Economic Analysis of Urban Fuelwood Demand

The case of Harare in Zimbabwe

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To

My parents, my wife (Beatrice) and my son (Emmanuel)

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Abstract

This study carries out an economic analysis of the demand for fuelwood in urban areas using Harare, the capital city of Zimbabwe, as a case study. The demand for fuelwood in urban areas is one of the causes of several environmental and health problems in Africa, where the up to 90% of energy requirements are met by wood.

The study first develops an energy mix model as the conceptual framework, using the energy ladder hypothesis as a starting point. The energy mix model is based on the fact that in any one period, urban households use multiple sources of energy. Consumer theory is used to underpin this reality, and link it to the analyses that follow. System of demands is used in the empirical analysis, using the Almost Ideal Demand System (AIDS model), in linear approximate form, as the empirical model, incorporating the effects of other household characteristics in addition to income and prices. A multi-stage budgeting process is used the analyses, which assumes that households first decide how much of their total expenditures to allocate to energy, among other household goods. At the second stage, they decide how much of their total energy outlays to allocate to specific fuels. Empirical analyses are carried out using household survey data collected in Harare from a sample of 500 households.

The share of energy in total expenditure is shown to be 13% and 11% for electrified and unelectrified households respectively. For all households, total energy expenditure increases with total household expenditure. Other factors that explain household differences in total energy expenditure shares are household size, energy-using appliances owned, the number of rooms owned, the number of families living together at the same property and the level of education of the household head. The main sources of energy are electricity, firewood and kerosene, accounting for 73%, 14% and 13% of total energy expenditure respectively. Electrified households spend 81%, 9% and 10% of their total energy outlays on these fuels respectively, while unelectrified households spend 55% and 45% of their total energy budgets on firewood and kerosene respectively. Among electrified households, the share of the energy budget allocated to fuelwood increases as household size, the number of households living together at the same property, the number of rooms being used by a household, the prices of electricity and kerosene increase. It decreases with total household expenditure, the educational level of the household head, the value of energy appliances, the square of household size and the price of fuelwood. Among unelectrified households, the share of fuelwood in the energy budget increases with total energy expenditure, the value of appliances, household size, the educational level of the household head and the price of kerosene. It decreases with households living together at the same property, the square of household size, the number of rooms used and the price of fuelwood. The shares of other fuels estimated in the same system of equations respond in different ways to these variables. The main policy implication of the findings is that fuelwood demand management is best approached by taking the whole energy urban system into account. The specific management options are pointed to by the response of demand to the different demand variables. Total electrification will not eliminate urban fuelwood demand if other demand variables are not attended to.

Contents

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Deforestation is one of the most pressing environmental problems in Africa. It has both local and global environmental consequences as well as implications for human health and livelihoods. In most sub-Saharan African countries, the rate of deforestation exceeds the global annual average of 0.8% (Agyei, 1998). The key driver of deforestation in Africa is human activity, and one of the most significant activities is removal of wood for energy. According to FAO data (Amous, undated), fuelwood consumption accounts for about 90% of total African energy consumption. This makes wood fuel consumption a major local and global environmental issue in Africa (Agyei, 1998). Because of the current high consumption levels, the dependence of African populations, and therefore the deforestation problem, is likely to continue in the foreseeable future. In fact, Africa has the highest per capita fuelwood consumption of 0.89 m^3 per year compared to any other continent (Amous, undated). Amous also shows that total fuelwood consumption in Africa increased by about 106 million m^3 between 1980 and 1996.

While the contribution of fuelwood consumption to deforestation varies from site to site, its most significant impact is associated with supplying wood to urban areas (Chidumayo, 1997). The harvesting of wood to supply fuel to urban areas often implies felling whole, live trees. This contrasts it with harvesting wood to meet the needs of rural residents, which often involves selective collection of dead wood. The contribution of urban areas to deforestation through fuelwood consumption is one aspect of the overall urban energy consumption context. The urban areas of African countries are major consumers of energy compared to rural areas. The high population densities of urban areas make them centers of concentrated energy consumption. Because of their higher integration in the market economy, their energy needs are often met by market arrangements. Their high levels of energy consumption makes urban areas have significant contributions to energy related problems such as deforestation and indoor air pollution (Karekezi and Majoro, 2002).

Urban areas in Africa have unique features such as rapid population growths, which, in Southern Africa, is causing an unprecedented level of localized resource depletion (UNEP, 2002). For most sub-Saharan African cities, urban population growth rates are double national averages (Karekezi and Majoro, 2002). According to UNEP (2002), the urban population growth rate in Southern Africa is expected to average 3.5% for the next 15 years. Consequently, the rate of growth of demand for energy of all types is also high in these areas, and should be matched by increased supply.

Generally, African urban areas are associated with the use of modern fuels like electricity. However, the consumption of electricity depends on the adequacy of supply and the incomes of consumers. In cities with rapidly growing populations, supply often gets limited. On the one hand, declining economic conditions in most African countries limit investments in the generation of modern fuels. On the other hand, high population growth rates are not matched by economic growth. As a result, real incomes of urban residents are falling, limiting their ability to afford the modern fuels. In fact, Karekezi and Majoro (2002) have noted that urban poverty in Africa is growing, with the gap between the poor and rich getting wider, and the proportion of the poor getting bigger. Income distribution shows that most African urban households are poor. The poor tend to depend more on fuelwood to meet their energy requirements thereby contributing to the problem of deforestation. In most African cities, the most common energy source for low-income people is fuelwood.

The dependence of cities on fuelwood is determined mainly by the access of the residents to alternative, modern fuels like electricity. While urbanization increases, and urban populations increase, the proportion of urban residents without electricity increases. Between 1970 and 1990, the number of urban inhabitants without electricity in Africa increased from less than 40 million to 100 million (Karekezi and Majoro, 2002).

All current trends in Africa indicate that as urban population growth drives energy consumption upwards, this consumption will mainly be in the form of wood fuels. The transition from fuelwood in urban areas will be largely determined by trends in real incomes and the increased supply of alternatives at prices that consumers can afford.

Since wood fuels are likely to remain a major source of energy and an important environmental and development issue in Africa in the medium to long term future, the management of fuel resources should be considered a major issue in energy planning processes (Amous, undated) to ensure that environmental impacts are minimized. There have been few attempts in Africa to include wood fuels in the energy sector planning processes. According to Amous (undated), these are mainly hampered by the scarcity, limited scope, and poor quality of existing data. Conclusions and policy prescriptions are mainly based on perceptions instead of facts. Moreso, the focus of most policies in the energy sector is on modern fuels such as electricity and liquid fuels, which have, direct macroeconomic implications such as requirements of foreign currency. Traditional fuels such as fuelwood on the other hand has remained informal and unregulated. In this study, we focus on the consumption of energy in Zimbabwean urban areas in studying the demand for fuelwood.

The demand for fuelwood in Zimbabwean urban areas has attracted fragmented policy and research attention. Some research on urban fuelwood consumption in Zimbabwe has concluded that the fuelwood sub-sector requires no major attention (Attwell, *et al*, 1989) owing to the high rates of electrification in the urban areas. In fact, due to the successful urban electrification program in Zimbabwe compared to most African countries, the fuelwood sub-sector has been overshadowed in terms of research attention. Recent literature however suggests that the economic and demographic trends in Zimbabwean urban areas puts them in the general African framework, which is characterized by increasing dependence on traditional fuels. The demographic and economic trends include high rates of urban population growth, declining real incomes, emergence of unplanned settlements (UNEP, 2002). The population growth rate of 3.1% is very high compared to the economic growth rate of 0.8% (Campbell, 2000). The demand for electricity, though growing, is not matched by supply. Generation of electricity has been static (Campbell, 2000), and is being met by imports. About 40% of Zimbabwe's electricity is imported while liquid fuels and gas are imported in their entirety.

The main form of fuelwood used in Zimbabwean cities is firewood, with charcoal being used in very limited cases. At household level, firewood is mainly used for cooking and heating space for warmth. The technology for the use of firewood in most urban areas is basic. In most cases, no stove is used when households use firewood. The three-stone technology is the most common, though in some cases households invest in metal grates, which are more of stands for cooking pots than energy-saving technologies. The use of firewood ranges from the preparation of regular family meals, preparation of special dishes, to special functions such as parties and other gatherings.

There are several alternatives to fuelwood in urban areas. In Zimbabwe, the most common alternatives are electricity and kerosene. Gas, coal and charcoal are very rarely used by households, mainly because they are not readily available to most households.

Most households buy the firewood from vendors either along main roads leading to residential areas or from small markets or stall located on the sides of roads and at shopping centers of residential areas. The markets are mainly informal. They are operated either by individuals, families or groups of individuals. These vendors either buy their supplies from whole-sellers, or from sources mainly located in farming areas.

1.2 Problem specification

Fuelwood is one of the fuels that contribute towards meeting the energy needs of urban households in Zimbabwe. The other major sources of energy are electricity and kerosene. Households use the different fuels in different combinations, depending on the uses they satisfy, their availabilities, and the socio-economic circumstances of households. The widespread use of woodfuels in Africa, and the in the developing world in general, has been linked to several environmental problems. The use of fuelwood to supply energy to urban households is a more imminent environmental concern compared to the use of fuelwood in rural areas. The intensive harvesting of wood to supply urban markets leading to localised impacts (CIFOR, 2003; Chidumayo, 1997) is associated with the higher involvement of both urban consumers and traders in the market economy compared to their rural counterparts. They all act as economic agents, with consumers seeking to maximise utility from energy consumption that includes fuelwood, and traders seeking to maximise profit through selling woodfuels. Thus urban fuelwood consumption presents a typical linkage between urban economic activity and the environment, in which the consumption needs of urban consumers have implications on the environment through the extraction of woodland resources. The scenario is made even more peculiar by the fact that the centre of consumption is often separated from the areas of impact. This is different from the rural setting in which woodland resources from which fuelwood is harvested are part of the immediate surroundings of the consumers, and the impact is evident to the user.

As a result, the impacts of fuelwood harvesting in rural areas are less intense because households do not cut whole trees, but leave other portions of trees to provide other resources. Also, collection of fuelwood for use in rural areas often involves collection of dead wood, which does not have big effects on the environment. Harvesting fuelwood for urban areas on the other hand is intensive on specific areas so as to reduce transport costs. It involves cutting whole, live trees, resulting in loss of entire species and habitats, changes in woodland structure and soil erosion. Downstream effects include siltation of rivers and dams and flooding.

This study contributes to the understanding of the linkages between urban economic activity and the environment by making an economic analysis of urban energy demand thereby estimating the demand for fuelwood by urban households in Zimbabwe. This is achieved by developing an energy mix conceptual framework that takes into account the other sources of energy consumed by urban households in addition to fuelwood. This framework is applied empirically using data from Harare, the capital city of Zimbabwe. The empirical findings provide estimates of the contributions of different fuels, including fuelwood, to urban household energy consumption, the factors affecting the observed patterns, and the welfare implications of different energy mixes. Though the consumption of other sources of energy has environmental consequences, the linkage with the environment in this study is made through the consumption of fuelwood, and as far as the problem of deforestation is concerned. The environmental impacts of other fuels include air pollution, indoor respiratory diseases for such fuels as kerosene. The negative impacts of electricity include those that result from dam construction and transmission of electricity. Policy suggestions based on the empirical findings are aimed at both managing fuelwood demand in urban areas for environmental concerns as well as taking into account welfare implications on urban households. Household energy welfare indicates the adequacy of energy available to a household for its energy requirements. The higher the amount of energy available to a household, the higher is its welfare. The output of this study contributes to the development of demand side management approaches to reducing environmental damage. This compliments supply-side management approaches.

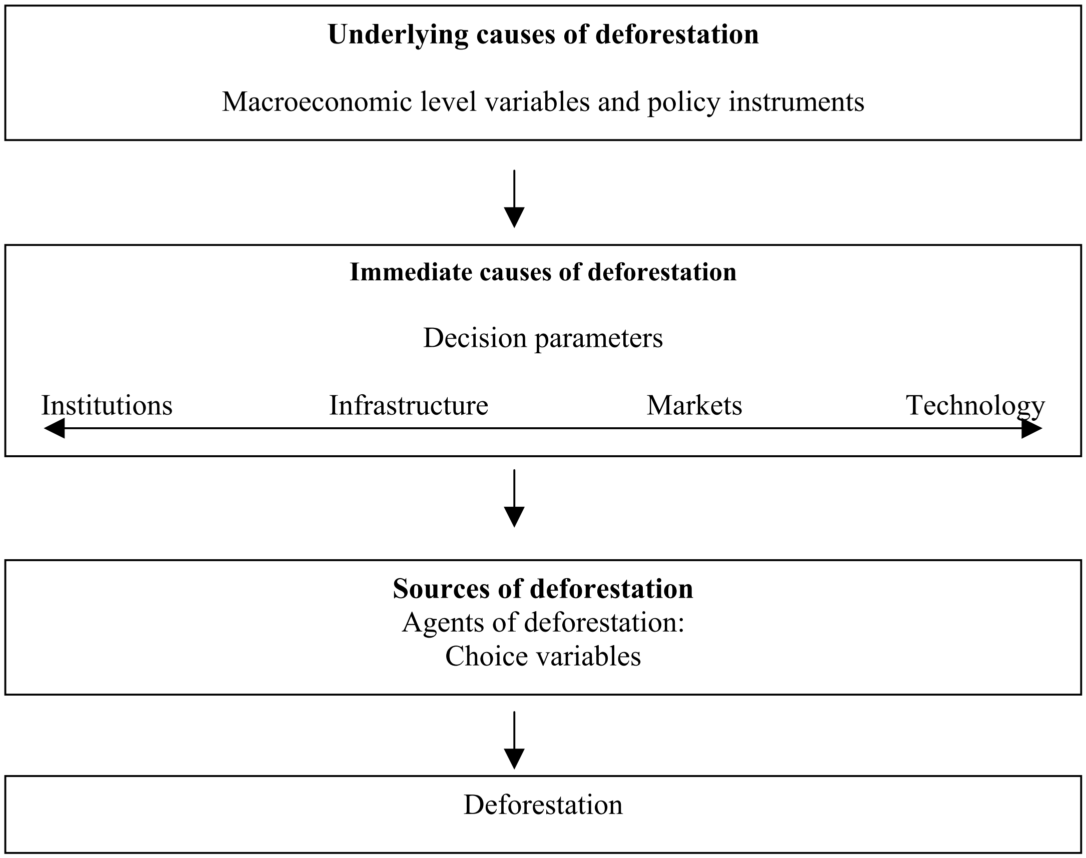
1.3 Economy-environment linkages

The rationale for an analysis of the demand for fuelwood in urban areas consists in the linkage with the environment. While the choice of fuelwood as a source of energy by households is an economic decision that contributes to their welfare, it contributes towards deforestation and pollution. Deforestation is one of the key environmental problems in Africa. The relationship between consumption and the environment has emerged as an important issue for academic and policy study only in recent years (Jacobs and Ropke, 1999). The linkage between the economy and the environment was formally brought into wider application with the emergence of such concepts as sustainable development, which were brought into common use by the World Commission on Environment and Development, or the Brutland Commission (World Bank, 1993). Such linkages require the integration of economic, ecological and sociological approaches in order to achieve the goal of sustainable development. Such an approach incorporates both environmental and welfare concerns into the structure of decision making and policy formulation (Munasinhge and Cruz, 1995).

Linking economic activity with the environment traces causes of environmental degradation to the root causes. An understanding of the root causes of environmental damage involves the identification and analyses of the several levels of the causes of damage, for example, the analysis of the root causes of biodiversity loss by Wood et al (2000). The first level of establishing the linkages is by understanding the factors at play at the level of the agents of environmental damage. These factors, according to Angelson and Kaimowitz (1999), are the choice variables of the agents. The choice variables can then be linked to higher level causes or root causes. In the case of urban fuelwood demand, the factors that determine household demand for fuelwood are linked to their driving forces, which are the root causes.

Although economy wide policies are not explicitly directed towards influencing the quality of the environment, they may affect it for the good or bad (Munasinghe and Cruz, 1995). Policies influence the behavior of individuals, which in turn impacts on the environment. In developing the variables affecting deforestation, Angelson and Kaimowitz (1999) identified the link between economy wide policies and the environment. In their study, they found that while deforestation is caused by the activities of agents (human beings), these human activities are influenced by a set of decision parameters, including institutions, infrastructure, markets and technology. These parameters are in turn influenced by macroeconomic level variables and policy instruments, which are in fact the underlying causes of deforestation. These include unemployment, general income levels, pricing of fuels, including subsidies. Angelsen and Kaimowitz (1999) represent the levels of the causes of deforestation as shown below. This representation also gives the relations among the main types of variables in deforestation in a logical approach. The different causes represented are the sources of deforestation, the immediate causes and the underlying causes. Since the dynamics of forest regimes depend upon the changes in natural factors and socio-economic factors, and on the interactions between them, failure to link natural and socio-economic systems can cause severe misperceptions and policy failures (Kant, 2000). For example, urban development initiatives that do not incorporate the energy requirements of growing populations result in most urban dwellers relying on polluting and environmentally damaging fuels such as firewood and charcoal. Similarly, economic programs that result in unemployment tend to drive the demand for fuelwood up.

Figure 1.1: Levels of causes of deforestation



Source: Angelsen and Kaimowitz (1999)

According to the figure above, the causes of deforestation are traced from the point where deforestation takes place, i.e. the local level. At the lowest level are the sources of deforestation, such as fuelwood harvesting to supply energy to urban households. The decisions of households are determined by the choice variables such as their incomes, household sizes etc. The characteristics of the agents of deforestation, and their motivations are important in developing linkages between economic factors and the environment. However, the literature available acknowledges that little is known about how the characteristics of agents affect their behavior (Angelson and Kaimowitz, 1999). These motivations are influenced by macroeconomic variables through complex paths, with many of the causal relations being indirect. These include such factors as employment, pricing mechanisms, inflation, government expenditure on social services, generation of foreign currency as dictated by the export performance and investment in an economy etc. These then affect the decision environment in which the agents of deforestation find themselves. The complex choices made by consumers determine how much wood is extracted from woodlands, thus how the environment deteriorates. The environment on the other hand responds to the demands made on it through its hierarchical, smaller, quicker processes embedded in and constrained by larger, slower processes (Carpenter *et al*, 1999). The smaller and quicker processes include immediate loss of vegetation leading to excessive runoff, soil erosion etc. The slower processes take longer periods to be evident. These include ecosystem disturbances leading to loss of species, disturbance of hydrological functions of systems and changes in climate.

In this study, we analyze the factors at play at the level of consumers who make their demands on the environment through the consumption of fuelwood among other fuels. An understanding of their motivations provides the policy levers that can be used to influence their consumption patterns. It is however acknowledged that other factors are also at play in the fuelwood problem. Specifically, forestry sector and land tenure policies affect the conditions of supply of fuelwood resources to urban areas. This study however focuses on the demand side of the problem, which could complement forestry sector and other supply side studies. This specific focus on the demand side is reflected in the objectives of the study.

1.4 Study Objectives

The consumption of fuelwood in urban areas is one of the factors contributing to deforestation. The demand for fuelwood in urban areas is largely driven by urban circumstances such as incomes of consumers, and the availability and prices of alternative sources of energy. Thus a clear linkage exists between the urban household economy and the environment. Household consumption patterns are on one hand driven by their utility maximizing behavior, while the environment is affected through households' demand for environmental goods. Accordingly, urban fuelwood consumption has both environmental implications and welfare implications on households. The management of environmental problems due to urban fuelwood consumption is therefore best approached from the demand side. Demand side management complements supply side management strategies, which include sustainable harvesting methods such as selective harvesting and lopping branches instead of whole trees, and post-harvesting management of woodlands. Demand side management requires an understanding of energy consumption dynamics in the urban areas, an area that has not attracted much research attention. The lack of data and appropriate analytical tools in the African urban context has weakened the premise on which policies for the management of urban fuelwood management are made.

It is the broad objective of this study to make economic analyses of urban household fuelwood demand within the context of overall energy consumption. The study develops a framework for household energy demand analysis and applies economic theory models to analyze household energy expenditure data for Zimbabwean urban areas using Harare as a case study. Specifically, this study aims to:

1. Develop an urban household energy consumption framework within which to analyze household fuelwood demand.
2. Use empirical data to estimate the energy mix for households in Harare using household energy expenditure data thereby estimating the demand for fuelwood.
3. Investigate the factors that significantly affect the demand for fuelwood in urban areas.
4. Highlight the policy implications of the energy demand patterns on household energy welfare and fuelwood demand.

