	0.13	0.27	0.03	0.30	0.04	0.24	0.06
Final Energy (MJ)	15.69	3.59	14.42	1.02	10.96	1.75	7.84	0.98	8.88	1.08	7.10	1.74
Average power (W)	6.26		4.71		5.45		1.99		1.62		2.00	
Unit Quantity Price (UGX)	163.00		163.00		163.00		850.00		850.00		850.00	
Unit Energy Price (US$/GJ)	4		4		4		12		12		12	
Cooking Fuel Cost (UGX)	190.71	43.70	175.23	12.38	133.25	21.23	225.25	28.19	255.00	31.04	204.00	50.05
Cooking cost (UGX)* Time (h)	133		149		74		247		389		201	
Annual fuel costs (UGX)	9,218		127,914		97,274		164,433		186,150		148,920	
Capital Costs (e.g. stove)	0		6000		6000		5000		15,000		15,000	
Lifetime (years)			1.5		1.5		1		2.5		2.5	
Payback Period (meals)			387		104						471	
Net Benefit			2,478		25,458				(42,147)		4,390.63	
Rate of Return			41%		424%				-281%		29%	
Depreciation	0		4000		4000		5000		6000		6,000	
Calculator interest on average.capital	0		360		360		300		900		900	
Depreciation+Caculatory interest (US$)	0		1.74		1.74		2.12		2.76		2.76	
Annual average total costs	139,218		132,274		101,634		169,733		193,050		155,820	
CO2 (kg)	1.609	0.369	1.478	0.104	1.124	0.179	3.401	0.426	3.850	0.469	3.080	0.756

B.10 **Standard Deviation for Liquid and Gas Fuels, and Electricity**

	Gel	*Gel STDEV*	*Kerosene (Paraffin)*		*LPG (Butane)*		*Black-hot*		*Red-hot*		Biogas	*Biogas (min)*
Fire preparation (min)	0.4	0.5	0.6	0.5	0.3	0.3	4.5	0.7	0.4	0.48		
Pot warming (min)	1.5	1	2.5	1.7	1.3	0.5	5	1.4	2	1.15		

Ingredients (min)	9.3	3.9	13	4.5	8.3	3.2	21	5.7	5.8	2.75		
Water (up to boiling)	23.5	3.8	12.5	4.7	23.8	5.7	25	24	21.5	3.87		
Rice ready	23.3	7.3	22.8	1.7	26	1.4	44.5	21.9	34.3	15.13		
Total cooking time (min)	57.9	14.7	51.4	8.4	59.5	4.9	100	53.7	63.9	14.55		
Used Fuel mass (Kg)	0.15	0.02	0.1	0.03	0.07	0.01	0.7	0	0.6	0.08		
Final Energy (MJ)	4.04	0.54	5.22	0.26	3.43	0.45	2.52	0	2.16	0.29		
Average power (W)	1.16		1.69		0.96		0.42		0.56	0		
Unit Quantity Price (UGX)	2000		3200		8000		600		600	0		
Unit Energy Price (US$/GJ)	30		29		68		67		67			
Cooking Fuel Cost (UGX)	300	40	328	91.91	580	76.59	350		300	40.8		
Cooking cost (UGX)* Time (h)	289		281		575		583		319			
Annual fuel costs (UGX)	219,000	29,200	239,440		423,400		255,500		219,000		35,978	23,400
Capital Costs	20,000		15,000		250,000		50,000		150,000		2,398,500	1,560,000
Lifetime	3		3		3		15		15		20	20
Depreciation	6,667		5,000		10,000		3,333		10,000		119,925	78,000
Calculatory interest on average capital	1200		900		1800		3000		9000		143910	93600
Depreciation+Caculatory interest (US$)	3.15		2.36		4.72		2.53		7.6		105.53	68.64

Annual average total costs UGX	226,867		245,340		435,200		261,833		238,000		299,813	195,000

APPENDIX C

C.1 Uganda Population Forecast

Year	Population	Yearly % Change	Yearly Change	Migrants (net)	Median Age	Fertility Rate	Density (P/Km²)	Urban Pop %	Urban Population	Uganda Global Rank
1955	**5,898,835**	2.72%	148,129	0	17.7	6.9	30	3.50%	208,359	65
1960	**6,788,214**	2.85%	177,876	0	17.1	6.95	34	4.40%	299,817	65

1965	**8,014,401**	3.38%	245,237	0	17.7	6.9	40	5.50%	441,546	65
1970	**9,446,064**	3.34%	286,333	10,666	16.5	7.12	47	6.70%	629,438	56
1975	**10,827,147**	2.77%	276,217	-48,106	16.4	7.1	54	7.00%	762,272	52
1980	**12,549,540**	3.00%	344,479	-33,332	16.2	7.1	63	7.50%	945,478	52
1985	**14,646,624**	3.14%	419,417	-23,068	16.1	7.1	73	9.20%	1,341,766	50
1990	**17,438,907**	3.55%	558,457	46,673	15.9	7.1	87	11.10%	1,942,129	47
1995	**20,550,291**	3.34%	622,277	23,999	15.5	7.06	103	11.80%	2,419,036	45

2000	**24,039,274**	3.19%	697,797	-9,147	15.2	6.95	120	12.20%	2,932,916	41
2005	**28,543,940**	3.49%	900,933	-1,000	15.1	6.75	143	13.10%	3,743,230	38
2010	**33,915,133**	3.51%	1,074,239	-27,000	15.3	6.38	170	14.50%	4,925,438	37
2015	**40,144,870**	3.43%	1,245,947	-30,000	15.8	5.91	201	16.10%	6,463,320	33
2016	**41,487,965**	3.35%	1,343,095	-30,000	15.9	5.82	208	16.40%	6,819,186	33
2017	**42,862,958**	3.31%	1,374,993	-30,000	15.9	5.82	215	16.80%	7,192,401	33
2018	**44,270,563**	3.28%	1,407,605	-30,000	15.9	5.82	222	16.20%	7,583,654	32

2020	**47,187,703**	3.29%	1,408,567	-30,000	16.4	5.46	236	17.90%	8,423,333	30
2025	**55,085,460**	3.14%	1,579,551	-30,000	17.2	5.02	276	19.80%	10,889,248	28
2030	**63,842,360**	2.99%	1,751,380	-30,000	17.9	4.62	320	21.90%	13,951,972	26
2035	**73,386,500**	2.83%	1,908,828	-30,000	18.8	4.24	367	24.10%	17,680,154	22
2040	**83,604,961**	2.64%	2,043,692	-30,000	19.7	3.91	418	26.50%	22,116,139	20
2045	**94,406,655**	2.46%	2,160,339	-30,000	20.7	3.61	472	29.00%	27,334,913	19
2050	**105,698,201**	2.29%	2,258,309	-30,000	21.9	3.36	529	31.60%	33,366,741	18