In light of these objectives, the main questions to be answered are:

1. What is the proportion of energy expenditure in total household expenditure?
2. What are the respective proportions of the main sources of energy in energy expenditure in Harare?
3. What are the factors that affect the observed expenditure patterns observed in questions (1) and (2) above?
4. What is the ultimate impact on fuelwood demand?
5. What are the policy implications of the observed patterns?

1.4.1 Methodology

This study follows three steps. At the first step, it develops a conceptual framework within which analyses will be made. The conceptual framework developed in this study is the energy mix model, which assumes that households make decisions on the types of sources of energy to use in a specified period, and this is evident in their expenditure patterns on the different sources of energy, of which fuelwood is one. The second step outlines the theoretical framework for the analysis of household energy consumption behavior. The theory of the consumer underlies the analyses that follow. The theoretical underpinning of the research ensures that the analyses that ensue are carried within the confines of economic principles, which allow for the testing of the various assumptions about the consumer. The third stage of the study is an empirical one, involving the collection of empirical data on household energy consumption and estimating empirical models based on the conceptual and theoretical models.

1.5 Thesis outline

This study is organized into seven chapters, including this introductory chapter. Chapter 2 provides a background to the whole study. It gives an overview of fuelwood consumption in Africa in general, in African urban areas, and in Zimbabwean urban areas in particular. The demographic and economic characteristics shaping energy and fuelwood consumption in Africa and Zimbabwe are presented in this chapter. This includes a discussion of the likely trend in fuelwood consumption given the current economic trends in the country. Key geographical features that have implications to fuelwood consumption in Zimbabwe are also given in this chapter. These include the location of major cities, the distribution of woodland resources and the land tenure systems that are important for the collection of fuelwood in Zimbabwe.

Chapter 3 develops the conceptual framework for the analysis of urban fuelwood demand, within the context of other sources of energy. Starting with the energy ladder hypothesis, we go on to develop an energy mix model, which is consistent with recent data on energy consumption patterns in urban areas from several regions. The energy mix model enables us to estimate the contribution of each fuel, including fuelwood, to total household energy consumption, thereby enabling the estimation of the demand for fuelwood.

Chapter 4 presents the theoretical background to household consumption behavior using consumer theory. Having recognized the household as the relevant domestic energy consumption unit in urban areas, this is the relevant theoretical basis. The household is assumed as seeking to maximize utility from the consumption of different sources of energy. The specific demand model applied is the Almost Ideal Demand System (AIDS), which enables the estimation of the demand for fuelwood in a system of demands for several sources of energy of which fuelwood is one. This is consistent with both the conceptual framework and the theory of the consumer.

Chapter 5 gives the methodology used in the estimation of empirical models and the collection of data used in the estimations. The estimation methodology specifies the empirical models and discusses the variables that explain household expenditures on energy in general and on individual fuels. The estimation procedure is based on a multi-stage budgeting process, in which households first decide the shares of their total expenditures to allocate to energy, and subsequently, the shares of the total energy expenditure to allocate to individual fuels. The data collection section focuses on the household survey carried out in Harare.

Chapter 6 presents the empirical findings in terms of expenditures and actual consumption. The factors explaining the observed expenditures are also presented in this chapter. The results are presented for households with access to electricity and those without access to electricity separately, accounting for the fact that the two groups of households have different energy choice sets, thus their choice variables also differ. This chapter also discusses the policy implications of the empirical findings, in terms of both managing fuelwood demand in urban areas, and also in terms of household energy welfare.

Chapter 7 gives a summary of the whole study, including its limitations and suggestions for further research.

CHAPTER 2

ZIMBABWE BACKGROUND: ENERGY CONSUMPTION AND THE ECONOMY

2.1 Introduction

Fuelwood consumption in Zimbabwe is affected by several factors ranging from the socio-economic setting, and the policy environment that the consumers are subjected to. Current trends in energy and fuelwood consumption in the generality of developing (including African) countries also largely provide insight into the expected patterns in fuelwood consumption in Zimbabwe. The purpose of this chapter is to highlight these factors and the features characterizing energy consumption in urban areas thereby providing a context in which demand analyses will be made. Section 2.2 gives a background of the peculiarities of energy choices in urban areas, thus putting this study on urban fuelwood demand in its proper context. Section 2.3 gives a description of the physical features of Zimbabwe while section 2.4 provides the demographic structure of the country in general and Harare in particular. In section 2.5 we describe the economic environment prevailing in Zimbabwe and the likely trend as a background to analyze the trends that fuelwood consumption is going to take. Fuelwood consumption details in Africa, Zimbabwe and Harare are discussed in section 2.6. The likely trends in fuelwood consumption in urban areas of Zimbabwe given the economic environment and the likely trends in the economy are discussed in section 2.7. The policy and institutional environment in the energy sector of Zimbabwe is discussed in section 2.8. In section 2.9, we highlight the negative consequences of fuelwood consumption. Section 2.10 concludes this chapter.

2.2 Characteristics of urban energy consumption

While the consumption of fuelwood in general has the negative impacts mentioned above, the peculiarities of urban fuelwood consumption and the impact of harvesting wood for the urban market has peculiar consequences on the environment. It is important to understand both the nature of urban areas and the energy consumption dynamics of urban areas in order to develop suitable methods of analyzing fuelwood demand in the cities. We briefly provide such a discussion in this section.

There is overwhelming evidence in the literature showing that there are differences between urban and rural areas of developing countries in energy choices, consumption patterns and methods of acquisition. The urban sector on one hand uses mostly purchased energy sources, which are dominated by modern fuels, to satisfy their energy needs, while the rural sector on the other hand relies heavily on own collected fuelwood for the same purposes (Masera and Navia, 1997). For example in Ethiopia, almost all modern energy is consumed in urban areas (Kebede, 2002). Similar patterns are true for many other African countries (Amous, undated; Kituyi *et al*, 2001). This duality is also evident in the differentiated income levels in which cash incomes are higher in urban than in rural areas. The differences between urban and rural societies, defined by incomes and energy options, require the separation of the analyses of their energy consumption patterns and behavior. In developing a framework for analyzing fuelwood and energy consumption in urban areas, one needs to understand the context in which consumption takes place.

The consumption of fuelwood in urban areas takes place within the context of several other sources of energy available in urban areas, together with the dynamics shaping urban societies as opposed to their rural counterparts. The most distinguishing factor between urban and rural societies is that the former are more involved in the market economy than the latter, with the former mostly purchasing their energy requirements on the market while the latter mostly depend on own collection of common pool resources. Cash income is often used to acquire energy in urban areas from markets. Therefore factors pertaining to the incomes of consumers, prices of the different source of energy, consumer peculiarities such as household demographics, supply factors etc all affect the demand for fuelwood.

The development of cities is accompanied by fundamental changes in human settlement patterns, resulting in a dramatic transformation of both the physical and socio economic environment as households get more involved in a cash and market economy.

This, according to Hosier (1993) includes an intensification of energy use (as households use energy for several domestic purposes in addition to cooking), and the way of acquisition of energy resources by consumers. The level of intensification of energy use depends on both the level of urbanization and the development status of a country. In fact, according to Karekezi (2002), there is a positive correlation between GNP per capita and modern energy use per capita. The high levels of poverty in Africa are reflected in the consumption patterns of modern energy. For example, energy consumption per capita is higher in developed countries than in the developing world (World Resources Institute, 1996; Dzioubinski and Chipman, 1999). In the developed world, energy is used for several uses including modern equipment like TV, radios etc. While most of the food is processed in the developed world, the degree of processing, which requires energy, is less in developing countries. According to the WRI statistics, energy use per person is more than nine times greater in developed countries than in developing countries. This is also true for urban areas where the types of energy consumed depend on the country's' level of development. According to Hosier (1993), the most important factor among many, shaping these patterns is income. Income levels of the inhabitants of cities are higher and more regular than the income levels of rural inhabitants. Wage employment that is associated with cities is a strong factor in this distinction. The level of transformation varies from city to city, each city having a unique array of activities and relying on a different mix of energy resources, depending on its level of development and industrialization. Overall, urbanization involves intensification of energy use.

Urbanization influences the requirements of energy in terms of both form and quantity. In India, the degree of urbanization has been shown by Filippini and Pachauri (2004) to influence electricity consumption such that households living in larger cities (more urbanized) consume more electricity than inhabitants of cities with less than 1 million inhabitants. Larger cities have better developed infrastructure, including supplies of electricity. Therefore households in large cities have better access to modern fuels such as electricity. Better employment opportunities that exist in lager cities also enable households to allocate more of their incomes to modern fuels. The limited connections to electricity, and limited incomes also limit electricity consumption in smaller cities and rural areas. Data from Tanzania shows the physical energy requirements of an urban resident to be lower than those of a rural inhabitant when measured in terms of end-use fuel requirements (Hosier, 1993). The energy consumed in urban areas is often in processed form e.g. electricity, gas etc, and it uses more efficient appliances such that the physical form of energy has smaller units in urban areas. For example in rural areas where firewood is mostly used, the physical quantity of this source of energy is higher than say charcoal or gas or electricity that is required to produce the same amount of energy. However, urban areas have higher per capita requirements than rural areas in terms of the energy resources needed to produce end-use fuels. This is mostly explained by the fact that urban residents consume processed energy, which is derived from the transformation of primary resources. For example, it takes four times as much wood on a weight basis to produce charcoal of equal weight (van der Plaas, 1995), which is used in urban areas, and this transported over a long distance to reach urban consumers. In addition, urban dwellers consume more processed goods, which have higher energy inputs compared to goods consumed in rural areas.

The economic costs of supplying energy to an urban resident are far higher than the cost of supplying a rural resident. In fact in Tanzania, it costs three times as much to supply an urban dweller with energy than a rural counterpart (Hosier, 1993). Transformation of energy from primary resources to processed form, transportation and transmission of energy and system losses partly explain such high costs in providing energy to urban residents. Thus one rural resident migrating to the city results in the tripling of economic costs of supplying them with energy. In addition to the increased costs of energy supply associated with urbanization, users meet only a small fraction of the costs of energy supply. The remainder is either being met by government subsidies, the depreciation of the national energy system or the degradation of the environment (Hosier, 1993).

In terms of expenditure, a household's share of energy consumption in total consumption decreases with moves from rural to urban areas and from small to large urban areas (Hosier, 1993), this being mainly explained by higher cash incomes in larger urban areas. Data from Thailand shows that the percentage of household expenditure on fuel is higher in non-municipal areas (rural business centers, growth points, rural areas) than in urban centers. In Bangok, the capital of Thailand, 7.6% of expenditure goes to fuel while in non-municipal areas and in other small urban centers, this is 8.8 % (National Statistical Office Thailand, 2000).

The type of energy is also influenced by income such that modern fuels dominate the energy consumption of high-income households. This has also been confirmed for countries in the Asia and Pacific region (UN ESCAP). Thus, there is also a shift towards more modern fuels in larger cities that are serviced by modern sources of energy such as electricity compared to small urban centers.

The future of the shifts in energy demand in urban areas will depend on the extent to which industrialization drives urbanization (Hosier, 1993) and the availability of fuels. Industrialization creates employment opportunities that improve the incomes of urban dwellers, making them able to afford modern sources of energy. Without these income opportunities created by industrial growth, the affordability of modern fuels remains low even in urban areas with high populations of unemployed people. This is mostly the case in many developing counties where urban population growth is not matched by economic development, resulting in higher levels of urban unemployment. In such cases, urban growth does not translate into higher usage of modern fuels. In general, continued urban growth will drive future urban energy demand, and without growth in the industrial sector, energy demand will entail an increased intensity in the use of traditional fuels. Data from Tanzania led Hosier (1993) to conclude that if urban growth resembles that of the recent past in that country, in that it occurs with little industrialization, the energy consumption in Tanzania is set to increase in magnitude, with the dominance of traditional fuels. The same pattern is also expected in other developing countries. This will be further magnified with rapid population growth (Hosier and Kipondya, 1993) and rapid rural to urban migration.

2.3 Zimbabwe's Physical Characteristics

Zimbabwe is a land-locked Southern African country, sharing borders with Botswana, South Africa, Mozambique and Zambia. The country emerged as an independent state in 1980 from British colonial rule. The total land area of Zimbabwe is 390,580 km^2, of which 386,670km^2 is land and the other 3,910 km^2 is water. Because of its land-locked position, Zimbabwe depends on its neighbors to access the oceans. The capital city of Zimbabwe is Harare, located in the northern region of the country. Harare is both the administrative capital, and has also the largest share of population and commercial activity compared to other urban centers in the country. The map of Zimbabwe presented below gives the geographical location of the country in relation to its neighbors and the location of the main cities in the country.

Figure 2.1: Map of Zimbabwe showing locations of major urban areas

Source: University of Texas Library Online

Altitude ranges from 162 m to 2,592 m above sea level in a country whose terrain is predominantly plateau. The dominant vegetation type in Zimbabwe is savanna (woodland savanna and grass savanna). The most dominant land cover type in Zimbabwe is woodland, covering 53.2% of the total land surface (Kwesha, 2000). The next most significant land cover type is cultivation, covering about 27% of total land area. Table 2.1 gives the different land cover types prevalent in Zimbabwe and their respective contributions to total land cover in the country.

Table 2.1: Land cover types and their % coverage of total land area

Land cover type	% contribution to total land area
Forest plantation	0.40
Natural moist forest	0.03
Woodland	53.20
Bushland	12.72
Wooded grassland	3.08
Grassland	1.76
Cultivation	27.47
Rock outcrop	0.20
Water body	0.77
Built up area	0.36
Total	100

Source: Kwesha, 2000

Land in Zimbabwe falls under the following land use categories:

- National Parks
- Forest Land
- State Farm Land
- Communal Land
- Resettlement Area
- Small Scale Commercial Farming Area
- Large Scale Commercial Farming Area
- Municipality (urban area)

This study involves analyses of fuelwood consumption, and this has impacts on woodlands. Therefore the amount of woodland cover in these respective land use categories is important as sources of fuelwood. Communal areas and large-scale commercial farming areas have the greatest area of woodland, amounting to about 6.5 million ha and about 7 million ha respectively. However, large scale commercial farming areas have a larger proportion of land area (58%) covered by woodlands while communal areas have 42% of their land area covered by woodlands. State land has the highest percentage of its land area under woodland (82%) although this is only about 168,200 ha. The ultimate availability of woodland resources from these areas depend on a number of factors, including the property rights of the different land tenure types. We briefly discuss different property rights and the major categories of land tenure that exist in Zimbabwe to put this into perspective.

Property rights fall under the categories open access (*res nullius*), common property (*res communes*), state property (*res publica*) and private property (Masomera, 2002), all with different degrees of exclusivity, enforceability, transferability (Tietenberg, 1994). Open access gives rights to all to access and use without restriction, and without allocating user cost to users, often resulting in depletion of resources and dissipation of rent (Masomera, 2002). Common property entitles rights of use to a defined group of individuals, who can exclude outsiders. Entitlements of members are defined by either formal legal rules or by informal arrangements enshrined in social norms, traditions or customs. State property regimes bestow ownership and control of the resource on the state, who make decisions on use and access. Private property gives full entitlement to an individual, company or other economic entity. This, according to Masomera (2002), is characterized by rights to exclude, transfer and enforce.

Different forms of land tenure and land uses fall under these general property rights regimes to varying degrees. Four major categories of land tenure exist in Zimbabwe (Katerere *et al*, undated), defining the control in the use of resources falling on specified land tenure types. These are state land, communal land resettlement areas and commercial farming areas. State land covers land under national parks, gazetted forests and state owned farms. Communal land legally belongs to the state, with communal households having rights to use but not to transfer. In the communal areas, land for cultivation and homesteads is used individually by households while grazing land is used communally. Resettlement land is used on a leasehold basis, with renewable leases being issued by the state. Commercial land is held under freehold title, and is the only form of private property in Zimbabwe. The other three are different forms of state property (Katerere *et al*, undated).

2.4 Demographic structure

The population of Zimbabwe was estimated to be 11.63 million people in 2002, with an average annual growth rate of 1.1% for the period 1992 to 2002 (CSO, 2003). This growth rate is a decline from the national annual growth rate of 3.1 for the period 1982 – 1992 (Campbell, *et al*, 2000; CSO, 2003). Females constitute 52% of the total population and males make up the remaining 48%. The total number of households in Zimbabwe is 2,653,082, with an average household size of 4.4. The average household size differs by province and degree of urbanization. Harare and Bulawayo, the most urbanized provinces, have the lowest average household sizes of 3.9 and 4.1 respectively. On the other hand, Matebeleland North and Matebeleland South provinces, both with little urbanization, both have an average household size of 4.9.

34% of the total Zimbabwean population lives in urban areas. The total number of households living in the urban areas of Zimbabwe was estimated at 996,940 in 2002. In 1992, urban population was growing at about 5% per annum, compared to the rural growth rate of 2.7 % per annum (Campbell and Mangono, 1994). The national growth rate was 3.1% per annum. While the national and urban growth rates have declined to 1.1% and 2.5% respectively, the urban population growth rate is still higher than the national rate. These differences are mostly explained by rural to urban migration.. Urban households grew in number at a rate of 4.3% per annum between 1992 and 1997, compared to the rural rate of 2.6% per annum (CSO, 1997). The average household size in urban areas in 1997 was 4.1 persons (CSO, 1997), compared to between 4.3 and 5.4 persons in 1992 (Campbell and Mangono, 1994), which indicates a decline in household size.

It is the capital cities of developing countries that have the largest shares of urban population (World Bank, 1998). In Zimbabwe, the largest city, Harare, has about 40% of the total urban population (World Bank, 1999; CSO, 2003). This makes capital cities the most significant consumers of all types of energy resources. In fact, 2003 census data shows that the population of Harare is double that of the second largest city in the country. Harare also has about 12% of the total national population. The total population of Harare urban in 2003 stood 1,444,534 people, with a total of 373,058 households (CSO, 2003).

The settlement pattern in Harare is composed of high density and low-density residential areas or suburbs. The general pattern is that low-income groups live in high-density areas while high-income households live in low-density areas. 80% of the total population live in high density areas with poor infrastructure, while 20% live in low and medium density suburbs where infrastructure and other services are well provided (Campbell *et al*, 2000). However, there are some exceptions to this settlement by income status. For example some poor households may live in low-density areas renting cottages, or as domestic workers, whereas some relatively well off households live in high-density suburbs.

2.5 Economic environment

The economic situation prevailing in Zimbabwe is an important variable in both current energy consumption and the expected future trends. This would also be true for fuelwood consumption. An understanding of the economic environment and the associated economic indicators contributes towards the understanding of the linkages between the economy and the environment via the consumption of energy and fuelwood. The consumers of fuelwood respond to changes in the economic environment by changing their energy choices and energy consumption patterns.

Since independence in 1980, Zimbabwe has undergone 3 phases of fundamental economic change. During the 1980s, a centralized approach to economic management, built on the socialist ideology, was followed. The 1990s saw the liberalization of the Zimbabwean economy, in line with the Economic Structural Adjustment Program (ESAP) sponsored mainly by the World Bank and the International Monetary Fund. The targets for ESAP included, among other things, tight fiscal policy, resulting in reduction of government expenditure aimed at reducing the budget deficit and improving efficiency

(Campbell, *et al*, 2000). The effect of this was to reduce government expenditure on social services such as subsidies. The period from 2000 saw another departure from structural adjustment, to economic growth based on land reform. During this period, a major change in the agricultural sector was experienced, which had negative ripple effects on the economy. The land reform received negative sentiment from several western countries. The effect was a fall in foreign investment in the country, which in turn negatively affected employment creation and generation of export revenues. In fact some companies closed, leading to higher levels of unemployment. The negative sentiment also affected other important sectors of the economy such as tourism and hospitality, which are important for employment creation and foreign currency generation. The land reform program also resulted in a reduction of farm production because of land reallocation. This led to further reduction in export earnings and downscaling of industries that depend on agriculture.

Within the energy sector, the controls of the 1980s tended to shield the poor more than under the liberalized economy, where all consumers are subjected to competitive prices as dictated by market forces. Energy prices used to be heavily subsidized, making them affordable to most consumers. Increased interest rates associated with economic reform have resulted in the postponement of investments in the energy sector in the 1990s as seen in the slow down in rural electrification (Campbell *et al*, 2000). Electricity generation declined by 4.6% per annum between 1991 and 1994 (partly explained by the adverse draught of 1992 and reduced government funding of the sector). Loss of foreign currency in the post 2000 period directly affected the energy sector through the shortage of liquid fuels such as kerosene. All liquid fuels are imported in Zimbabwe. Supply of imported electricity was also affected, leading to power cuts at times. Fuelwood became a major alternative to many households in urban areas. Reduction in foreign currency inflows into the country affected the shortage of foreign

Zimbabwe is classified by World Developing Indicators (world Bank, 1999) as a low-income country, with 41% of the population living below US$1 per day. The average household income in Harare was estimated at US$754 per annum in 1993 (World Bank, 1999) and has obviously declined up to now because of continuing economic adversity. 35% of the population were estimated to be living below the poverty line in

2003 (World Bank, 2002). Between 1990 and 1991, 68.2% of the Zimbabwean population had incomes of less than the US$2 purchasing power parity per day (PPPUUS$2) (Karekezi, 2002). The life expectancy at birth in Zimbabwe is about 39 years, compared to averages of 46 and 59 years n Sub-Saharan Africa and low-income countries respectively. Zimbabwe enjoys low infant mortality, high access to safe water and high literacy levels compared to other low-income countries as shown in table 2.2 below.

Table 2.2: Selected social indicators for Zimbabwe, compared with regional and low-income countries' averages

Indicator	Zimbabwe	Sub-Saharan Africa average	Low income countries average
Poverty (% of population below national poverty line)	35	-	-
Life expectancy at birth	39*	46	59
Infant mortality (per 1000 live births)	72	105	81
Child malnutrition (% of children under 5)	13	-	-
Access to improved water sources (% of population)	83	58	76
Illiteracy (% of population age 15+)	10	37	37
Gross primary enrollment (% of school-age population)	95		
Male	96		
Female	93		

Source: World Bank Online (2003)

* The low life expectancy is mainly attributed to AIDS/HIV.

In the recent years, economic performance has been declining as shown by trends in several indicators. Since 1998, annual GDP growth has been negative, with the 2001 growth rate being –8% (World Bank, 2003). Gross capital formation has also been declining over the past five years, declining from 17% of GDP in 1998 to 8% of GDP in 2002. Both imports and exports of goods and services have been falling, indicating an absolute shrinking of the economy (see table 2.3). Fiscal deficit has also been on the rise, and in the 2002 budget, fiscal deficit was estimated at 17.8% of GDP.

Table 2.3: Selected economic indicators for Zimbabwe

Indicator	Year				
	1998	1999	2000	2001	2002
GDP Growth (annual %)	3	-1	-5	-8	-6
Gross capital formation (% of GDP)	17	16	13	8	8
Imports of goods and services (% of GDP)	48	47	27	21	22
Exports of goods and services (% of GDP)	46	46	29	22	24
Industry, value added (% of GDP)	24	24	25	24	24
Agriculture, value added (% of GDP)	22	19	18	18	17
Aid per capita (US$)	22	20	14	12	--

Source: World Bank (2003)

The sectors contributing to GDP are agriculture (18%), industry (24%) and services (58%). The main export earnings for the country come from agriculture (tobacco and fresh produce), while the other commodities being exported by Zimbabwe are gold, ferroalloys and textiles/clothing. The European Union forms the largest market, accounting for 44% of the value of exports from Zimbabwe. The trends of indicators of selected sectors of the economy show a decline in the performance of the economy, especially for the period after 2000. These trends are shown in table 2.4 below

Table 2.4: Average annual growth of selected economic indicators

Indicator	1982-1992	1992-2001	2001	2002
Agriculture	2.6	3.8	-12.0	-7.0
Industry	3.5	-.14	-9.8	-8.2
Manufacturing	3.2	-2.5	-19.0	-12.0
Services	3.5	1.7	-5.3	-4.2
Private consumption	3.3	3.8	2.7	-5.7
General government consumption	5.2	-4.7	-29.3	-17.0
Gross domestic investment	5.3	-8.3	-28.6	-3.2
Imports of goods and services	7.1	2.9	-0.7	-4.8

Source: World bank (2003)

Economic adversity in recent years has been characterized by declining investment, suspension/withdrawal of IMF/World Bank support, decline in agricultural production and rising unemployment. Because of declining exports, falling foreign investment and withdrawal of most aid, acute foreign currency shortages have been gripping the country. Two foreign currency markets and exchange rates have emerged. On the official market where the government has fixed the exchange rate at about US$1 to 800 units of the local currency (Zimbabwe dollar), very little exchange of currency takes place. On the parallel market which dictates its own exchange rates, significant exchange of currencies takes place at rates as high as US$1 to Z$5,000. Most businesses cannot get foreign currency from the banks at the official rate, thus buy it on the parallel market, with rates going up frequently, reflecting foreign currency shortages and speculation. As such prices of most goods frequently go up, raising the rate of inflation. The official inflation rate for August 2003 was above 400%, and is still going up, with unofficial sources suggesting that it could by as high as 800% in October 2003. Shortage of local currency has also been experienced in the recent months, leading to a parallel market in local currency at which local notes were being traded at rates as high as 30% of value.

The deteriorating economic environment has negatively impacted the welfare of consumers. Unemployment has been rising (estimated at 60% in 2001) and real incomes have been going down. Poverty levels have gone up, and in 2002, 70% of the population was estimated to be living below the poverty line. In September of 2003 for example, the net salary of most government workers like school teachers was equivalent to US$36 per month using parallel exchange rates, while the minimum wage was equivalent to about US$12 per month. Prices of most goods, including basic commodities are therefore beyond the reach of most ordinary Zimbabweans. This is worse for urban households who purchase most of their consumption goods.

In the outlook, the harsh economic climate is expected to continue being experienced at both national and household levels. This will also continue to affect consumption of energy in urban areas.

2.6 Background to fuelwood and energy consumption

2.6.1 Africa and the developing world

In the developing world, wood fuels continue to dominate as primary sources of energy (Amous, undated). Africa's energy consumption mix is dominated by traditional fuels such as firewood, charcoal, crop residues, which make up about 67% of final energy consumption, compared to only 3% in OECD countries (US Department of Energy, 1999). In fact, Africa is the largest consumer of biomass energy (firewood, animal wastes, charcoal, agricultural wastes) when calculated as a percentage of overall energy consumption. In Tanzania for example, 84% of urban households use wood fuels for energy and biomass makes up 92% of total primary energy (Boberg, 1993; Mapako and Dube, 2003). Africa has the highest per capita woodfuel consumption of 0.89m3 per year compared to other continents (c.f. Asia: per capita fuelwood consumption is 0.3 m3 per year) (Amous, undated). In sub-Saharan Africa, biomass accounts for 70 – 90 % of primary energy, which is higher than in any other continent. In the Southern African sub-region, the use of wood, its dominance as an energy source, together with the associated impacts is referred to as the "fuelwood crisis" (Luoga, Witowski and Balkwill, 2000).

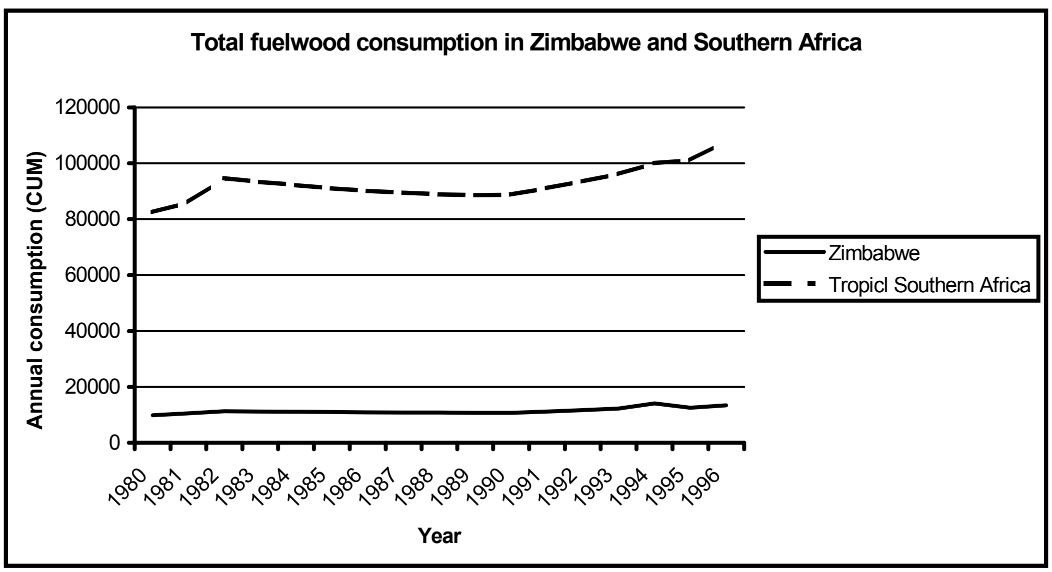
This indicates the extent to which the use of the fuel is important to the whole region, thus requiring attention. The dependence on wood fuels however varies within the sub-Saharan region. In countries like Tanzania on one hand, 90% of total energy consumption is fuelwood while in countries such as South Africa, only 14% of energy consumption is met by fuelwood (US Department of Energy, 1999; Luoga *et al*, 2000). However these figures indicate huge dependence on wood fuels by African countries in particular, and developing nations in general. Fuelwood consumption is set to continue growing as F.A.O. data in Amous (undated) shows that the annual growth rate in woodfuel consumption Africa is 1.4%, compared to 0.8% in Europe and non-Europe OECD countries. The household sector is the most significant consumer of woodfuels, consuming between 74% and 97 % of the total.

Woodfuel consumption in developing countries is mainly in the form of firewood or charcoal. Firewood is the primary form of woodfuel consumption while charcoal is a value added product of wood (Chidumayo, 1997; Luoga *et al*, 2000). The proportions in which charcoal and firewood are consumed vary with country. For example, in Zambia firewood and charcoal contribute 16.4% and 56.3% respectively of total household woodfuel consumption (Banda, Kalumiana and Sakachite, 1996 in Negatu, unpublished). In Zimbabwe on the other hand, household charcoal consumption is very negligible (used by only 1% of households) while firewood dominates among fuelwood users (Attwell *et al,* 1989; Campbell and Mangono, 1994). Charcoal dominance also characterizes the urban areas of countries such as Mozambique, Malawi, Tanzania, where the economics of fuelwood supply have resulted in a strong tendency to convert wood into charcoal on site to minimize transport costs (Barnes, 1995).

2.6.2 Energy and fuelwood consumption: Zimbabwe

In Zimbabwe, a dual energy consumption pattern exists, which is characterized by the dominance of electricity in urban areas on one hand, and the dominance of biomass fuels in rural areas on the other. However, mixes of different types of energy occur in both sectors, with the tendency to mix being high in urban areas where several options exist. Attwell *et al* (1989) have confirmed the use of multiple sources of energy within the same households in urban areas. The degree of mix varies across urban areas, and across different households in the same urban areas as determined by income and other household characteristics. Woodfuel consumption in Zimbabwe accounts for 88% of total wood consumption (Amous, undated). Statistics by Griffin (1999) show that woodfuel in Zimbabwe constitutes 52% of total fuel. While these figures vary by source, it is clear that the contribution of woodfuel to total energy consumption has increased over time. Total fuelwood consumption has been increasing from 1980 to 1996 (period for which F.A.O. data is available) in absolute terms, whilst per capita fuelwood consumption has only marginally declined since 1980. In 1984, the annual total fuelwood consumption in urban areas of Zimbabwe was estimated by the Beijer Institute (in Attwell *et al*, 1989) to be 0.24 million tones, making up 3.7% of national energy consumption.

Figure 2.2: Trends in fuelwood consumption in Zimbabwe



Source: Amous (undated)

Data on urban household energy consumption levels are mainly based on surveys carried out irregularly and on an *ad hoc* basis by different individuals and institutions independently. In particular, no consistent data exits on fuelwood consumption, to the extent that trends are impossible to establish over reasonably long periods of time. Studies focussing on Harare are particularly limited. The few studies include the studies by Attwell *et al* (1989), Campbell *et al* (2000) and Campbell and Mangono (1994). Other studies on woodfuel consumption tend to cover rural areas, the traditional fuelwood consumption areas. It is until recently that urban fuelwood consumption has raised concern, thus has come under spotlight.

Data available until the year 2000 shows that Harare households mainly depend on electricity (Attwell *et al*, 1989; Campbell *et al*, 2000). In fact, electricity dominates energy consumption in the larger cities of Zimbabwe, followed by kerosene, with fuelwood playing a smaller role (Campbell and Mangono, 1994). Harare is a high electricity use city, with over 90% of households using this form of energy (Campbell *et al*, 2003). Wood is used by between 10 and 40% of households in Harare as the main cooking fuel. Other sources of energy such as gas, solar power and charcoal are consumed in very insignificant amounts. In fact, coal, charcoal and LPG are used by less than 1% of households.

Greater Harare alone was in 1989 found to consume 93,000 tones of fuelwood annually (Attwell *et al*, 1989), with 85% of such consumption being accounted for by high-density suburbs. On a per household basis, consumption was recorded by the same study at 0.4 tons of fuelwood annually. The figure obtained by Campbell and Mangono (1994) is between 92 and 247 kg per household per year in different suburbs. On the other hand, kerosene consumption in urban areas is between 60 and 120 liters per household per year. In Zambia, the average annual household consumption of firewood and charcoal in urban areas is 635 kg and 1040 kg respectively (Chidumayo, 1997). Highest dependence on fuelwood in Harare is in high-density suburbs and cottages of low-density suburbs. In these categories, 16% and 21% of consumers respectively use wood as the dominant source of energy for cooking (Attwell, *et al*, 1989).

Household fuelwood consumption changes with season, with consumption being higher in the cold winter season than in the warm seasons. For all urban areas, winter consumption of fuelwood is between 1.2 and 1.9 times greater than summer consumption (Campbell and Mangono, 1994), while for Harare, high density suburbs increase their fuelwood consumption by 1.5 times in winter, and low density households increase their consumption 9.3 times in winter (Attwell *et al*, 1989). Because of the cold weather in winter, wood consumption increases for the purposes of heating space (mainly among high-income households), to supplement other sources of energy whose cost increases increasingly with consumption, because of load shedding implemented by the Zimbabwe Electricity Supply Authority (ZESA) to reduce consumption, and other reasons.

Consumers tend to prefer to use indigenous species of firewood than exotic species. Indigenous species are perceived to have better burning qualities, last longer, and do not emit unpleasant smells when they burn. Most of the wood coming from outside Harare is dominated by indigenous species. In 1989, Attwell *et al* (1989) observed that about 80% of firewood loads coming into Harare were of indigenous species. However, firewood obtained from sources within the city's residential properties is mainly of exotic species.

Expenditure on energy differs with income. In 1999, low income, medium income and high income households were spending 9%, 4% and 2% of their incomes on energy respectively (Campbell *et al*, 2003). These are lower than 1994 figures (Campbell and Mangono, 1994; Campbell *et al*, 2003). A drop in real prices of electricity, kerosene and firewood between 1994 and 1999 resulted in households in the medium and high-income groups spending smaller proportions of their total incomes on energy. Thus further declines in income are expected to result in higher proportions of household incomes being devoted to the purchase of energy, or a resort by households to cheap and low quality sources of energy. In Mozambique, the proportion of energy expenditure to total income is even higher at 12%.

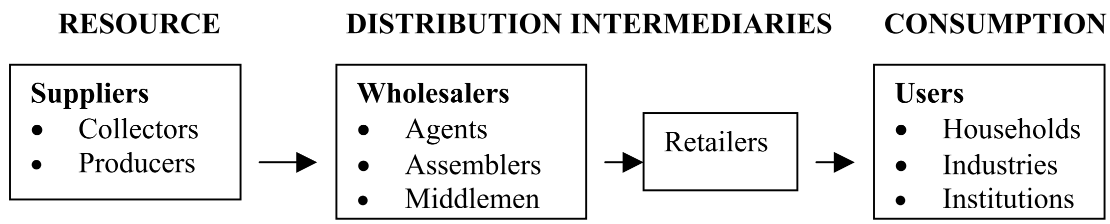
Generally, the data shows that until 1999, woodfuel consumption was very low compared to electricity and kerosene, which are the real substitutes to firewood. However, the data also shows increasing allocation of income to energy, especially among poor households in urban areas. Thus the economic well- being of households, as indicated by real income, and the prices of different fuels will, to a large extent determine the future levels and trends in the consumption of different sources of energy. Further declines in real incomes, accompanied by increases in prices of firewood alternatives will see households increasing their firewood consumption.

2.6.3 Fuelwood acquisition in Harare

Most of the wood consumed in Harare is acquired on the market. In fact, as Attwell *et al* (1989) found, 91%, 65% and 65% of high density, medium density and low-density residential areas respectively rely on purchase for fuelwood. Low density and medium density household supplement their consumption from harvesting fuelwood at own properties. Wood purchased from the market is normally sourced from large-scale commercial farming areas around Harare, but especially south of Harare (54% of the wood). In 1989, most wood came from within 100 km of Harare (Attwell *et al* 1989). However recent observations show that wood comes from far away as Mvuma (some about 180 km) from Harare. In Tanzania, charcoal is transported over an average distance of 121 km from the point of production to the point of consumption. In the same country (Boberg, 1993) firewood is transported over some 55 km on average. In Harare, recent observations show that wood is also being obtained from woodlands and trees along some roads in the city or in city limits.

There is no distinct chain peculiar to the urban fuelwood market in Harare. Different means of acquisition exist, from different sources, and the routes between sources and consumers vary from direct (own collection) to winding ones that involve several middlemen. The information on the chain is also not readily available from most of the players in the chain, especially transporters. However, Attwell *et al* (1989) attempted and developed a market chain for Harare, with several routes. Actors in any marketing system are generally segregated into producers, traders and consumers. This is the simplest model that considers the production, distribution and consumption of the basic marketing channel (Hulsebosch, 1993). This is represented as follows.

Figure 2.3: The basic marketing channel model



Source: Hulsebosch: 1993

In brief, the informal nature of the fuelwood market system in Harare, and in other urban areas of developing countries, though largely competitive, is impervious to finer analysis. The commodity has diverse routes from source to consumer such that a single model is almost impossible to establish. However the system reflects the absence of value addition through processing (especially in Zimbabwe where wood is consumed as firewood). The system also shows the exclusion of the rent value of the resource in the pricing structure. The price only reflects the cost of harvesting, transportation and the profits of the market agents such as middlemen. The value of the resource with regards to its ecological, aesthetic, spiritual functions is not reflected in the price.

2.7 Likely impact of economic environment on urban energy consumption

Energy consumption patterns in Africa are highly linked to the state of the economy, with FAO data showing that this is linked to GDP (Amous, undated). While the majority of African countries have high rates of fuelwood consumption in their urban areas, fuelwood consumption in the urban areas of Zimbabwe has been low because of widespread electrification and a positive economic climate. The study carried out by Campbell *et al* (2000) in 1994 and 1999 shows that economic adversity had not halted or reversed energy transition in Zimbabwe from traditional to modern fuels. This stems mainly from the fact that Zimbabwe has had a successful electrification program compared to other sub-Saharan Africa, to the effect that wood formed a relatively small component of the urban energy sector. World Bank (1999) statistics also show Zimbabwe to be consuming more commercial energy such as electricity and petroleum fuels as opposed to traditional energy per capita compared to other sub-Saharan African countries. Zimbabwe's consumption of commercial energy is also high compared to other African countries (World Bank, 1999). The respective per capita commercial energy use (kg oil equivalent) in 1996 for Zimbabwe, Zambia and Mozambique was 928, 628 and 481. This is al result of the country's investment in modern energy sources, mainly electricity generation and transmission. The electricity transmission system in Zimbabwe reaches many consumers in urban areas, compared to other countries in the region.