C.2 Sectors Using Biomass – Household, Industry and Commerce

	Urban household Woodfuel (kg/per cap)	Rural household Woodfuel (kg/per cap)	Urban household woodfuel consumption (tons)	Rural household woodfuel consumption (tons)	Total household woodfuel equivalent (tons)	Industrial woodfuel	Commercial woodfuel
2014	1,440	720	11,874,139	19,741,126	31,615,265	4,448,671	11,955,575
2015	1,365	708	11,494,894	19,430,162	30,925,056	4,982,511	12,732,687
2016	1,297	696	11,152,288	19,696,626	30,848,914	5,580,413	13,560,312
2017	1,235	685	10,845,616	19,945,908	30,791,524	6,250,062	14,441,732
2018	1,179	673	10,569,991	20,176,597	30,746,588	7,000,070	15,380,445
2019	1,127	662	10,321,370	20,387,396	30,708,766	7,840,078	16,380,173
2020	1,080	651	10,094,739	20,578,100	30,672,839	8,780,887	17,444,885
2021	1,036	640	9,888,982	20,746,619	30,635,601	9,834,594	18,578,802
2022	996	629	9,701,692	20,891,943	30,593,635	11,014,745	19,786,424
2023	958	618	9,530,819	21,013,150	30,543,970	12,336,514	21,072,542
2024	923	608	9,371,690	21,111,328	30,483,018	13,816,896	22,442,257
2025	891	597	9,225,790	21,183,829	30,409,619	15,474,924	23,901,004
2026	860	587	9,091,791	21,230,003	30,321,794	17,331,914	25,454,569
2027	831	576	8,968,533	21,249,293	30,217,826	19,411,744	27,109,116
2028	804	566	8,855,001	21,241,235	30,096,236	21,741,153	28,871,209
2029	779	556	8,750,301	21,205,460	29,955,761	24,350,092	30,747,837
2030	755	545	8,648,478	21,145,431	29,793,908	27,272,103	32,746,447
2031	732	535	8,554,104	21,057,249	29,611,352	30,544,755	34,874,966
2032	710	525	8,466,541	20,940,836	29,407,378	34,210,126	37,141,839
2033	689	515	8,385,221	20,796,216	29,181,437	38,315,341	39,556,058
2034	670	505	8,309,630	20,623,510	28,933,140	42,913,182	42,127,202
2035	651	495	8,232,099	20,428,419	28,660,518	48,062,764	44,865,470
2036	633	485	8,159,540	20,205,778	28,365,317	53,830,295	47,781,726

2037	616	475	8,091,563	19,956,002	28,047,565	60,289,931	50,887,538
2038	600	465	8,027,814	19,679,609	27,707,423	67,524,722	54,195,228
2039	584	455	7,967,969	19,377,212	27,345,180	75,627,689	57,717,917
2040	569	445	7,906,682	19,053,464	26,960,146	84,703,012	61,469,582
2041	555	435	7,848,803	18,705,191	26,553,995	94,867,373	65,465,105
2042	541	425	7,794,078	18,333,280	26,127,357	106,251,458	69,720,337
2043	528	415	7,742,269	17,938,704	25,680,974	119,001,633	74,252,159
2044	515	405	7,693,161	17,522,523	25,215,684	133,281,829	79,078,549
2045	503	396	7,641,399	17,089,929	24,731,328	149,275,648	84,218,655
2046	491	386	7,592,012	16,638,024	24,230,035	167,188,726	89,692,867
2047	479	376	7,544,819	16,168,087	23,712,906	187,251,373	95,522,903
2048	468	366	7,499,655	15,681,465	23,181,120	209,721,538	101,731,892
2049	457	356	7,456,363	15,179,565	22,635,928	234,888,122	108,344,465
2050	447	347	7,414,798	14,663,850	22,078,647	263,074,697	115,386,855

C.3 Population Forecast and Total Wood Equivalent up to 2050

			.03			***0***	***.20***		***0***			***80***		***31,024,218***	
	Population	Urbanizati	op. rate	Urban pop.	Rural pop.	Charcoal	η-kiln	Charcoal	Firewood	Charcoal	Charcoal	Wood	Average	Total tons wood equ	Commercial Woodfuel (million

2014	34,844,095	.11	.03	8,245,930	26,598,165	20	.1	200	40	.00	0	80	90	31,024,818	2.0
2015	35,899,314	.11	.03	8,423,333	27,475,981	20	.1	200	40	.00	0	80	89	31,912,306	12.7
2016	36,986,488	.11	.03	8,600,736	28,385,752	20	.1	200	40	.00	0	80	87	32,822,802	3.6
2017	38,106,587	.11	.03	8,781,876	29,324,712	20	.1	200	40	.00	0	80	86	33,759,693	4.4
2018	39,260,607	.11	.03	8,966,830	30,293,777	20	.1	200	40	.00	0	80	84	34,723,755	15.4
2019	40,449,575	.11	.03	9,155,680	31,293,896	20	.1	200	40	.00	0	80	83	35,715,784	16.4
2020	41,674,550	.09	.03	9,346,981	32,327,569	20	.1	200	40	.00	0	80	81	36,735,502	17.4
2021	42,936,622	.09	.03	9,542,279	33,394,343	20	.1	200	40	.00	0	80	80	37,784,809	18.6
2022	44,236,915	.09	.03	9,741,658	34,495,257	20	.1	200	40	.00	0	80	79	38,864,573	9.8