Despite the empirical data showing major changes towards more modern energy sources, the persistently declining economy is likely to eventually negatively impact on the energy sector. In urban areas for instance, this would imply a shift towards greater use of fuelwood (Campbell, *et al*, 2000). This is being compounded by the current economic woes that have resulted in acute shortages of foreign currency which is required for the importation of commercial energy. Investment in the generation of electricity has also gone down, with there not being any new major developments recently (Mangwengwende, 2002; Campbell, *et al*, 2003). According to the World bank statistics (1999), Zimbabwe is a net importer of energy. In fact petroleum products are imported in their entirety. Recently this has resulted in acute shortages of kerosene which is used by most poor households in urban areas. With continuing shortages of foreign currency, local prices of imported fuels are like to continue to soar, limiting the ability of ordinary consumers to afford them. The study by Campbell *et al* (2000) shows that demand for kerosene in particular had increased relative to supply. Those who depend on it, during such periods of scarcity, switch to fuelwood. The current economic climate in Zimbabwe is also characterized by high inflation, high and increasing unemployment levels, declining investment due to reduced investor confidence etc. This negatively affects the energy sector in several ways, including:

1. stagnation of domestic energy production which reduces supply,
2. inability of consumers to keep pace with prices,
3. the unemployed and retrenched getting engaged in fuelwood supply activities that damage the environment,

4. inability by households to afford decent housing in electrified areas, and inability to afford connections and electricity appliances.

Thus the economic climate strongly suggests a strong tendency for increasing woodfuel consumption in Zimbabwe, and more particularly in urban areas like Harare. This is substantiated by recent press reports from observations like the following:

- "Deforestation worsens as paraffin shortage persists", The Herald, 8 September 2000.
- "Sellers make killing as demand for firewood, paraffin increases", The Herald, 16 august 2000.
- "Paraffin price up 101%", The Daily News, 1 September 2000.

The ultimate scenario, however, depends on the response of consumers to the economic environment in which they find themselves, and the dictates of their characteristics and behavior.

2.8 Policy and institutional environment of the energy sector in Zimbabwe

The energy policies of Zimbabwe are generally aimed at the adequate provision of energy for domestic and industrial utilization. In this regard, government efforts have been focussed on investment in commercial energy, to the extent that energy investment during 1980 – 1989 was about 12% of Gross Domestic Capital Formation (Department of Energy, undated). Of importance to note is that Zimbabwe is not self-sufficient in energy requirements, with petroleum products having to be imported in their entirety, and 40% electricity also being imported (Karekezi, 2002). This makes the energy sector foreign exchange intensive, tending to influence economic policy decisions. Thus energy policy decisions are strongly linked to economic policy decisions. This, as discussed earlier, explains the decline in investment in the energy sector upon the adoption of the Economic Structural Adjustment Programme (ESAP) in the 1990s in line with World Bank and IMF targets of reducing government expenditure. On the other hand, the provision of biofuels such as firewood does not influence macroeconomic decisions, do not have foreign exchange requirements, and do not have a bearing on government expenditure, foreign debt (Campbell *et al*, 2000). It is therefore not an area of priority as far as policy is concerned, thus is often left running on its own without government intervention. As such no direct policy exists on the supply and consumption of wood fuels. Rather, wood, being a natural product of forests or woodlands, is covered under policies regarding forests/woodlands and their products.

Overall, the Ministry of Mines and Energy is the responsible authority for energy policy and for public administration of the energy sector in Zimbabwe (Southern Center, 1997). The Department of Energy within this ministry is responsible for the day to day administration of the sector. The responsibility of the department is to (Southern Center, 1997).

:

(a) formulate and guide national energy policy
(b) ensure adequate supply of energy to all sectors of the economy
(c) administer all government parastatals in the energy sector
(d) coordinate with other government organs who are involved or who affect the energy sector
(e) facilitate and set out operational guidelines for parastatals and private entities involved in the energy sector
(f) spearhead research and development and the dissemination of new technologies in the energy sector.

Different government parastatals are responsible for the different sources of energy in Zimbabwe. For example, the petroleum sector (covering kerosene) is controlled by the National Oil Company of Zimbabwe (NOCZIM) under the Ministry of Mines and Energy, specifically under the Department of Energy. The Zimbabwe Electricity Supply Authority is responsible for the generation and distribution of electricity. Coal is mainly mined and supplied by Wankie Colliery and Rio Tinto. The woodfuel energy sector has no specific authority responsible for the generation and distribution of wood fuels (Southern Center, 1997; Mapako and Dube, 2002). While the Department of Energy is responsible for the generation of all forms of energy to the household and commercial sectors, it does not have the mandate to influence generation of wood fuels in the same way it controls electricity generation and supply through the Zimbabwe Electricity Supply Authority (ZESA), or kerosene through the National Oil Company of Zimbabwe (NOCZIM). As a result of this skewed attention to the commercial energy sector of electricity and petroleum, the development priorities of government have been biased towards that sector at the expense of the bioenergy sector. This is despite the fact that over 80% of the Zimbabwean population depends on biomass for energy. It is thus not surprising that official data on wood fuel consumption in Zimbabwe are not available.

Focusing on woodfuel, a typical woodland resource, government does not exert any price controls on its trade. Pricing is determined by the market forces of supply and demand, at least in urban areas where 90% of fuelwood is traded (Department of Energy). Wood is simply acquired, legally or illegally, through arrangements between traders and suppliers in totally private agreements on both price and quantity. Land tenure influences the types of access to resources, prices paid, and the long-term decisions that primary suppliers can make with regards to investment in, and use of resources. As long as market prices reflect the value of the resource, and the cost to the environment of using firewood, the *laissez faire* situation is ideal. However, in most cases, and in the overall sub-Sahara African context, consumers are seldom levied for the stumpage of wood fuels, neither do they pay other energy related taxes for the same, even in cases where there is formal legislation to that effect (Hofstad, 1996). The diffused and informal nature of the woodfuel business, no matter how big it may be, is impervious to central planning and any government control. In fact, it is the conclusion of some studies that government intervention through taxes and legislation has very little effect in improving wood flow, apart from making it difficult to monitor wood trade (Attwell, *et al*, 1989). Boberg (1993) actually suggests that as long as the price of the fuel (any fuel) reflects its costs to society, government should be indifferent whether the fuel is chosen by consumers. A study by Chambwera (1996) shows that incorporating the scarcity value of wood in the price of fuelwood significantly reduces the quantities of wood consumed in Zimbabwe, bringing the fuelwood harvesting rates to near sustainability levels. In this scenario, consumers tend to increase quantities of other sources of energy to maximize their utility.

Upon realizing the importance of the biomass energy sector in Zimbabwe, and in a bid to bring it to closer attention, a National Biomass Energy Strategy Task Force was set up, with membership from government ministries and departments, non-governmental organizations and research institutions (Department of Energy). The task force produced the draft National Biomass Energy Strategy paper, recommending the Department of Energy to undertake the following tasks:

(a) formulate biomass policy and policy instruments
(b) assess biomass production and use
(c) promote biomass research and development

The extent to which the recommendations from the strategy paper or the task force have been acknowledged, adopted or implemented is not known. The task force itself no longer has regular activities towards purpose.

It could be summarized that while clear policy and institutional responsibility exists for the energy sector, such responsibility exists in organized and coordinated form only for commercial fuels of electricity and petroleum products, which sectors have been the focus of investment and government policy intervention. Both monitoring and research and development of the wood fuel sector have been neglected at the policy level for long. Total policy control of the sector is difficult as the production, supply and consumption of wood fuels touches on different government organs and policies. In the wake of these realities and difficulties, the sector has remained informal, and prices continue to exclude the scarcity value of the resources and the economic cost of harvesting to society and the environment. Efforts put in place to address the policy issues of the woodfuel energy sector have largely been ineffective and rather abandoned, leaving the wood fuel sector with little policy direction.

2.9 Environmental Impact of fuelwood consumption

The concern over the consumption of wood fuels arises from the impact that harvesting and use of the commodity has on the natural environment and on the users. Deforestation, loss of biodiversity, loss of environmental amenities and services, etc are all impacts associated with unsustainable harvesting of wood for energy purposes. Thus woodfuel consumption is one of the causes of environmental problems where harvesting levels exceed the capacity of the environment to regenerate itself. In Africa, according to Amous (undated), woodfuel consumption is a major contributor to total wood removal. It accounts for about 92% of total African wood consumption and contributing to greenhouse gas emissions.

One of the major consequences of woodland loss due to fuelwood harvesting is deforestation. Deforestation is now one of the most pressing environmental problems faced by most African nations (US Department of Energy, 1999). Deforestation is one of the major causes of environmental damage, and the decline in natural forests and woodlands is of concern for social, economic and environmental reasons. In Zimbabwe, the annual rate of deforestation is estimated at 0.4% (CSO, 2000). Deforestation rates for other countries in the region are: Zambia (0.2%), Tanzania (0.3%), Botswana (0.1%), Mozambique (0.8%), Malawi (3.3%) and Angola (0.2%). Compared to its regional neighbors, Zimbabwe has a significantly high rate of forest loss. Campbell *et al* (1989) estimate that natural forests and woodlands of Zimbabwe are declining at the rate of 1.5% per annum due to factors including agricultural expansion, population pressure, overgrazing, fires and over exploitation for timber, fuelwood and other purposes. Woodfuel consumption is only one of the factors explaining deforestation. In rural areas in Zambia, subsistence firewood collection rarely affects the natural miombo woodland structure (Chidumayo, 1997). Only dead wood or wood cut for other purposes is collected. However the cutting of live trees for fuel in miombo that has been associated with the emergence and growth of urban fuelwood markets affects the structure of woodlands locally (Chidumayo, 1997). Boberg (1993) stresses that the environmental costs of woodfuel harvesting have implications beyond the provision of energy. They affect topsoil, protection of watersheds and the supply of water, preservation of species diversity and fauna populations (thus economic benefits from tourism), the rural urban dichotomy whereby rural dwellers bear the costs of urban dwellers' consumption, and other issues. Peri-urban deforestation is the main result of firewood consumption in urban areas that is mostly attributed to this cause. In and around Harare, since the shortages of kerosene, and the subsequent growth of the urban fuelwood market, deforestation has been visible along major roads leading out of the city. The loss of scenic value is the most obvious consequence, in addition to other environmental consequences such as carbon sequestration, erosion control etc, which are not so obvious to the casual observer.

Since trees, thus woodlands and forests are a renewable resource, the extent of the impact of fuelwood consumption on the environment has to be viewed from the comparison of the rates of extraction with the rate of natural regeneration. The resilience of woodlands to harvesting for woodfuel purposes has also to be taken into account. However, there are almost no measurements of woodland productivity in Zimbabwe (Campbell and Mangono, 1994). Estimates are rather for the Southern Africa region. Such estimates show growth rates of mature woodlands to be 1ton per ha per year (Campbell and Mangono, 1994). Chidumayo (1997) also acknowledges the lack of adequate studies on annual incremental growth in uneven age miombo. In the central dry miombo of Zambia, this has been estimated by Chidumayo (1997) at 1% of above ground (AG) wood standing biomass. Very little is known in Zimbabwe and the region about the productivity of immature or cut-over woodlands. These, according to Campbell and Mangono (1994), may have higher growth rates. The point is that it cannot be concluded with certainty whether or not urban consumption of fuelwood is exceeding regeneration rate. What is clear is the site- specific impact associated with harvesting wood for the urban fuelwood market, which is area intensive due to the economics of the business. In their study, Campbell and Mangono (1994) estimate that the amount of firewood consumed in the urban areas of Zimbabwe can be harvested sustainably from about 300,000 to 450,000 ha of miombo woodland. While this sounds optimistic, given the area of miombo woodland in Zimbabwe, it however assumes centrally coordinated harvesting and marketing in which wood is selectively harvested from surplus areas on a sustainable and rotational basis from wood surplus areas and sold in demand areas. In reality however, suppliers may concentrate on harvesting wood in certain areas so as to reduce transport costs , and may avoid areas where access to wood is restricted by security or tenure, such as commercial farming areas. This subsequently leads to excessive harvesting in the supply areas. It disregards the micro-economic motivations of the players:

- traders, who want to minimize costs, and therefore maximize profits by transporting wood over short distances and,
- consumers, who want to maximize their utility from a limited budget, and who may also want to collect firewood on their own from sources close to them.

Woodfuel harvesting for the urban market generally comes from larger tress, and is based on selective cutting, resulting in qualitative impoverishment of the woodlands (ESMAP, 2001). Loss of woodlands also results in the loss of biodiversity, increase in soil erosion, reduction in soil quality, increased risk of flooding in surrounding areas and loss of livelihood options for communities who depend on woodland resources (UNEP, 2002). The loss of habitats for other species which depend on woodlands and woodland resources also results from woodland loss. The removal of trees in urban areas themselves, even trees on private property compromises the process of carbon sequestration and the general ability to absorb gaseous emissions from vehicles and industry. Vegetation in urban areas also functions to reduce dust, improve the scenic value of urban areas, and providing several other amenity functions. In the fuelwood source areas outside the cities, natural woodlands play many functions on which livelihood strategies of most poor people depend. These include food, fruit, fiber, shelter, medicines and spiritual and aesthetic functions.

It should be noted that the problem of deforestation, though usually stated in global terms, is rather more localized, manifesting itself in varying degrees in different areas (Chidumayo, 1997). The types of degradation associated with urban fuelwood consumption are most severe within a given radius from the urban center, mostly along major roads leading to the cities (Leitmann, 1991).

Karekezi (2002) and Leitmann (1991) have highlighted indoor air pollution, leading to respiratory illnesses as the main drawbacks in the use of biomass. These mainly affect women and children who are in the cooking areas most of the times (Leitmann, 1991).

2.10 Conclusion

The literature shows the consumption of woodfuels to dominate in most developing countries. Zimbabwe is characterized by low fuelwood consumption compared to its regional neighbors. In the urban areas of Zimbabwe, with particular reference to Harare, consumption of fuelwood is dominant among low-income households. Firewood is almost the sole form in which wood fuels are consumed in

Zimbabwe. The economic environment is very important in shaping the direction of fuelwood consumption in Zimbabwe, thus the impact on the environment. Earlier data and literature indicate very little response of fuelwood consumption to economic adversity. However, the most recent literature shows that the persistence of negative economic trends resulting in declining real incomes, rising unemployment etc will see a reversal of the switch towards modern fuels, or at least a slow down in the rate. This implies possible back switching to fuelwood in urban areas. The policy environment in Zimbabwe is not well defined and coordinated with respect to firewood acquisition, trade and consumption such that the sector is largely unregulated, informal and does not incorporate environmental and social costs in its pricing mechanism. The ultimate impact on the environment is thus driven by several social, economic and ecological variables whose effects are difficult to determine individually. A model incorporating these variables is thus required in studying the consumption of wood fuels and its impact on the environment.

CHAPTER 3

CONCEPTUAL FRAMEWORK OF HOUSEHOLD ENERGY CONSUMPTION

3.1 Introduction

This chapter develops a framework for carrying out analyses of fuelwood demand in urban areas in general, and in Harare in particular. This contributes towards the overall focus of this study, which is to analyze urban household fuelwood consumption as far as its effect on the environment is concerned. We use the peculiar characteristics of urban households, together with earlier models of energy consumption in developing countries to develop a suitable conceptual and analytical framework. This analytical framework enables the estimation of household demand for fuelwood in urban areas, as well as enabling the analyses of factors endogenous and exogenous to the household, which affect such demand. The result of this framework is to suggest the theory to be used in the analyses and the specification of the models to be estimated in the subsequent chapters.

The first section of this chapter introduces the concept of the energy ladder model and the associated inter-fuel substitution as a general framework for describing energy consumption behavior in developing countries. In the second section, we highlight its shortfalls as a demand-analysis framework especially for urban consumers. The last section of the chapter extends the energy ladder concept to develop an energy mix model as a conceptual framework on which urban household energy demand can be estimated and analyzed.

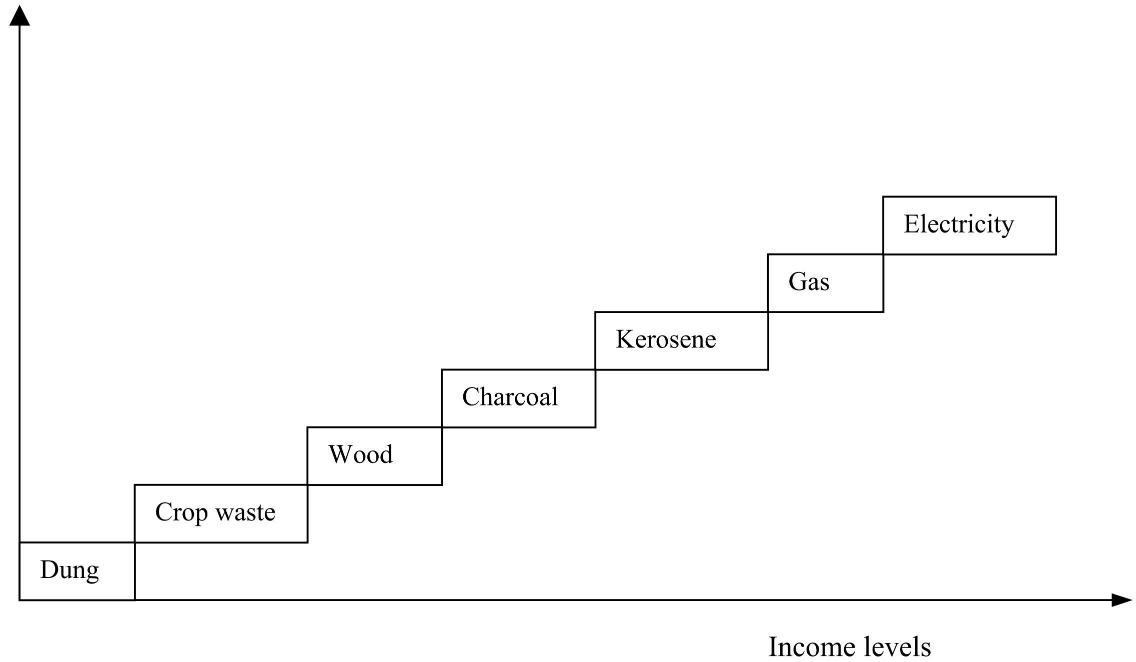
3.2 Fuel substitution and the energy ladder model

The peculiar characteristics of urban areas in terms of the energy choices available, the physical characteristics of the fuels and the associated technologies, the means of acquisition and the socio-economic characteristics of consumers suggest the means by which fuel choices are made. The nature in which choices are made on the basis of these factors is best described in the context of the "energy ladder" model.

The understanding of urban household energy consumption in developing countries is mainly built on the concept of fuel substitution, or more commonly, the energy ladder hypothesis (Hosier and Dowd, 1987; Leach, 1992; Hosier and Kipondya, 1993; Masera and Navia, 1997 Masera, Saatkamp and Kammen, 2000 and Campbell *et al*, 2003). The hypothesis has been mainly advanced by Richard Hosier in characterizing energy consumption patterns in Africa in the 1980s and 1990s. Subsequent models such as the inverted – U used by Foster *et al* (2000) basically use the energy ladder model as the starting point. The inverted – U hypothesis describes the relationship between energy consumption and per capita income, showing for example in Guatemala (Foster *et al*, 2000) gross energy consumption increasing with per capita income to e certain income level before declining.

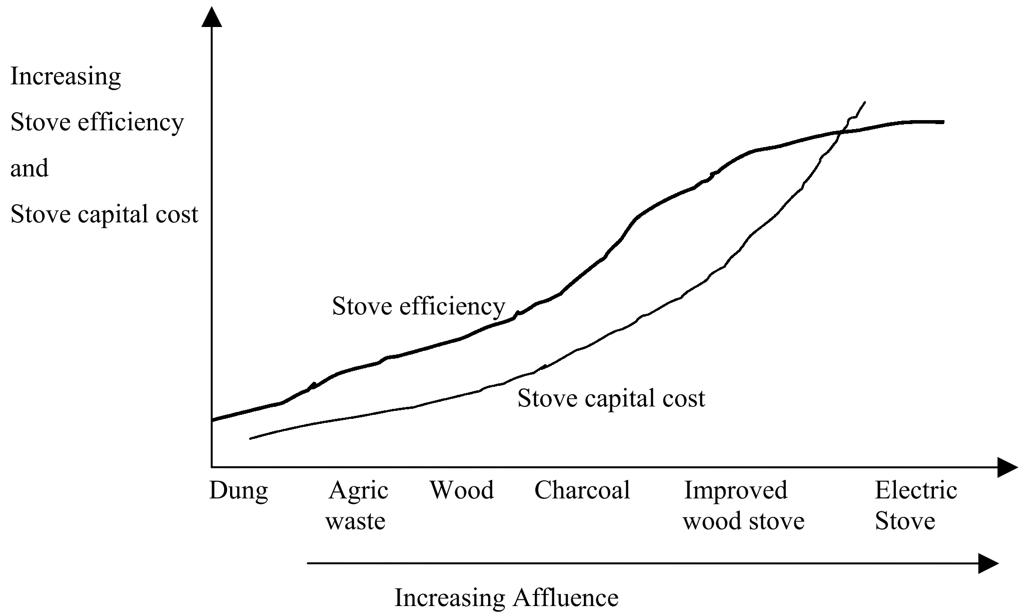
The energy ladder model hypothesizes that as households gain socio-economic status, they abandon technologies that are cheaper, and start using more modern technologies (Masera *et al*, 2000). This is mostly dictated by the preferences of consumers for more modern fuels. The underlying assumption of the model, according to Hosier (1987) is that households are faced with an array of energy supply choices, which can be arranged in order of increasing technological sophistication. At the top of the list is electricity, and at the bottom are traditional fuels such as fuel wood, dung and crop wastes. Fig.1 below gives a schematic representation of the energy ladder model adapted from Masera *et al* (2000). As a household's economic well being increases, it is assumed to move up the ladder to more sophisticated energy carriers, and it moves to less sophisticated energy carriers as economic status decreases through either a decrease in income or an increase in fuel price (Hosier and Dowd, 1987). Figure 3.1 below illustrates the hypothesized relationship between income level and energy type, from the basic fuels (dung) to the most sophisticated ones (electricity).

Figure 3.1: Schematic illustration of the energy ladder hypothesis: Change in fuel with increasing income level



The energy ladder hypothesis also relates the technological advancement of a fuel to the efficiency of the appliances used as shown in Figure 3.2. According to this schematic, both stove efficiency and capital cost increase with energy sophistication, and the use of any type of energy is an indicator of household affluence. For example dung and agricultural waste require little if any investment in appliances, and they are the least efficient technologies, used by the least affluent consumers. Electricity on the other end of the scale requires high investment in more efficient appliances, and is used by the more affluent households. As an indication, the end-use efficiencies of technologies that use firewood, charcoal, kerosene, gas and electricity are 10 – 25%, 20 – 35%, 35 – 50%, 45 – 65% and 75 – 85% respectively (van der Plas, 1995).

Figure 3.2. Schematic representation of the energy ladder hypothesis. Adapted from Masera *et al* (2000)



The stove efficiency curve is above the stove cost below a certain level of technology, reflecting that efficiency increases at a decreasing rate as technology increases. Beyond the threshold level of technology, increasing the capital cost of the appliance does not result in substantial gains in efficiency. This is depicted by the intersection of the two curves.

According to the literature, this assumption of the energy ladder model operates at both micro and macro levels. The scenarios at the micro level have just been described above. At the macro level, according to Hosier and Dowd (1987), energy consumption increases with development, and is also accompanied by higher reliance on modern fuels. Comparison of energy consumption across cities is also shown by the literature to exhibit the characteristics of the energy ladder model where, according to Hosier (1993), the share of modern fuels increases with city size, with evidence of decreasing per capita consumption of traditional fuels in larger cities.

The concept of the energy ladder hypothesis (or the energy transition model) is loosely based on the economic theory of household behavior (Hosier and Kipondya, 1993). Hosier and Kipondya (1993) further assume that modern fuels are normal economic goods and that traditional fuels are inferior goods. This concept is expected to hold with respect to both cross sectional and longitudinal variations in income. Cross sectional evidence from Tanzania support this (Hosier and Kipondya, 1993). Amous (undated) also argues that this cross sectional pattern holds in all developing countries. Specifically the wealthier countries will be expected to be more reliant on modern fuels than on traditional fuels, while the opposite holds for poorer countries. This is confirmed by data from other regions i.e. Asia and the Pacific (UN ESCAP) where increases in incomes at household level, and GDP at national levels, have seen a shift towards more modern fuels. In Thailand, fuel expenditure is shown to increase in absolute terms as both household income and household expenditure increase (National Statistical Office Thailand, 2000). In the Tanzanian example, charcoal serves as a basic fuel and electricity as the modern, preferred fuel, while kerosene is a transitional fuel whose relative importance decreases as households' access to electricity increases. In economic terms, data from Tanzania show electricity and LPG to be normal economic goods, with ownership of electrical appliances increasing with income categories. Kerosene behaves like an inferior good i.e. its use decreases as income rises. Woodfuel consumption demonstrates the characteristics of a normal economic good at lower income levels, and then shifts to being an inferior good at higher income levels (Hosier and Kipondya, 1993). This classification of fuels as normal, inferior is used to partly explain observed consumption patterns.

The speed and extent of fuel switching along the preference ladder depend on several factors, including physical access, equipment costs, reliability, incomes and relative fuel prices (Masera *et al*, 2000). Data from Sri Lanka and Colombo show that the first cost that hinders households from switching upward to modern fuels is the cost of modern appliances (Leach, 1992). In Sri Lanka and Colombo in the 1980's, the entry cost for LPG equaled at least one month's income for 70% of households and three months' income for the poorest 12% of households. Observations from Zimbabwe show that stove cost can indeed be a barrier to the use of modern fuels. For example, a basic two plate electric stove costs about twice the net monthly salary of a school teacher in Zimbabwe (personal observation, July 2003). Lumpy payments associated with the use of modern fuels also determine the ability of households to switch to them. Lumpy payments involve the payment of bills for energy consumed over say one month for electricity, or filling gas tanks, purchase of stove etc. These all require large cash outlays. In fact, avoiding lumpy payments is a major household strategy for the poor, even though it often means paying up to twice as much per unit of energy than does bulk purchasing (Leach, 1992). As such, and according to literature, household income is a major determinant of the urban energy transition. Data from Africa (Hosier and Dowd, 1987) and from Mexico (Masera and Navia, 1997) support that household energy patterns are differentiated with respect to income status, and specifically in Mexico, the use of LPG is highly correlated with income. The same patterns were also observed in Kenya by Barnes *et al* (1985) (in Hosier and Dowd (1987)) and in the Indian city of Hydrabad by Alam *et al* (1985) (in Hosier and Dowd (1987)).

Fuel price differences are cited by Leach (1992) as another factor determining fuel choice. Where differences are large, the cheaper the fuel, the more the fuel is consumed. Data from Java (Leach, 1992) show that the price of LPG relative to kerosene was the second most important factor after equipment cost for not using LPG. The price per unit of useful energy, after correcting for stove inefficiency is the important price to consider. However, longitudinal data on biomass consumption is very limited to give reasonable estimates of the effect of prices on fuel substitution.

Other variables affecting fuel consumption include demographic conditions such as family size, local cooking practices and broader cultural issues related to preferences and traditions. These, according to Masera and Navia (1997) only come into play once an initial investment in the appliance of a fuel is made.

The preceding discussion shows the energy ladder hypothesis as providing the basis for analyzing energy consumption dynamics in urban areas. Income and physical access to sources of energy are highlighted as the major factors determining movements up and down the ladder. Income determines ability of households to acquire both the technologies to use modern fuels, and to meet energy user costs. Thus the energy ladder hypothesis provides the basis for understanding energy consumption choices made by urban households, with data from several case studies confirming some of the underlying assumptions. While the model can be used to provide a general description of household energy consumption, in its current specification, it cannot be easily used to estimate and analyze actual demand for fuelwood. Also, while it gives an overall true picture of patterns in energy demand, it may not be capable of explaining finer differences on a lower level of aggregation (Kebede *et al*, 2002). The next section highlights the limitations of the energy ladder model with regards to our objectives.

3.3 A critique of the energy ladder model

Household energy use in the urban areas of developing countries is most poorly understood (Hosier and Kipondya, 1993), and this is mainly due to the complexity of the switching process where, according to Masera and Navia (1997), economic aspects are inter-linked with social and cultural issues. As a result of such complexity, the energy ladder model has been rendered insufficient to represent actual energy consumption dynamics e.g. Foster (2000). Whereas economic factors such as incomes and prices suggest that consumption of modern fuels increases with increasing incomes, and that changes in relative prices of fuels influence types and quantities of fuels consumed, social and cultural factors may make consumers behave contrary to these expected patterns. Factors associated with characteristics of the dwelling place, preparation of traditional meals, the gender of the household head, educational levels attained etc are examples of factors that contribute to the complexity. The energy ladder hypothesis provides the basis upon which further understanding of the subject may be built. However, the model, in its current simplified specification, such as equating progression up the ladder with development (Masera *et al*, 2000) provides a limited representation of the fuel switching process. The process, according to Masera *et al* (2000) should be considered as a process resulting from simultaneous interactions of factors pushing households away from biofuels and pulling them back towards biofuel use i.e. a bi-directional process. Factors such as convenience from the use of modern fuels, pride associated with the use of these fuels, social status may push consumers up the ladder while economic factors such as incomes and prices push consumers down the ladder.

The energy ladder model represents energy consumption as a linear process, with a simple progression from traditional to modern and more efficient fuels together with costly stoves as income increases. Even when augmented with the influences of economic and social factors e.g. that by Hosier and Dowd (1987), the model still retains its representation of energy consumption dynamics as a linear progression from inferior fuels to more advanced ones (Masera *et al*, 2000). In reality however, decision making on energy consumption is more complex, involving partial adoption and relinquishment of several fuels at the same time, and this being influenced by a complex set of factors.

It is one of the strongest assumptions of the model that movement of households or societies up the ladder is a result of improving economic circumstances, and the ability to purchase appliances associated with modern fuels, and that in the reverse of these factors, households move down the ladder. It should however be acknowledged that there are different switching curves for moving up and for moving down the ladder. Movement up the ladder is associated with huge financial or capital outlays in acquiring appliances and getting connections to carriers of modern fuels. Movement down the ladder on the other hand simply involves using appliances already possessed and does not therefore represent large expenditures, at least compared to household income, for a household that had gotten to a higher level on the ladder. Similarly, re-movement up the ladder takes a different form from the initial transition upwards in that it may not involve heavy investment in appliances. The different paths followed in going up and down the ladder is not reflected in the energy ladder hypothesis, as the hypothesis assumes the same path is used in going up and in going down.

Whilst the model assumes households to behave in a manner consistent with the neoclassical theory of consumer behavior (Hosier and Dowd, 1987), its deficiency is in its assumption that households move to more sophisticated energy carriers as incomes increase, without being explicit on the status of abandoned fuels. Thus in its formulation, for example in Hosier and Dowd (1987), the model is presented as a problem of discrete fuel choices. A single fuel is assumed to be chosen at a time, while the fuel used before the new one is abandoned. This is contrary to findings by Hosier and Kipondya (1993) in Tanzanian cities, which showed all surveyed households to be using more than one fuel for cooking. This is supported by Masera *et al* (2000) who confirm from Mexican data that it is unusual for families to make a complete fuel switch from one technology to another. Rather, they begin to use an additional technology without completely abandoning the old one. This strategy is often used to maximize fuel security and at the same time receive the advantages of different fuels. Their data from Mexico confirm that households add fuels and stove types, but seldom leave any fuel or stove type behind completely. Specifically, the survey conducted by Masera *et al* (1997b) (in Masera *et al*, 2000) in three Mexican states shows that only 7% of households in two states, and 16% of households in one other state had completely switched to LPG. Even longitudinal data show that of the families adopting LPG technologies, none ceased using firewood (Masera *et al* (2000). Switch-backs to biofuels in the escalation of prices of kerosene in Africa also serve to confirm that fuel switching is not unidirectional.

The energy ladder hypothesis assumes that movement of households up the ladder is based on the premise that households effectively consider some fuels better than others, with biofuels being used only because of income and infrastructure constraints. Contrary to that, households have preferences for fuels for different cooking tasks such that different fuels are used for different cooking tasks concurrently within the same household. For example in Mexico, Masera *et al* (2000) have found that households prefer to eat tortillas prepared using wood fire than those prepared over a gas flame. This further weakens the energy ladder model as a tool that represents household energy choice. Not only do households keep fuels for preferred uses, but they also continue to use other fuels to spread risk associated with the unreliability in the supply of modern fuels like electricity.

In addition, household fuel choices are not only based on economic factors such as incomes and prices, but they are also determined by several household variables such as demographic structure, educational levels, status and ownership of the dwelling place etc. The contribution of these variables to fuel choice are lacking in the specification of the energy ladder model, neither is it easy to incorporate them to predict discrete fuel choices.

Though the energy ladder model has been used to generally understand the energy use dynamics of urban households in the developing world, in its general specification, the model provides a limited view of reality in actual households. It is especially limited in its ability to estimate the actual quantities of different fuels consumed by households. This necessitates the development of a framework that enables us to estimate the demand of fuelwood to meet our objectives. An extension of this hypothesis will provide better insights into household energy use in urban areas of developing countries. This understanding is critical for policies aimed at facilitating sustainable development within the context of the complex linkages between fuelwood use and the environment, health, social and development issues. The next section develops a framework that attempts to overcome these deficiencies. Beginning with the concept of the energy ladder, and inter-fuel substitution, we develop an analytical framework that will be used to understand and estimate the demand for fuelwood in Harare.

3.4 The energy mix model

The gaps prevalent in the energy ladder hypothesis provide a basis for building on it alternative models that describe household energy consumption. In particular, in this study, we develop a model that will serve as a conceptual framework on which theoretical and empirical models of household fuelwood demand will be based. Such a model should lend itself to both theoretical and quantitative application.

The literature confirms the fact that households use multiple fuels e.g. Campbell *et al* (2003), Kebede *et al* (2002), Foster *et al* (2000) and Masera *et al* (2000). The estimation of the demand for one fuel (fuelwood in this case) should therefore be carried out within the context of other fuels consumed by households. The formulation of an analysis framework should capture this reality, and also capture the fact that the use of different fuels is associated with several indicators of socio-economic status such as income household size etc. In the case of income, the wealthier the household, the more likely that the household will use more of modern fuels than traditional fuels. Masera *et al* (2000) propose an alternate "multiple fuel" approach that takes into account economics of fuel and stove type and access conditions to fuels, technical characteristics of cooking practices, cultural preferences and health impacts. Using data from three Mexican states, they show that households do not switch fuels, but rather follow a general multiple fuel or fuel stacking strategy. The specific combination and the relative consumption of each fuel is governed by the characteristics of fuels and end-use devices, fuel availability and local cultural and social contexts. The appeals of the two models (the energy ladder model and the multiple fuel model) provide a basis on which a framework for the analysis of fuelwood consumption in Harare can be based. Such a framework will possess both analytical and predictive prowess to guide demand estimation and policy decisions.

Since urban households purchase most of their energy, the consumption of different sources of energy within a household can be considered in terms of the financial allocations made on each fuel for its purchase. Economic theory postulates that consumers allocate their disposable income amongst different goods to maximize utility (see next chapter). In utility theory, the combination of goods with different prices enables the consumer to attain a specific level of satisfaction. The objective of the consumer is to attain the highest possible level of utility subject to constraints. The main constraint is that the total outlay to all commodities must not exceed the available income. Given the above realities on the consumption patterns by households of different sources of energy, we can employ economic theory to analyze the behavior of the consumer; how the consumer allocates expenditure to different sources of energy.

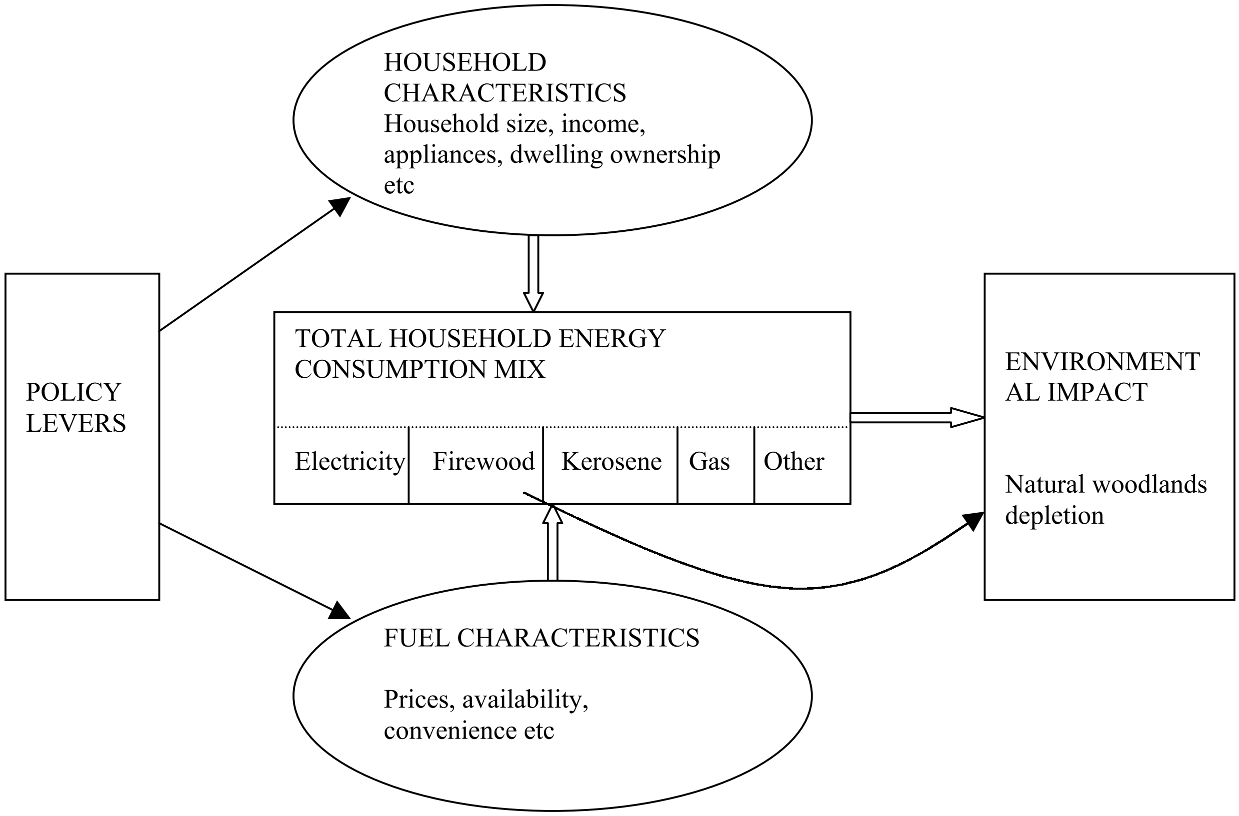
Using the empirical findings of earlier studies that indicate the use of multiple fuels by households, and the postulations of economic theory concerning the allocation of income to several goods to maximize utility, a framework presents itself in terms of urban household energy consumption. To meet their energy requirements with limited incomes, households decide how much of their total income or expenditure to allocate to energy such that their needs are met. In any particular period, households are assumed to choose a set of energy types that they use for household tasks under different circumstances to meet their total energy requirements. For example, a household chooses to use electricity for cooking, and lighting, kerosene for boiling bath water and firewood for heating space and cooking special dishes. Alternatively, electricity may be used for cooking evening meals while firewood is used for preparing day meals. A household may also decide to use different energy types on specified days of the week or month, for example firewood during the weekend etc. These decisions differ from household to household, and are influenced by several factors that have to do with the socio-economic status and cultural background of households. The total cost of this set of energy for any particular period does not exceed total energy outlay. The ultimate decisions that all households make are on how much of its total energy expenditure to allocate to each fuel to achieve maximum satisfaction. Households therefore work out their fuel mixes for specified periods based on these and other factors. This approach is used for example for studying the demand for commodities like food types (Elsner, 2001; Edgerton *et al*, 1996).

When the circumstances pertaining to a household or a particular fuel changes, the household is expected to change its fuel mix. For example, when a household moves to a house without electricity, it changes its fuel mix; when kerosene becomes unavailable, it changes to another combination etc. When the price or cost of using any one of the fuels used by a household change, the combination is also changed to accommodate the price change while maintaining the same level of utility. Different sources of energy are adopted or dropped, increased or reduced in any period when factors pertaining to the household or the fuels themselves change.

In this formulation, the key feature are the types of energy and their levels of consumption in any mix. For any household with defined characteristics such as income and household size, it is possible to analyze its mix of energy sources and determine how much of each fuel it consumes based on its expenditure on it. The formulation provides a way to determine the quantity of fuelwood that a particular household consumes. When this is aggregated over all consumers, the demands that are being made on natural woodlands can be estimated. Similarly, impacts of changes in factors such as prices of other sources of energy on the environment via the demand for fuelwood can also be determined.