2023	45,576,586	.09	.03	9,945,203	35,631,383	20	.1	200	40	.00	0	80	77	39,975,688	21.1
2024	46,956,827	.06	.03	10,149,845	36,806,982	20	.1	200	40	.00	0	80	76	41,116,804	22.4
2025	48,378,868	.06	.03	10,358,699	38,020,169	20	.1	200	40	.00	0	80	74	42,291,048	23.9
2026	49,843,973	.06	.03	10,571,850	39,272,124	20	.1	200	40	.00	0	80	73	43,499,393	25.5
2027	51,353,448	.06	.03	10,789,387	40,564,061	20	.1	200	40	.00	0	80	71	44,742,841	27.1
2028	52,908,636	.06	.03	11,011,400	41,897,236	20	.1	200	40	.00	0	80	70	46,022,426	28.9
2029	54,510,921	.06	.03	11,237,982	43,272,940	20	.1	200	40	.00	0	80	68	47,339,210	30.7
2030	56,161,730	.00	.03	11,462,379	44,699,351	20	.1	200	40	.00	0	80	67	48,689,359	32.7
2031	57,862,532	.00	.03	11,691,258	46,171,274	20	.1	200	40	.00	0	80	65	50,078,728	34.9

2032	59,614,841	.00	.03	11,924,706	47,690,134	20	.1	200	40	.00	0	80	64	51,508,474	37.1
2033	61,420,216	.00	.03	12,162,816	49,257,400	20	.1	200	40	.00	0	80	63	52,979,784	9.6
2034	63,280,266	.00	.03	12,405,681	50,874,585	20	.1	200	40	.00	0	80	61	54,493,882	42.1
2035	65,196,646	.91	.03	12,642,325	52,554,320	20	.1	200	40	.00	0	80	60	56,044,059	4.9
2036	67,171,061	.91	.03	12,883,484	54,287,577	20	.1	200	40	.00	0	80	58	57,639,272	7.8
2037	69,205,269	.91	.03	13,129,243	56,076,027	20	.1	200	40	.00	0	80	57	59,280,849	0.9
2038	71,301,082	.91	.03	13,379,689	57,921,392	20	.1	200	40	.00	0	80	55	60,970,155	54.2
2039	73,460,364	.91	.03	13,634,914	59,825,450	20	.1	200	40	.00	0	80	54	62,708,600	57.7
2040	75,685,037	.84	.03	13,886,137	61,798,901	20	.1	200	40	.00	0	80	52	64,491,245	61.5

2041	77,977,083	.84	.03	14,141,988	63,835,095	20	.1	200	40	.00	0	80	51	66,325,731	5.5
2042	80,338,541	.84	.03	14,402,554	65,935,987	20	.1	200	40	.00	0	80	49	68,213,588	9.7
2043	82,771,513	.84	.03	14,667,921	68,103,593	20	.1	200	40	.00	0	80	48	70,156,392	4.3
2044	85,278,166	.84	.03	14,938,177	70,339,989	20	.1	200	40	.00	0	80	46	72,155,767	9.1
2045	87,860,730	.77	.03	15,203,163	72,657,567	20	.1	200	40	.00	0	80	45	74,206,003	4.2
2046	90,521,504	.77	.03	15,472,850	75,048,654	20	.1	200	40	.00	0	80	43	76,315,935	9.7
2047	93,262,858	.77	.03	15,747,321	77,515,537	20	.1	200	40	.00	0	80	42	78,487,328	5.5
2048	96,087,230	.77	.03	16,026,660	80,060,569	20	.1	200	40	.00	0	80	40	80,722,001	01.7
2049	98,997,136	.77	.03	16,310,955	82,686,180	20	.1	200	40	.00	0	80	39	83,021,825	108.3

2 050	101 ,995,165	.77	.03	1 6,600,293	8 5,394,872	20	.1	200	40	.00	0	80	37	8 5,388,730	115.4
						0	***.3***		***80***	***.00***		***80***		***6*** ***00***	

C.4 Population Slow Down and Efficient Use of Woodfuel

			3.03	7,425,864		40	0.20		60	2.00		680		1,614,665
	Population	**Urbanization (%)**	**Pop_ rate**	**Urban pop.**	**Rural pop.**	**Charcoal (Urban) kg)**	**η-kiln**	**Charcoal (Urban kg wood eq)**	**Wood (Urban kg)**	**Charcoal (Rural kg)**	**Charcoal (Rural kg wood eq)**	**Wood (Rural kg)**	**Average wood per cap kg**	**Total tons wood equ**
2014	34,844,095	2.11	3.03	8,245,930	27,418,231	120	0.10	1,200	240	4.00	40	680	0.91	31,615,265
2015	35,870,012	2.11	2.94	8,423,333	27,446,679	119	0.11	1,126	238	3.94	37	671	0.86	30,925,056
2016	36,895,970	2.11	2.86	8,600,736	28,295,234	118	0.11	1,060	237	3.89	35	661	0.84	30,848,914
2017	37,920,245	2.11	2.78	8,781,876	29,138,369	117	0.12	1,000	235	3.83	33	652	0.81	30,791,524
2018	38,941,066	2.11	2.69	8,966,830	29,974,236	116	0.12	945	233	3.78	31	642	0.79	30,746,588
2019	39,956,621	2.11	2.61	9,155,680	30,800,941	114	0.13	896	232	3.72	29	633	0.77	30,708,766
2020	40,965,060	2.09	2.52	9,346,981	31,618,079	113	0.13	850	230	3.67	28	623	0.75	30,672,839
2021	41,964,500	2.09	2.44	9,542,279	32,422,221	112	0.14	808	228	3.61	26	614	0.73	30,635,601
2022	42,953,035	2.09	2.36	9,741,658	33,211,377	111	0.14	769	227	3.56	25	604	0.71	30,593,635
2023	43,928,734	2.09	2.27	9,945,203	33,983,531	110	0.15	733	225	3.50	23	595	0.70	30,543,970
2024	44,889,656	2.06	2.19	10,149,845	34,739,810	109	0.16	700	223	3.44	22	586	0.68	30,483,018
2025	45,833,847	2.06	2.10	10,358,699	35,475,149	108	0.16	669	222	3.39	21	576	0.66	30,409,619
2026	46,759,355	2.06	2.02	10,571,850	36,187,505	107	0.17	640	220	3.33	20	567	0.65	30,321,794
2027	47,664,229	2.06	1.94	10,789,387	36,874,842	106	0.17	613	218	3.28	19	557	0.63	30,217,826
2028	48,546,531	2.06	1.85	11,011,400	37,535,131	104	0.18	588	217	3.22	18	548	0.62	30,096,236