Analytically, the framework of the household choice set, the driving forces and the outcomes are represented in the conceptual framework shown below. In this scheme, the total household energy mix is shaped by household characteristics, and factors pertaining to the fuels themselves, which are determined outside the household. Both household and energy factors are assumed to be influenced by a set of policy levers. When a particular energy mix is considered, the environmental impact on woodlands is determined through the amount of firewood in the mix, and the environmental impact is measured, just in this study, by the depletion of natural woodlands. Other impacts such as health and air quality are not particularly addressed in this study.

Fig. 3.3: Conceptual framework of the energy mix model



The framework of the energy mix model presents household energy consumption in terms of combinations of different fuels to make up total energy. In addition to the physical combinations of different fuels, the framework also presents energy consumption in terms of relative expenditures on different fuels. This formulation enables the estimation of demand for both total energy and for individual fuels, fuelwood in particular in our case.

3.4.1 Formal presentation of the energy mix model

We start with overall household consumption of different household goods and services. We assume energy to be a compound commodity, which can be broken into its separate components of the different sources of energy such as kerosene, electricity etc. Households decide how much of their income or total expenditure to allocate to total energy. This total energy expenditure will depend on several factors such as income and other household factors. Further to the allocation of expenditure towards energy, households make decisions on how much of the total energy outlay to allocate to each source of energy in their consumption mix. The allocation of total energy expenditure to individual sources of energy is done in such a way that a household maximizes energy utility given its energy outlay, the prices of the different sources of energy, and other factors.

Past research in Harare has shown that electricity, kerosene and firewood are the principal sources of energy in Harare (Campbell, 2000; Campbell *et al*, 2003). In our framework, we take these three as the only sources of energy that households mix to satisfy their energy needs. This is for analytical purposes only. Other sources of energy used in very limited cases are coal, gas and solar. A household therefore chooses quantities of electricity, firewood and kerosene to use in order to satisfy its total energy requirements. When energy from different sources is measured in a common unit i.e. the mega joule (mj), the household's consumption scenario can be put as:

$$TQE = Q_e + Q_f + Q_k + Q_0$$

Where:

TQE denotes total quantity of energy consumed (in mega joules MJ)

Q_e, Q_f, Q_k and Q_0 denote quantities of electricity, firewood kerosene and others respectively, all measured mj. These can be translated into their respective physical quantities using appropriate conversion factors.

In terms of expenditure, the household scenario is as follows,

$$TEE = E_e + E_f + E_k + E_0$$

Where:

TEE is total energy expenditure by a household,

E_e, E_f, E_k and E_0 are household expenditure on electricity, firewood, kerosene and others respectively.

Total energy expenditure itself is expressed as a share of total household expenditure such that

$$w_{TEE} = \frac{TEE}{TE}$$

where w_{TEE} is the share of total energy expenditure in total household expenditure TE.

The share of each fuel in the expenditure mix is a ratio of its expenditure and total energy expenditure such that for all fuels in the mix, these ratios add up to unity i.e.

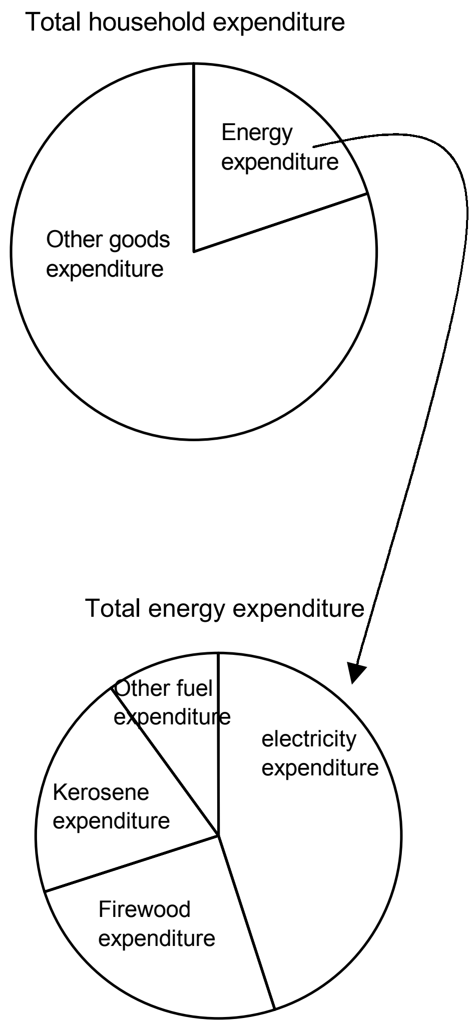
$$\sum w_i = 1$$

where w_i is the share of fuel i, defined as

$$w_i = \frac{E_i}{TEE}$$

The pie chart below shows a diagrammatic representation of the problem. In the first stage, household expenditure is allocated to energy and other commodities (composite). In the second case, energy expenditure is allocated to the different sources of energy in the household's consumption set. This is consistent with the principles of multi-stage budgeting discussed by Deaton and Muellbauer (1980), Edgerton *et al* (1996), Elsner (2001).

Figure 3.4: Schematic representation of the energy mix model in terms of expenditures



This description comprises the basic structure of the energy mix model, whose maim premise is that urban households allocate their total energy expenditures to different fuels available to them in order to maximize utility from energy consumption. Expected consumption levels and changes in the consumption patterns are determined using standard economic and statistical tools.

This model lends itself to quantitative verification from actual household data. It also possesses predictive power through its ability to show how both total energy consumption and consumption of different sources of energy respond to changing household circumstances, such as household income, household size and changes in the availabilities of different sources of energy. Through its predictive abilities, the model can be used to inform policy decisions such as those associated with pricing of alternative sources of energy, subsidies, taxes, macroeconomic variables such as unemployment levels etc.

The energy mix model as specified above has the flexibility that enables us to incorporate the factors that influence household energy consumption behavior as found by Masera *et al* (2000), Masera and Navia (1997) and Hosier and Kipondya (1993). At the same time, the model carries with it the basic attribute of the energy ladder hypothesis without locking households in exclusive energy choices. This means that the model accommodates a household whose energy mix is comprised of say 90% kerosene, 5% electricity and 5% firewood. At the same time, it can be considered as being dominantly consuming kerosene, thus in gross terms, be classified as being at the level of kerosene on the energy ladder, without neglecting the fact that it still contributes towards the consumption of other energy sources. Its total contribution to firewood consumption for example, will depend on the absolute amount of firewood in the mix. Also important in this attribute of the energy mix model is that zero consumption of a fuel can still be considered as consumption, thus the fuel is included in the mix. This is also handy when calculating average consumption levels and mixes for defined localities or cities. This is especially important when longitudinal data is used, in which case at one point, a household may not be consuming a given fuel, yet it may use it later on. In that case, the fuel is still retained in the household's consumption equation.

This model also has the advantage that it enables us to look at energy consumption and expenditures in real terms i.e. the absolute amount consumed, instead of just the position of a household on a ladder. This makes quantitative analyses of consumption of fuels with different units possible. This is especially important in estimating the current demand for fuelwood in cities such as Harare where the majority of residents use electricity. Earlier approaches using or referring to the energy ladder approach consider such cities and their households to be on the electricity stage of the ladder, thus the threat of fuelwood consumption on the environment in such cases is downplayed, even when consumption of fuelwood increases e.g. Campbell *et al* (2000).

This framework however allows fuelwood consumed even among electrified households to be taken into account as it contributes to total demand. It also allows us to estimate how this consumption will change if conditions assumed to be prevailing with respect to the circumstances of household change from initial assumptions.

This section has presented an energy mix model as a framework for the analysis of fuelwood demand in urban areas, which takes into account the consumption of other sources of energy used by urban households. This model, when verified by data, will incorporate the attributes of both the energy ladder hypothesis and the inter-fuel substitution concept. Moreso, weaknesses in these earlier approaches to the understanding of urban energy consumption are addressed without rendering these approaches irrelevant. This study adopts the energy mix model as the framework on which to estimate and analyze the demand for fuelwood in Harare, taking into account other fuels consumed by households.

3.5 Conclusion

Household fuelwood demand has its basis in households' quest to meet their basic livelihood requirements through energy consumption, together with other commodities. We have considered the general framework in which fuelwood consumption takes place as far as urban areas of developing countries are concerned. This chapter has taken urban fuelwood consumption within the framework of general energy consumption in urban areas. From earlier approaches that have been used to study fuelwood and energy consumption, this chapter has developed an approach in which fuelwood is part of a household energy mix, with other sources of energy being considered simultaneously with fuelwood in household consumption decisions. The conceptual framework works as a basis for the theory to be developed in the next chapter, together with the empirical specification of the theoretical models. Therefore this chapter acts as a bridge between the general understandings of urban fuelwood consumption and its impact on the environment, and the specific methodology used to estimate such demand.

CHAPTER 4

THEORETICAL BASIS OF THE EMPIRICAL DEMAND MODEL

4.1 Introduction

This chapter provides the theoretical framework on which to base the empirical analysis of fuelwood consumption in urban areas. The overall objective being to study urban fuelwood consumption as one of the factors contributing to woodland depletion, we single urban household consumers and provide a basis for making inferences about their behavior. While most studies on urban energy issues are based on market data, the driving force is the demand for energy by households in urban areas whose socioeconomic circumstances determine both their consumption choices on the specific types of fuels to use and the respective quantities of those fuels. The theory should be able to capture the complexities associated with the households' choice set and those associated with their very nature and circumstances.

The demand for fuelwood in the urban areas of Zimbabwe is based on the market concept, in which most of the wood consumed by households is purchased on the market. It is therefore assumed that consumers are players on the market, exerting demand for the commodity. A formal investigation of the demand and factors affecting such demand therefore requires the guidance of the theory pertaining to the players i.e. the consumers. The theory of consumer demand is the underlying one in the empirical investigations. To study and model urban fuelwood consumption, general principles need to be established to guide predictions that will be made from the models. With the aim being to establish the contribution of fuelwood to total urban energy consumption, and to be able to predict how consumption of fuelwood responds to changes in the consumer's environment, we study the behavior of consumers. The purpose of this chapter is to develop an understanding of consumer behavior with respect to fuel wood consumption in particular, and energy demand in general. In order to arrive at rational energy planning and policy formulation that ensures their adoption, efforts have to be made to understand the energy use behavior at micro and macro levels (Rijal, Bansal and Grover, 1990). First, in section

4.2, we present demand theory, built on the concept of consumer preferences. This works as a general framework that supports the specific demand model that will be used in the empirical analysis. This is followed by a description of the household budgeting process in the context of the theory, specifically the concept of multi-stage budgeting. The model to which the theory is applied is presented in section 4.4. This is the concept of demand systems, whose presentation follows the general theory. From an array of alternative forms of demand systems, we then focus on the Almost Ideal Demand Systems, whose derivation from the general theory of consumer demand is presented in the section discussing the systems of demand. We finally discuss the incorporation of other household characteristics in the demand model before concluding the chapter in section 4.6.

4.2 Theory of consumer demand

4.2.1 Specification of the theory

The primary objective of consumer theory is to describe the factors that determine the amounts spent by the consumer on available goods and services, and to determine the factors that influence these decisions (Theil, 1975). The starting point is to consider consumer preferences (Deaton and Muellbauer, 1980 and Theil, 1975), on which, together with consumer possibilities, consumer behavior is built. In classical consumption theory, a consumer is assumed to have a stable preference system which can be described by means of a utility function (Theil, 1975). Varian (1984) develops the theory of the consumer by deriving demand functions based on a model of preferences i.e. maximizing behavior coupled with a description of the underlying economic constraints. The basic hypothesis about consumer behavior according to Varian (1984) is that a rational consumer will always choose a most preferred bundle from a set of feasible alternatives. This is the hypothesis that we adopt i.e. utility maximization. Consumer behavior is commonly presented in terms of preferences on one hand, and possibilities on the other. Preferences provide the justification for the existence of demand functions (Deaton and Muellbauer, 1980b).

Consider a consumer faced with possible consumption bundles in some set Q. The consumer is assumed to have preferences on the consumption bundles in Q (Varian, 1984) i.e. the consumer can rank them as to their desirability (Varian, 1987). We assume that for the preference system to order the bundle q in Q, the consumer has a set of axioms that guide such ordering. These are reflexivity, completeness, transitivity, continuity, no satiation and convexity (Deaton and Muellbauer, 1980b; Varian, 1984; Varian, 1987). We briefly describe the implications of these axioms on consumer preference ordering.

- Reflexivity assumes that each bundle is as good as itself i.e. for any bundle q, $q \succsim q$.

  The symbol $\succsim$ is used to mean at least as good as.
- Completeness says any two bundles can be compared such that for all q^1 and q^2 in Q, either $q^1 \succsim q^2$ or $q^2 \succsim q^1$.
- Transitivity ensures the consistency of preference orderings by saying that if q^1 is preferred to q^2 and q^2 is preferred to q^3, then q^1 is preferred to q^3 i.e.

  If $q^1 \succsim q^2$ and $q^2 \succsim q^3$ then $q^1 \succsim q3$

According to Deaton and Muellbauer (1980b), this axiom is at the center of consumer theory and choice, and has the greatest empirical content of the axioms responsible for the existence of preferences.

- Continuity rules out any discontinuous behavior by saying that for any bundle q^1, the set $A(q^1)$ and the set $B(q^1)$ are defined by:

  $$A(q^1) = \{q \mid q \succsim q^1\},\ B(q^1) = \{q \mid q^1 \succsim q\}$$

  i.e. the set $A(q^1)$ is at least as good as q^1 and the set $B(q^1)$ is no better than q^1. Therefore $A(q^1)$ and $B(q^1)$ are closed. They contain their own boundaries for any q^1 in the choice set (Varian, 1984; Deaton and Muellbauer, 1980b).
- Non satiation says that one can always do with a little bit more, even if one is restricted to only small changes in the consumption bundle (Varian, 1984). Under

this axiom, the utility function $v(q)$ is non-decreasing in each of its arguments, and the choice set is increasing in at least one of its arguments.

- Convexity simply implies that an agent prefers averages to extremes, or that indifference curves are convex to the origin i.e.

  If $q^1 \succsim q^0$, then for If $0 \leq \lambda \leq 1$, If $\lambda q^1 + (1-\lambda)q^0 \succsim q^0$

If preferences are complete, reflexive, transitive, continuous and convex, then according to Varian (1984), there exists a continuous utility function which represents these preferences. This proposition takes us to the next stage of the development of consumer demand theory, that of utility. Since the first four axioms are sufficient to allow the representation of preference orderings by a utility function $v(q)$ (Deaton and Muellbauer, 1980b), addition of non-satiation completes the transition from axioms to utility. Thus the consumer's choice problem is reduced to that of constrained utility maximization, which is the next step in our derivation of consumer demand functions.

The consumer behaves as if he maximizes a utility function $u(q) = u(q_1 ... q_n)$ from the consumption of commodities $q_1 ... q_n$ (Theil, 1975). The maximization model requires the consumer to choose values of $q_1 ... q_n$ that satisfy the budget constraint and also gives larger values of $u(q_1 ... q_n)$ than any other values of $q_1 ... q_n$ within the consumption possibilities of the consumer.

The limits of the consumer are imposed by a budget constraint, which specifies the outlay or total expenditure x, which is to be spent within a given period on some or all of the commodities (Theil, 1975). When $p_1 ... p_n$ are the prices of the n commodities, the budget constraint is put as

$$x = \sum_{i=1}^{n} p_i q_i$$

i.e. the sum of the products of prices and quantities must be at most equal to the total expenditure x.

In the next step, we combine the reality of the budget constraint and the theory of preferences which, through the axioms discussed above, culminated in the theory of utility. The problem reduces to the standard utility maximization problem stated by Varian (1984) and Deaton and Muellbauer (1980) as

$$\text{Max } v(q)$$

$$\text{Subject to } \sum p_k q_k = x$$

q is expressed as a function of prices and expenditure to give the demand functions

$$q_1 = q_1(x, p_1 \ldots p_n)$$
$$\vdots$$
$$q_n = q_n(x, p_1 \ldots p_n$$

This, by Theil (1975) reduces to:

$$q_i = g_i(x, p)$$

which is a system of Marshallian demand functions in which utility from the consumption of q is maximized subject to expenditure and prices. The consumer has rules for deciding how much of each good to purchase faced with given prices and total outlay. In the demand equations of the form $q_i = f_i(y, p)$, where income is taken as given, the theory to be developed is an allocation theory (Theil, 1975), which is concerned with the way in which total expenditure is allocated to the available commodities, given their prices and the level of total expenditure. The specification and estimation of such demand systems, according to Theil (1975) is done on the basis of a set of assumptions. First, all variables (prices, quantities, expenditures) can be varied continuously. Second, the solution of q in any price-income region is unique, and has strictly positive values. Third, the utility function has continuous derivatives up to the third order, and the first order derivatives are all positive.

The basic features of the utility maximization problem are as follows (Varian, 1984):

- There will always be a utility maximizing bundle as long as prices and income are positive i.e. $g(x, p)$ is continuous at all $p >> 0$ (prices are strictly greater than zero) and $x > 0$.
- The optimal choice is independent of the choice of the utility function used to represent the preferences.

- The optimal choice is homogenous of degree zero in prices and income i.e. multiplying all prices and income by the same positive constant will not change the budget set, thus will not change the optimal choice.

We have just developed the consumer's problem as that of maximizing utility subject to a budget constraint, the solution of which results in some utility level u. This arrives at the optimal consumption bundle by allocating the available expenditure.

Deaton and Muellbauer (1980) introduce the dual problem, which uses Hicksian or compensated demand functions, and which, instead of using utility maximization, uses cost minimization to maintain the same level of utility when prices change. While the original problem is stated as:

Maximize $u = v(q)$

Subject to $p.q = x$,

the dual problem is stated as:

Minimize $x = p.q$

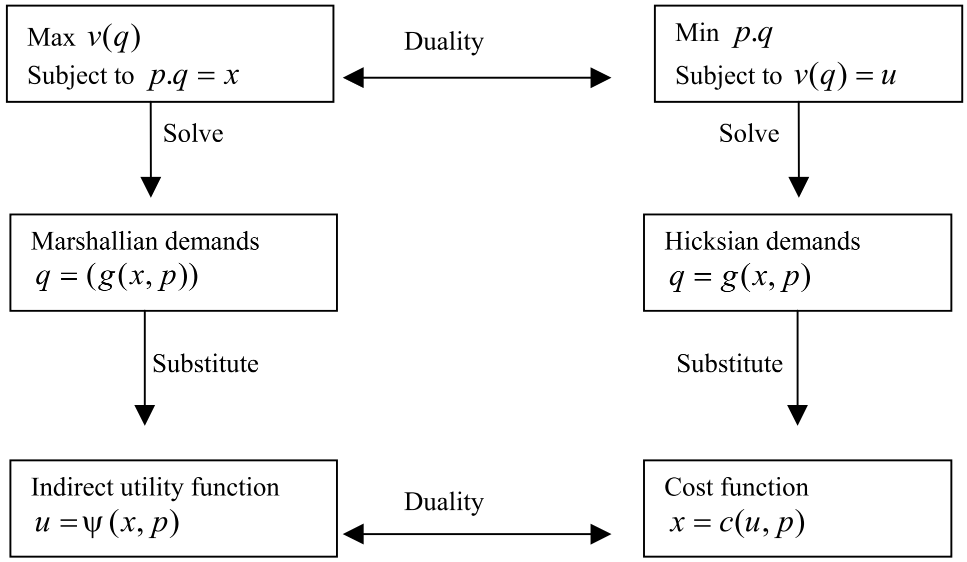
Subject to $v(q) = u$

The Marshallian demands $(g(x, p))$ of the original problem coincide with the Hicksian demands ($h(u, p)$) of the dual problem such that:

$$q_i = g_i(x, p) = h_i(u, p)$$

The relationship between the utility maximization and cost minimization problems are summarized by Deaton and Muellbauer (1980a) as follows:

Figure 4.1: Utility maximization and cost minimization



Source: Deaton and Muellbauer (1980a)

The properties of the cost minimization function are given by Deaton and Muellbauer (1980a) as follows:

1. The cost function is homogenous of degree one in prices i.e. if prices double, twice as much outlay is required to stay on the same indifference curve.
2. The cost function is increasing in u, non-decreasing in p, and increasing in at least one price.
3. The cost function is concave in prices i.e. as prices rise, cost rises no more linearly because the consumer minimizes costs, rearranging purchases to take advantage of changes in the structure of prices.
4. The cost function is continuous in p, and the first and second derivatives with respect to p exist everywhere except possibly at a set of specific price vectors.
5. Where they exist, partial derivatives of the cost function with respect to prices are the Hicksian demand functions i.e. $\frac{\partial c(u, p)}{\partial p_i} \equiv h_i(u, p) = q_i$. This allows us to move back from any known cost function to the cost-minimizing demands that underlie it.

4.2.2 Theoretical postulations

The postulations of the theory guide the predictions that the theory is used to make i.e. the expected responses of q to changes in x and p. Consumer choices of goods between alternatives, within given budget constraints, are guided by preferences. Preferences determine the quantities or shares of each commodity in a given outlay.

Income elasticity e_i, which measures the effect of variation in income on the quantities bought when prices are fixed, is formally defined by Theil (1975) as:

$$e_i = \frac{\partial(\log q_{i})}{\partial(\log x)} = \frac{\partial q_i x}{\partial x q_i}$$

If prices are absorbed into the functional form, and if other household characteristics are set aside, $q_i = f(x, p)$ becomes $q_i = f^*(y)$, referred to as the Engel curve (Deaton and Muellbauer, 1980). Engel curves are used to classify goods into the categories luxuries, necessities and inferior goods. This classification is then used to predict how demands for them change as income changes. Luxuries are the goods that take up a larger share of the budget of better-off households. The opposite is true for necessities, which take up larger shares of low-income households. The respective income elasticities e_i of luxuries and necessities are given by Theil (1975) and Deaton and Muellbauer (1980):

e_i>1 and e_i<1.

Inferior goods are those goods the purchases of which decline absolutely (not just proportionately) as income increases i.e. e_i< 0.

The weighted average of income elasticities is equal to unity such that $\sum_{i=1}^{n} p \frac{\partial q_i}{\partial x} = 1$, and with the corresponding budget shares $\left(w_i = \frac{p_i q_i}{x} \right)$ as weights, is also equal to 1 (Theil, 1975). This is as shown by $\sum w_i \frac{\partial(\log q_i)}{\partial(\log x)} = 1$.

When income increases, the shares of luxuries go up and those of necessities go down. An increase in real income reduces the demand for inferior goods ($\partial q_i / \partial x < 0$) (Theil, 1975).

The effect of changes in prices is given by the derivative $\partial q_i / \partial p$ of the demand function. But as can be realized, prices of other commodities also affect the demand for one commodity, such that this needs to be developed further. This is dealt with by the use of the cost function (Hicksian demands).

The effect of prices changes are given by the Slutsky equation (Varian, 1984), which decomposes the demand change due to a price change into an income effect and a substitution effect (Varian, 1984; Deaton and Muellbauer, 1980). The Slutsky equation says that when price p_i changes, the change is equal to the change in demand while holding expenditure fixed, plus the change in demand when income changes times how much income has to change to keep utility constant. Thus a price change results in an income effect and a substitution effect. The Slutsky equation is formulated as:

$$\frac{\partial q_j(p,x)}{\partial p_i} = \frac{\partial h_j(p,v(p,x))}{\partial p_i} - \frac{\partial q_j(p,x)}{\partial x} \cdot q_i$$

In reality, prices of different commodities within a given bundle change simultaneously, and this is also provided for in the Slutsky formulation which in the two-good case, would, from Varian (1984), look like:

$$\begin{bmatrix} \frac{\partial q_1(p,x)}{\partial p_1} & \frac{\partial q_1(p,x)}{\partial p_2} \\ \frac{\partial q_2(p,x)}{\partial p_1} & \frac{\partial q_2(p,x)}{p_2} \end{bmatrix} = \begin{bmatrix} \frac{\partial h_1(p,u)}{\partial p_1} & \frac{\partial h_1(p,u)}{\partial p_2} \\ \frac{\partial h_2(p,u)}{\partial p_1} & \frac{\partial h_2(p,u)}{\partial p_2} \end{bmatrix} - \begin{bmatrix} \frac{\partial q_1(p,x)}{\partial x} q_1 & \frac{\partial q_1(p,x)}{\partial y} q_2 \\ \frac{\partial q_2(p,x)}{\partial x} q_1 & \frac{\partial q_2(p,x)}{\partial x} q_2 \end{bmatrix}$$

The observation brought about by this theory is that a change in the price of a commodity has two effects. One commodity will become more or less expensive than the other, and total purchasing power changes.

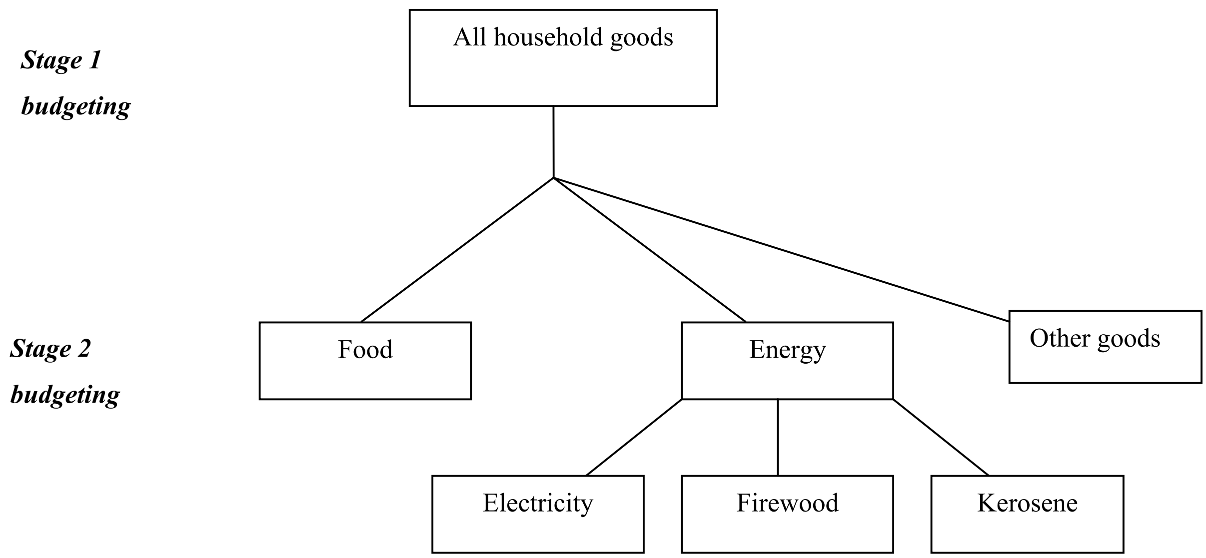
This section has presented the theory of consumer demand, and the properties of demand that a specific demand estimation model should possess. It has also discussed how the theory provides for investigating the effects of incomes and prices on consumption choices. The extension of the theory to carter for the specific case of the household energy mix model is outlined in the next section.

4.3 Household budgeting process

In this section, we present an extension of the theory to fit the context within which household energy demand is modeled. The conceptual framework developed in the previous chapter is matched by the theory thereby providing a basis for specifying the empirical models to be estimated. The energy mix model that forms the conceptual basis of this study takes energy as one of the household consumption goods and break it into the individual fuels. Households chose how much of their energy budgets to allocate to each fuel. Therefore households implement a two-stage budgeting process. They first decide how much of their total incomes to allocate to energy among other consumption goods. At the second stage, they decide how much of their total energy budgets to allocate to individual fuels. These decisions are made in accordance with the theory of consumer demand just presented, as described below. The demand for fuelwood is therefore considered in a system that includes other sources of energy.

The two stage budgeting process described above is consistent with the concepts of separability of preferences and multi-stage budgeting (Szulc, 2001; Elsner, 2001; and Deaton and Muellbauer, 1980b). Separability partitions commodities into groups such that preferences within groups can be described independently of quantities in other groups (Deaton and Muellbauer, 1980; Edgerton *et al*, 1996). Examples of commodity groups are food (made up of milk, bread, meat, rice, sadza etc), energy (made up of individual fuels such as electricity, gas, kerosene, firewood etc). The consumers can then rank different commodity bundles within one group in a well-defined ordering that is independent from other groups. This implies a multi-stage budgeting process, in which expenditures allocated to broad groups of commodities are sub-allocated to specific commodities in subsequent stages. The sub-utilities from consuming individual commodities in a group, according to Deaton and Muellbauer (1980a), can be aggregated to give total utility for the group. The same principle of a two-stage budgeting process is also followed in the estimations, with household decisions on allocating their expenditures to groups of commodities, energy being one, are estimated first, followed by estimations of the allocation of the energy budget to specific fuels. This is represented by a utility tree in figure 4.2.

Figure 4.2: Utility tree and multi-stage budgeting



Adapted from Deaton and Muellbauer (1980a)

The utility tree presented above depicts both separability and multi-stage budgeting. When energy is taken as a group, the consumer can rank different energy choices in a well defined ordering that is independent of his or her consumption of food and other goods outside energy.

The implication of the multi-stage budgeting process is that decisions made at each stage can be regarded as corresponding to a utility maximization problem of its own. Different fuels or foods are chosen so as to maximize an energy or food sub-utility function subject to an energy or food budget constraint. For separable groups energy, food and other goods for instance, the utility function, according to Deaton and Muellbauer (1980a) is written as:

$$u = v(q_1, q_2, q_3, q_4, q_5, q_6) = f[v_E(q_1, q_2), v_F(q_3, q_4), v_O(q_5 q_6)]$$

where $f()$ is some increasing function and v_E, v_F and v_O are sub-utility functions associated with energy, food and other goods respectively. This study focuses on maximization of the energy utility function v_E.

The concepts of separability of preferences and multi-stage budgeting have been shown by Deaton and Muellbauer (1980a) to be consistent with the theory of demand, and we use them in specifying the empirical model in the next chapter. In the next section, we discuss the actual demand model that underpins the empirical analyses. The fact that households make decisions about the consumption of energy in a system of different fuels suggests the use of systems of demands, which we discuss next. We specifically narrow down to the almost ideal demand system.

4.4 Systems of demand

Before the 1954 monograph by Stone titled "Measurement of Consumers' Expenditure and Behavior," commodity demands were commonly modeled individually for each good, equation by equation (Deaton and Muellbauer, 1980a). This had the advantage of flexibility as the functional form can be varied and special explanatory variables included. This approach is only suitable for modeling of individual commodities in isolation. According to Deaton and Muellbauer (1980a), it also suffers from the fact that theory plays only a minor role i.e. only the homogeneity restriction has any immediate consequence for a single equation. The estimation of demand for several goods in a system makes the theory more directly relevant. The properties of demands discussed earlier can be applied. In this section, we give a general discussion of systems of demands before we specifically focus on the almost ideal demand systems, a type of systems of demands.

4.4.1 General properties of systems of demands

There are two approaches that are generally used for the estimation of demand equations (Thomas, 1987). One involves the estimation of the demand for a single commodity or commodity group, and the other involves the simultaneous estimation of complete systems of demand equations. While the former pays great attention to any special characteristics of the single market involved, the latter, developed almost entirely since the 1960s, includes the equations for almost every commodity group purchased by consumers (Thomas, 1987). The use of systems of demand equations has been advanced by several authors, including Deaton and Muellbauer (1980b), Deaton and Muellbauer (1980b), Berck, Hess and Smith (1997), Muellbauer (1974). Their work has mainly culminated in the derivation and application of the Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980b; Berck *et al*, 1997), which offers flexibility in the estimation of demand for groups of commodities.

The appeal of complete systems of demand is in both their theoretical and practical characteristics. By incorporating prices of all goods as explanatory variables in each equation in the system, and being subject to the restrictions imposed by consumer theory, complete systems have a sound theoretical base (Thomas, 1987). Thomas has also concluded that the estimation of a complete system of demand equations in principle provides better estimates of each equation in the system than approaching each single equation in isolation. Berck *et al* (1997) mentions the flexibility of systems of demand equations, and proved the flexibility of a Linear Approximate Almost Ideal Demand System (LA/AIDS). An example of the earlier application of systems of equations is that by Deaton and Muellbauer using British data for groups of non-durable commodities (Thomas, 1987). More recently, Elsner (2001), Sheng (1997) and Brosig and Hartmann (2001) used demand systems to analyze food consumption in Russia and in Central and Eastern Europe using household data.

Complete systems of demand consist of a set of demand functions for goods or categories of goods, describing the allocation of the entire budget on them (Elsner, 2001). They are embedded in a theoretically consistent framework as they are derived from stringently applying the microeconomic theory of consumer behavior to the multi-good case i.e. utility maximizing behavior. Demand functions derived from neoclassical theory have the properties that characterize the Hicksian and Marshallian demand functions, and for systems of demand functions to be theoretically consistent, they should possess these properties. These are adding up, symmetry, homogeneity, and negativity (Deaton and Muellbauer, 1980b). We briefly discuss them here before we apply them to the specific form of the system of demand that we discuss later.

Adding up

The total value of both Hicksian and Marshallian demands is total expenditure , shown as:

$$\sum p_k h_k(u,p) = \sum p_k g_k(x,p) = x$$

It results from the assumption of a rational consumer i.e. a rational consumer spends his or her entire budget to maximize utility.

Homogeneity

This property implies that the Marshallian demand functions are homogenous of degree zero in prices and income (Deaton and Muellbauer, 1980b). This means that if all prices and income are multiplied by a scalar θ , quantity demanded or level of utility remain the same i.e.

$$g_i(\theta x, \theta p) = g_i(x,p)$$

Elsner (2001) presents homogeneity in elasticity form by applying the Euler theorem on Marshallian demand functions such that the sum of uncompensated price elasticities and of the income elasticity equals zero i.e.

$$\sum_{i=1}^{n} e_{ij} + e_x = 0$$

where e is elasticity.

Symmetry

Symmetry follows from the assumption that any cost function is continuously differentiable (Deaton and Muellbauer, 1980a), and also from Young's theorem (Elsner, 2001). This states that the order of differentiating a function that is continuously differentiable with respect to two of its arguments does not change the value of its derivatives. The property of symmetry then says that the cross-price derivatives of the Hicksian demands are symmetric i.e. for all $i \neq j$,

$$\frac{\partial h_i(u,p)}{\partial p_j} = \frac{\partial h_j(u,p)}{\partial p_i}$$

Negativity

The n-by-n matrix formed by the elements $\partial h_i / \partial p_i$ is negative semidefinite such that for any n vector ξ, the quadratic form

$$\sum_i \sum_j \xi_i \xi_j \, \partial h_i / \partial p_i \leq 0$$ (Deaton and Muellbauer, 1980b).

A necessary condition, according to Elsner (2001) for negativity is that all diagonal elements of the substitution matrix are non-positive i.e. $s_{ii} \leq 0$. An increase in the price of one good causes demand for that good to decrease or remain constant if the income effect is compensated.

There are different forms of systems of demand equations, including earlier forms such as the Linear Expenditure System (Deaton and Muellbauer, 1980b; Thomas, 1987; Pollak and Wales, 1992), the Rotterdam Model, first developed by Henri Theil in 1965 and A.P. Barten in 1966 (Deaton and Muellbauer, 1980b), the Indirect Addlog Model of Houthakker in 1960, and other flexible functional forms (Thomas 1987).The Almost Ideal Demand System (AIDS) is the latest form of the systems of demand models. The analyses in this study are based on the AIDS, whose derivation follows.

4.4.2 The Almost Ideal Demand System

The Almost Ideal Demand System (AIDS) model was first developed by Deaton and Muellbauer (1980a), based on earlier models of systems of demand equations, which have their roots in the model that was first developed by Richard Stone in 1954. The AIDS model gives an arbitrary first-order approximation to any demand system (Deaton and Muellbauer, 1980b; Thomas, 1987). The appeal of the AIDS model is based on the fact that it satisfies the axioms of choice perfectly; it aggregates perfectly over consumers without invoking parallel linear Engel curves; it has a functional form which is consistent with known household budget data; it is simple to estimate, avoiding the need for non-linear estimation; and it can be used to test the restrictions of homogeneity and symmetry through linear restrictions on fixed parameters (Deaton and Muellbauer, 1980b). Aggregation associated with the AIDS model means that we can relate representative expenditure to mean expenditure (Thomas, 1987) i.e. the representation of market and demand as if they were the outcome of decisions by a rational representative consumer (Deaton and Muellbauer, 1980a). When comparing different forms of systems of demands, Elsner (2001) also found the AIDS to be superior on the properties just presented. Although may of these properties are contained in the other systems of demands such as the Rotterdam and translog models, neither possesses all of them simultaneously, making the AIDS more superior.

4.4.2.1 AIDS Specification

AIDS demand functions are derived from a flexible function that approximates the true underlying function and is consistent with utility maximizing behavior (Elsner, 2001). They are derived from the estimation of Engel curves of the form

$$w_i = \alpha_i + \beta_i \log x \qquad (1)$$

using the model proposed by Working and Lesser (Deaton and Muellbauer, 1980a). This model relates value shares to the logarithm of expenditure. This general Engel curves model is extended to include the effects of prices which gives the AIDS system. In their derivation of the AIDS model, Deaton and Muellbauer (1980b) start from a specific class of preferences, the PIGLOG (price independent generalized logarithm) class. The PIGLOG permits exact aggregation over consumers i.e. representation of market demands as if they were the outcome of decisions by a rational consumer (Deaton and Muellbauer, 1980b; Thomas, 1987). PIGLOG preferences are represented via the cost function or expenditure function which defines the minimum expenditure necessary to attain a specific utility level at given prices.

The base cost function from which the AIDS is derived is the cost function Elsner (2001):

$$c(u, p) = e^{a(p)+ub(p)} \qquad (2)$$

This translates into the logarithmic form

$$\log c(u, p) = a(p) + ub(p) \qquad (3)$$

for utility u and price vector p. According to Deaton and Muellbauer (1980a), u lies between 0 and 1 where 0 is subsistence and 1 is bliss, with some exceptions. Thus the positive linearly homogenous functions $a(p)$ and $b(p)$ can be regarded as the costs of subsistence and bliss respectively. We specify a and b as:

$$a(p) = \alpha_0 + \sum_k \alpha_k \log p_k + \frac{1}{2}\sum_k \sum_j \gamma^*_{kj} \log p_k \log p_j \qquad (4)$$

$$b(p) = \beta_0 \prod_k p_k^{\beta_k} \qquad (5)$$

α, β and γ^* are parameters.

The AIDS cost function $\log c(u, p)$ can now be written as

$$\log c(u, p) = \alpha_0 + \sum_k \alpha_k \log p_k + \frac{1}{2}\sum_k \sum_j \gamma^*_{kj} \log p_k \log p_j + u\beta_0 \prod_k p_k^{\beta_k} \qquad (6)$$

α_i, β_i and γ^*_{ij} are parameters (Deaton and Muellbauer, 1980a).

The demand functions are derived from (6) above. We use the fundamental property of the cost function which states that its derivatives are the quantities demanded i.e.

$$\frac{\partial c(u, p)}{\partial p_i} = q_i$$

multiplying both sides by $\frac{p_i}{c(u, p)}$ yields

$$\frac{\partial \log c(u, p)}{\partial \log p_i} = \frac{p_i q_i}{c(u, p)} = w_i \qquad (7)$$

where w_i is the budget share of good i

Consequently, the logarithmic differentiation of (6) yields the budget share as a function of prices and utility i.e.

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i u \beta_0 \prod_k p_k^{\beta_k} \qquad (8)$$

For any two goods i and j:

$$\gamma_{ij} = \frac{1}{2}\left(\gamma^*_{ij} + \gamma^*_{ji}\right) = \gamma_{ji} \qquad (9)$$

Under the assumption of a utility maximizing consumer, total expenditure x is equal to $c(u, p)$. This cost function can be inverted to give utility as a function of prices p and expenditure x (Elsner, 2001) i.e. the indirect utility function. If this is done for (6), and the result substituted into (8), we have the Marshallian demand functions in budget share form (shares as a function of p and x):

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log\left(x/P\right) \qquad (10)$$

These are the AIDS demand functions in budget share form, with P being a price index. Deaton and Muellbauer (1980a) and Berck *et al* (1997) define P as:

$$\log P = \alpha_0 + \sum_k \alpha_k \log p_k + \frac{1}{2}\sum_j \sum_k \gamma_{kj} \log p_k \log p_j \qquad (11)$$

The restrictions adding-up, homogeneity and symmetry which apply to (6) and (9) are also implied on the parameters of the AIDS equation (Deaton and Muellbauer, 1980a). These are defined by Deaton and Muellbauer (1980a; Deaton and Muellbauer, 1980b) as:
Adding up requires that for all j,

$$\sum_{i=1}^{n} \alpha_i = 1,\ \sum_{i=1}^{n} \beta_i = 0,\ \sum_{i=1}^{n} \gamma_i = 0 \qquad (12)$$

Homogeneity is satisfied if and only if, for all i,

$$\sum_i \gamma_{ij} = 0$$

Symmetry requires that, (13)

$$\gamma_{ij} = \gamma_{ji} \qquad (14)$$

If these restrictions hold, according to Deaton and Muellbauer (1980), (10) represents a system of demand functions which add up to total expenditure $\left(\sum w_i = 1\right)$, are homogenous of degree zero in prices and total expenditure taken together, and which satisfy Slutsky symmetry.