2029	49,404,340	2.06	1.77	11,237,982	38,166,358	103	0.18	564	215	3.17	17	538	0.61	29,955,761
2030	50,235,760	2.00	1.68	11,462,379	38,773,381	102	0.19	541	213	3.11	16	529	0.59	29,793,908
2031	51,038,927	2.00	1.60	11,691,258	39,347,669	101	0.19	520	212	3.06	16	519	0.58	29,611,352
2032	51,812,013	2.00	1.51	11,924,706	39,887,307	100	0.20	500	210	3.00	15	510	0.57	29,407,378
2033	52,553,239	2.00	1.43	12,162,816	40,390,423	99	0.21	481	208	2.94	14	501	0.56	29,181,437
2034	53,260,874	2.00	1.35	12,405,681	40,855,193	98	0.21	463	207	2.89	14	491	0.54	28,933,140
2035	53,933,248	1.91	1.26	12,642,325	41,290,923	97	0.22	446	205	2.83	13	482	0.53	28,660,518
2036	54,568,756	1.91	1.18	12,883,484	41,685,272	96	0.22	430	203	2.78	13	472	0.52	28,365,317
2037	55,165,862	1.91	1.09	13,129,243	42,036,619	94	0.23	415	202	2.72	12	463	0.51	28,047,565
2038	55,723,111	1.91	1.01	13,379,689	42,343,421	93	0.23	400	200	2.67	11	453	0.50	27,707,423
2039	56,239,129	1.91	0.93	13,634,914	42,604,215	92	0.24	386	198	2.61	11	444	0.49	27,345,180
2040	56,712,631	1.84	0.84	13,886,137	42,826,494	91	0.24	373	197	2.56	10	434	0.48	26,960,146
2041	57,142,428	1.84	0.76	14,141,988	43,000,439	90	0.25	360	195	2.50	10	425	0.46	26,553,995
2042	57,527,428	1.84	0.67	14,402,554	43,124,874	89	0.26	348	193	2.44	10	416	0.45	26,127,357
2043	57,866,645	1.84	0.59	14,667,921	43,198,724	88	0.26	336	192	2.39	9	406	0.44	25,680,974
2044	58,159,199	1.84	0.51	14,938,177	43,221,023	87	0.27	325	190	2.33	9	397	0.43	25,215,684
2045	58,404,324	1.77	0.42	15,203,163	43,201,161	86	0.27	314	188	2.28	8	387	0.42	24,731,328
2046	58,601,367	1.77	0.34	15,472,850	43,128,517	84	0.28	304	187	2.22	8	378	0.41	24,230,035
2047	58,749,795	1.77	0.25	15,747,321	43,002,474	83	0.28	294	185	2.17	8	368	0.40	23,712,906
2048	58,849,193	1.77	0.17	16,026,660	42,822,532	82	0.29	285	183	2.11	7	359	0.39	23,181,120
2049	58,899,270	1.77	0.09	16,310,955	42,588,315	81	0.29	275	182	2.06	7	349	0.38	22,635,928
2050	58,899,859	1.77	0.00	16,600,293	42,299,566	80	0.30	267	180	2.00	7	340	0.37	22,078,647
						80	***0.30***		***180***	***2.00***		***340***		***600***

C.5 Quantity of Woodfuel (tons and MJ and in %) and LPG (MJ, barrel and %) and Populations

Years	Wood Quantity (tons)	Total (MJ)	Woodfuel (%)	LPG(%)	Wood (MJ)	LPG(MJ)	LPG(Barrel)	Year	Wood quantity (million tons)	Total Population (millions)
2013	30,120,869	298,764,256.8	98.0%	2.0%	292,788,972	5,975,285	1,485	2013	19.0	33.7
2014	31,615,265	292,241,778	95.3%	4.7%	278,506,414	13,735,364	3,414	2014	19.9	34.8
2015	30,925,056	291,522,241	92.6%	7.4%	269,949,595	21,572,646	5,363	2015	19.5	35.9
2016	30,848,914	290,979,901	89.9%	10.1%	261,590,931	29,388,970	7,306	2016	19.4	36.9
2017	30,791,524	290,555,252	87.2%	12.8%	253,364,180	37,191,072	9,245	2017	19.4	37.9
2018	30,746,588	290,197,842	84.5%	15.5%	245,217,176	44,980,666	11,182	2018	19.4	38.9
2019	30,708,766	289,858,328	81.8%	18.2%	237,104,113	52,754,216	13,114	2019	19.3	40.0
2020	30,672,839	289,506,429	79.1%	20.9%	228,999,585	60,506,844	15,041	2020	19.3	41.0
2021	30,635,601	289,109,852	76.4%	23.6%	220,879,927	68,229,925	16,961	2021	19.3	42.0
2022	30,593,635	288,640,513	73.7%	26.3%	212,728,058	75,912,455	18,871	2022	19.3	43.0
2023	30,543,970	288,064,522	71.0%	29.0%	204,525,810	83,538,711	20,767	2023	19.2	43.9

2024	30,483,018	287,370,901	68.3%	31.7%	196,274,325	91,096,576	22,646	2024	19.2	44.9	
2025	30,409,619	286,540,952	65.6%	34.4%	187,970,864	98,570,087	24,503	2025	19.2	45.8	
2026	30,321,794	285,558,453	62.9%	37.1%	179,616,267	105,942,186	26,336	2026	19.1	46.8	
2027	30,217,826	284,409,427	60.2%	39.8%	171,214,475	113,194,952	28,139	2027	19.0	47.7	
2028	30,096,236	283,081,943	57.5%	42.5%	162,772,117	120,309,826	29,908	2028	19.0	48.5	
2029	29,955,761	281,552,433	54.8%	45.2%	154,290,733	127,261,700	31,636	2029	18.9	49.4	
2030	29,793,908	279,827,278	52.1%	47.9%	145,790,012	134,037,266	33,320	2030	18.8	50.2	
2031	29,611,352	277,899,719	49.4%	50.6%	137,282,461	140,617,258	34,956	2031	18.7	51.0	
2032	29,407,378	275,764,578	46.7%	53.3%	128,782,058	146,982,520	36,538	2032	18.5	51.8	
2033	29,181,437	273,418,175	44.0%	56.0%	120,303,997	153,114,178	38,063	2033	18.4	52.6	
2034	28,933,140	270,841,897	41.3%	58.7%	111,857,703	158,984,194	39,522	2034	18.2	53.3	
2035	28,660,518	268,052,249	38.6%	61.4%	103,468,168	164,584,081	40,914	2035	18.1	53.9	
2036	28,365,317	265,049,491	35.9%	64.1%	95,152,767	169,896,724	42,235	2036	17.9	54.6	
2037	28,047,565	261,835,146	33.2%	66.8%	86,929,269	174,905,878	43,480	2037	17.7	55.2	
2038	27,707,423	258,411,954	30.5%	69.5%	78,815,646	179,596,308	44,646	2038	17.5	55.7	
2039	7,345,180	261 ,773,380	27.8%	72.2%	70,827,000	183,946,380	45,727	2039	17.2	56.2	

2040	26,960,146	250,935,249	25.1%	74.9%	,984,747	7,950,501	46,722	2040	17.0	56.7	
2041	26,553,995	246,903,528	22.4%	77.6%	55,306,390	191,597,138	47,629	2041	16.7	57.1	
2042	26,127,357	242,685,201	19.7%	80.3%	47,808,985	194,876,216	48,444	2042	16.5	57.5	
2043	25,680,974	238,288,212	17.0%	83.0%	40,508,996	197,779,216	49,166	2043	16.2	57.9	
2044	25,215,684	233,711,049	14.3%	85.7%	33,420,680	200,290,369	49,790	2044	15.9	58.2	
2045	24,731,328	228,973,833	11.6%	88.4%	26,560,965	202,412,869	50,318	2045	15.6	58.4	
2046	24,230,035	224,086,964	8.9%	91.1%	19,943,740	204,143,225	50,748	2046	15.3	58.4	
2047	23,712,906	219,061,586	6.2%	93.8%	13,581,818	205,479,767	51,080	2047	14.9	58.4	
2048	23,181,120	213,909,521	3.5%	96.5%	7,486,833	206,422,688	51,314	2048	14.6	58.4	
2049	22,635,928	208,643,216	0.8%	99.2%	1,669,146	206,974,070	51,452	2049	14.3	58.4	
2050	22,078,647	-	0.0%	100.0%	-	-	-	2050	13.9	58.4	