Clearly, and according to Deaton and Muellbauer (1980b), conditions (12) to (14) are all implied by utility maximization.

For cross-sectional data, where prices can be regarded as constant, the AIDS equation above reduces to

$$w_i = \alpha_{0i} + \alpha_{1i} \log(x)$$

Where α_{0i} and α_{1i} are functions of constant prices (Thomas, 1987).

From an econometric point of view, $w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log(x / P)$ is very close to being linear. Apart from the expression in P, which involves the parameters, it can be estimated equation by equation using ordinary least squares (Deaton and Muellbauer, 1980b). The parameters are interpreted as follows:

The parameters β determine whether goods are luxuries or necessities. For example (Deaton and Muellbauer, 1980b),

when $\beta_i > 0$, w_i increases with x, thus i is a luxury.

When $\beta_i < 0$, i is a necessity

The γ_{ij} parameters measure the change in the i^{th} budget share following a unit proportional change in p_j with (x/P) held constant.

At any given point, Hicksian demand equals ordinary or uncompensated (Marshallian) demand, and the following own price, cross-price and income elasticities can be derived (Berck *et al*, 1997).

$$\varepsilon_{ii} = -1 + \frac{\gamma_{ii}}{w_i} - \beta_i \tag{15}$$

$$\varepsilon_{ij} = \frac{\gamma_{ij}}{w_i} - \frac{\beta_i w_j}{w_i} \tag{16}$$

$$\varepsilon_{iy} = \beta_i + 1 \tag{17}$$

Elsner (2001) and Deaton and Muellbauer (1980a) interpret the AIDS as:

- In the absence of changes in real prices and real expenditure $\left(x/P \right)$, the budget shares are constant.
- At a given level of expenditure, if the price of j increases by 1%, the budget share of i increases by $100\gamma_{ij}$.

- The effects of real expenditure work through the β_i coefficients. These add to zero. They are positive for luxuries and negative for necessities.

This interpretation of the AIDS makes it a useful tool in the analysis of household energy consumption given the fact that both household expenditures and the prices of alternative sources of energy influence the share of any one source of energy in the energy mix.

Deaton and Muellbauer (1980b) justify the claims that the AIDS model is more superior to other demand systems. These include flexibility of its functional form, aggregation over households, ease of estimation and compatibility with budget studies. Specific to this study, the PIGLOG Engel curve property inherent in the AIDS model is recommended by Leser (1963, 1973) in Deaton and Muellbauer (1980b) as providing an excellent fit to cross-sectional data. This property is convenient in our case of energy demand in a developing country where there are severe time series data limitations. Cross-sectional data can be used to estimate demand. The property also enables us to incorporate other household characteristics, in addition to income and prices, that influence household demand in a cross section.

4.4 Incorporation of other household characteristics

While in the traditional neoclassical theory of the consumer prices and income (expenditure) are the main demand variables, demand is not only explained by prices and income which use historical data on consumption, prices and budget allocations. Demand analysis is also concerned with the behavioral differences between households in cross-section (Deaton and Muellbauer, 1980; Elsner, 2001). Therefore, we note that demand is multivariate, being determined by many factors simultaneously (Koutsoyannis, 1979). Even in energy consumption, the case under study, it is noted by Nesbakken (1999) that there is a lot of individual variations among households. In cross-sectional studies, we seek to understand differences in demand due to different prices, total expenditure and in household characteristics of interest e.g. household size, family composition. In this study, we seek to incorporate other household characteristics as determinants of demand.

Elsner (2001) notes two methods of investigating the effect of household characteristics on demand. These are the indirect and the direct approaches. The indirect approach investigates different sub-groups of households with similar characteristics. A separate analysis is carried out for each group of households that share the same value of the characteristic in question. The functional form incorporates only prices and income, without other household characteristics. In the direct approach, household characteristics are explicitly included into the functional form. An example of the inclusion of household characteristics into the demand function is the use of equivalence scales by Deaton and Muellbauer (1980) to investigate the effect of household composition on demand. However, this works only as far as the introduction of one household characteristic is concerned. In practice, several household characteristics need to be considered in the analysis. While very little theoretical work exists on this subject, household characteristics will be justifiably included in the empirical model. The few studies that discuss household characteristics in demand analyses such as e.g. Szulc (2001) and Deaton and Muellbauer (1980b) only include demographic characteristics such as household composition. In this study, we incorporate several household characteristics into the functional form so as to capture the several factors that affect energy demand. The incorporation of specific variables is presented in the next chapter.

4.6 Conclusion

The objectives of this study bind us to use a theoretical framework that establishes consumer decision-making, which underlies the decisions made by households in their consumption of energy. Consumer theory was thus the starting point on this chapter. Next, the theory is put in the context of the conceptual framework, which breaks energy into individual fuels. This culminates in the two-stage budgeting process which is also supported by the theory of separability of preferences. This followed by the development of a form of systems of demands, the AIDS model. Because of its theoretical and practical appeals, the model is being used as the form of systems of demands by which the demand for alternative sources of energy within a given energy expenditure may be investigated. The derivation of the AIDS model was the ultimate highlight of this chapter, as it narrowed down the theoretical base to a specific formulation. Lastly, the chapter acknowledges the need to incorporate other household characteristics into the demand model. In principle, the theory underlying this study has been set. In the next chapter, we outline the methodology applied in the study and analyses, specifically the empirical model to be estimated and household data collection process.

CHAPTER 5

MODEL SPECIFICATION AND DATA COLLECTION

5.1 Introduction

The overall objective of this study is to make analyses of urban fuelwood consumption. Specifically, we aim to estimate the demand for fuelwood within the context of other sources of energy. So far we have developed the theoretical basis on which analyses can be made. It has already been mentioned in Chapter 3 that fuelwood is consumed as one of the several alternatives available to households. In that chapter, a framework in which an energy mix comprising different sources of energy characterizes household consumption was adopted, and that will be used in the analyses. This chapter presents the actual models that will be estimated and used for carrying out simulations on household energy and fuelwood consumption. It also presents the methodology used in data collection. As far as model specification is concerned this chapter is based on both the theoretical model and the conceptual framework i.e. the AIDS model and the associated energy mix model respectively. Data collection uses a household survey questionnaire(in appendix).

Section 5.2 presents the specification of the empirical models that will be estimated. Section 5.3 discusses the incorporation of household characteristics and price data into the models. It provides the rationale for the inclusion of each variable and the expected trends in the dependent variables when each variable changes. Section 5.4 describes the data collection process. This includes the household survey data and data for prices of alternative sources of energy. Section 5.5 is a conclusion of this chapter.

5.2 Model specification

In the development of the conceptual framework, we have assumed households as implementing a two-stage budgeting process. At the first stage, decisions are made on the expenditures to be allocated to groups of commodities, with energy being one such group. At the second stage, decisions are made on the specific allocations made to alternative sources of energy in the energy mix. Decisions at the second stage are based on the types of fuels that households have access to, thus affecting their decisions in the short term. For example, decisions on the share of total energy expenditure to allocate to electricity in the short term can only be made by those households who have access to electricity. Some households have access to electricity while others do not have access to electricity. All households with access to electricity live in areas or wards that are connected to the electricity grid (electrified wards). Households without access to electricity either live in unelectrified wards, or in electrified wards, but in houses that are not connected to electricity. This involves separate treatment of electrified and unelectrified households at the second stage of decision making.

The models to be estimated are therefore specified according to the two-stage budgeting concept. The estimation of models depicting household decisions at the two stages provides a greater understanding of household fuelwood consumption by first putting it in the context of energy consumption among other household goods, and then the choices and consumption levels of different fuels indicated by expenditure allocations.

5.2.1 Probit models

As a first step in the estimation, a distinction between households with access to electricity and those without access is made. Households with access to electricity are located only in areas that have electricity supplies. Households without access to electricity either live in areas without electricity, or areas with electricity. Using a probit model (Greene, 2000; Maddala, 1992), we estimate the probability that a household lives in an electrified area or not. For the households who live in the electrified areas, we also estimate the probability that a household is electrified or not. This enables estimations of the models explaining household allocation of budgets to energy and individual fuels to yield consistent estimates. Since the sample is split into electrified and unelectrified sub-samples, the result of this stage, specifically the Inverse Mills Ratio (IMR) is incorporated into the estimations of the budgeting stages to address sample selection bias (Greene, 2000; Heckman, 1979).

In the first probit model, the dependent variable is a dichotomous variable stating whether a household lives in an electrified area (y = 1) or does not live in an electrified area (y = 0). This is specified as follows:

$$\Pr ob(Y1 = 1) = F(\mathbf{x}, \beta) \qquad (1)$$

$$\Pr ob(Y1 = 0) = 1 - (F(\mathbf{x}, \beta)$$

where F is the cumulative distribution function of the error term which, in the case of the probit model, is the cumulative normal distribution,

$\mathbf{x}$ is a vector of explanatory variables assumed to affect the probability of a household living in an electrified area or not, to be discussed later, and

β is a vector of parameters to be estimated

The estimation of this model yields an Inverse Mills Ratio (λ) (Greene, 2000) which is carried to the next probit model.

In the second probit model, we select all households living in electrified areas, and estimate the probability that a household in that area is electrified (y2 = 1) or is not electrified (y2 = 0). This is specified as follows:

$$\Pr ob(Y2 = 1) = F(\mathbf{x2}, \lambda_1, \beta 2) \qquad (2)$$

$$\Pr ob(Y2 = 0) = 1 - (F(\mathbf{x2}, \lambda_1, \beta 2)$$

where F is the cumulative distribution function of the error term which, in the case of the probit model, is the cumulative normal distribution,

$\mathbf{x2}$ is a vector of explanatory variables assumed to affect the probability of a household living in an electrified area or not, to be discussed later, and

$\beta 2$ is a vector of parameters to be estimated

λ_1 is the Inverse Mills' Ratio (IMR)

The estimation of this probit model also yields an Inverse Mills Ratio (λ_2) which is used as a regressor in the estimations of the models of the two-stage budgeting process.

5.2.2 Energy budgeting models

These models pertain to the two-stage budgeting process discussed earlier. They form the second step of our estimations. These are made up of two stages depicted in figure 5.1. The first stage refers to the allocation of total household expenditure, and the second stage refers to the allocation of the energy budget to different fuels.

At the first stage, we estimate total energy expenditure as a function of total household expenditure. Total energy expenditure is important as households' fuelwood consumption patterns are influenced by overall energy requirements as shown by the energy budget. An Engel function, that relates the share of household energy expenditure in total household expenditure in logarithm form is estimated, based on Elsner, 2001. This function is extended to include other household characteristics such that the specification has the form

$$w_{TEE} = \alpha + \beta \ln TE + \phi \mathbf{X} + \mu \lambda_2 + \varepsilon \qquad (3)$$

where w_{TEE} is the share of energy expenditure in total household expenditure

TE is total household expenditure

$\mathbf{X}$ is a vector of household characteristics, to be discussed later in this chapter

λ_2 is the Inverse Mills Ratio

α , β , ϕ and μ are parameters to be estimated

ε is an error term

We use the value of β to determine whether energy is a luxury, a necessity or an inferior good. If β >0, the commodity is a luxury, and if β <0, the commodity is a necessity or inferior good (Deaton and Muellbauer, 1980). The household factors $\mathbf{X}$ enter into the model in a linear specification (Deaton, 1997 and Elsner, 2001). The coefficients of the variables enable us to assess how the energy share is affected by household factors.

Household survey data collected in Harare is used to estimate this model. Details of the data and its collection are discussed later in this chapter.

At the second stage of household budgeting, we estimate a linear specification of the Almost Ideal Demand System (LA/AIDS) (Elsner, 2001; Berck *et al*, 1997; Edgerton *et al*, 1996) using household data. At this stage, we specify a system of demand equations based on the AIDS model, with the value shares of the sources of energy being a function of total energy expenditure, fuel prices faced by households and household factors. This defines a utility-maximizing problem (Deaton and Muellbauer, 1980). The total energy expenditure (for the group) comes in as total outlay in the typical problem, with prices being those of individual sources of energy faced by different households at a particular point in time i.e. in a cross section.

The budget shares to be estimated are those of electricity, firewood and kerosene. The data available and the literature, show that only electricity, firewood and kerosene are consumed to any significant levels. Other sources of energy like gas, solar, coal etc, are rarely consumed at household level such that they are left out of the analysis. Campbell *et al* (2000) found that these together are consumed by less than 2% of Harare households. There is also no indication that they could come into the household energy consumption mix in the near future, neither do households indicate their strong preference for these. The model to be estimated therefore is:

$$w_i = \alpha_i + \beta_i \ln TEE + \delta \mathbf{X} + \sum \gamma_{ij} \ln p_j + \eta\lambda_2 + \upsilon \qquad (4)$$

where w_i are the shares of household expenditure on fuel i in total energy expenditure

p_i is the price of fuel i

$\alpha, \beta, \gamma, \eta$ are parameters to be estimated

$\mathbf{X}$ is a vector of household characteristics with corresponding coefficient vector δ. The actual household characteristics that go into the functional form will be determined by a combination of theoretical, pragmatic and econometric considerations. The characteristics considered for the analysis are discussed later.

λ_2 is the Inverse Mills Ratio

υ is an error term

This system is subject to the homogeneity, additivity and symmetry conditions discussed in the previous chapter. Equations (3) and (4) are related in the decision-making process of the household since utility maximization at stage 2, implied by equation (4) contributes to utility maximization at stage 1, implied by equation (3). The decision to allocate a certain share of total expenditure ultimately affects the specific allocations made to different fuels at the second stage. The parameters of the model are related to the elasticities as follows (Berck, *et al* (1997).

$$\varepsilon_{ii} = -1 + \frac{(\gamma_{ii})}{w_i} - \beta_i \quad (5)$$

$$\varepsilon_{ij} = \frac{(\gamma_{ij})}{w_i} - \frac{\beta_i w_j}{w_i} \quad (6)$$

$$\varepsilon_{ix} = \beta_i + 1 \quad (7)$$

where ε_{ij} and ε_{ix} are the price and income (expenditure) elasticities respectively.

The system specified above is the energy mix model, estimating the shares of expenditures of different fuels, including fuelwood, in total energy expenditure, and how these shares change as energy expenditure, prices and household characteristics change. Models (3) and (4) constitute the actual models that will be estimated in the analyses using household survey data. They form the basis on which further investigations of household energy and fuelwood consumption will be based, specifically the estimation of aggregate demand for fuelwood, and policy simulations.

5.3 Incorporation of household characteristics and prices

5.3.1 Household characteristics

Since households differ in several respects, such as size, educational levels and other characteristics, they are expected to have different expenditure patterns (Deaton and Muellbauer, 1980). Therefore demand can be made to depend not only on prices and total expenditure, but also on a set of household characteristics. In fact, in some cases, prices explain little of the variations in household consumption patterns. Other characteristics are more pertinent in such cases. The literature does not have standard rules for the inclusion of household characteristics in demand analyses, despite their importance in shaping household consumption behavior. There is, however, evidence in the literature of the influence of household socio economic, demographic and dwelling attributes on household energy requirements.

The incorporation of household characteristics in the literature is closely tied to the objectives of the particular studies and the types of commodities being considered. The characteristics included in this study and their hypothesized effects on household energy expenditure are based on a combination of pragmatic considerations and on past demand studies such as Huang and Lin (2000), Linderhof (2001), Elsner (2001), Thomas (1972), Elsner (2001), Lippitt (1959), Durrenberger *et al* (2001), Kebede *et al* (2002), and others. Most studies mainly focus on a few factors like household size and the social status of the household. The variables discussed here are hypothesized to have an influence on household energy consumption at both the first and the second stages of decision-making. Their influence at these two stages is also expected to differ between electrified and unelectrified households. We differentiate between electrified and unelectrified households as they have different choice sets and their energy expenditure and choice patterns are thus affected by both economic and social factors differently. While electrified households can use electricity, firewood and kerosene, unelectrified households have only firewood and kerosene at their disposal. While one fuel may be a necessity in one group, it could be inferior in another. We first discuss the factors that pertain to the probit models and then discuss each characteristic in the two stage budgeting process in turn.

5.3.1.1 Household characteristics for the probit models

Probit models are used to correct energy expenditure regression models for sample selection bias that arises from splitting the sample into two sub-samples of electrified and unelectrified households. The energy expenditure patterns of households are affected by their electrification status. Electrification status itself depends on whether the area where a household lives is supplied with electricity or not. Some wards are not connected to the electricity grid. All households who live in these wards are not electrified. The first probit model estimates the probability that a household in Harare lives in an electrified ward or not. Households living in wards that are supplied with electricity can either be connected to electricity or not connected. A household living in an electrified ward may occupy a cottage that is not connected to electricity when the main house is connected to electricity, or may not just afford electricity connection. The second probit model estimates the probability that a household living in an electrified ward is connected to electricity or not. The details of using the probit models to correct for sample selection bias are discussed in the next chapter. The probability that a household living in an electrified ward is connected to electricity or not is also affected by these factors, and whether or not it owns the house, in addition. The probability that a household lives in an electrified ward is affected by the income of the household, the gender of the household head, the employment status of the household head and the educational level attained by the head.

It is hypothesized that housing with electricity is more expensive than unelectrified housing. Therefore as household income increases, the probability that a household lives in an electrified area increases. The probability that a household living in an electrified area is connected to electricity also increases as household income increases. We use household expenditure as an indicator of income.

If the head of a household is employed, the probability that the household lives in an electrified area increases for all households. For households in electrified areas, the probability that a household is connected to electricity is also higher when the head is employed, irrespective of income level. Electricity is fast and efficient. This is convenient for employed persons who need to prepare meals and boil bathing water before going to work in the morning, and in the evenings after work. Employed heads are also able to commit themselves to the monthly obligation of paying monthly electricity bills because they have regular incomes. Unemployed heads on the other hand, even if they have incomes from other sources such as fruit and food vending, cannot commit themselves to monthly bills as their income is not assured every month.

Households with heads who have higher educational levels, as indicated by the number of schooling years are more conscious of the health impacts of different fuels, have an appeal for status, thus prefer to use cleaner and modern fuels. The probability that a household lives in an electrified area therefore increases with the educational level attained by the household head. Similarly, we also expect higher educational levels to increase the probability that a household living in an electrified area is connected to electricity.

We hypothesize that female heads of households are more likely to choose to live in electrified wards and homes compared to male-headed households *ceteris paribus*. The use of electricity demands less labor and is fast for common tasks such as cooking. Female household heads are responsible for preparing meals for the family and for carrying out many other tasks such as nursing children, bathing them, sending them to school, and also providing the income for the family. The use of electricity reduces demand for their labor, compared to using fuels such as firewood, which usually requires extra labor for splitting, making fires etc. Households headed by females therefore have a higher probability of living in electrified areas. The probability that a female-headed household is connected to electricity within the electrified areas is also higher than that for a male-headed household.

The ownership of the house where a household dwells increases the probability of its electrification. Ownership is expected to have an effect only for households living in electrified areas. Owners are more likely to invest in the electrification of their houses than would households who are renting in accommodation. The probability that a household is connected to electricity is therefore higher among households who own the houses they live in than those who rent accommodation.

5.3.1.2 Household characteristics for the energy budgeting models

Household expenditure is a key determinant in energy demand in urban areas, according to Attwell *et al*, (1989). Household expenditure is used as an indicator of income in this study as explained below. Several energy demand studies indicate that energy consumption rises with income e.g. Campbell *et al*, (2000), Dzioubinski and Chipman (1999), Foster *et al* (2000). Increased incomes enable households to purchase more energy for such tasks as cooking, warming, lighting etc. Increased incomes also give households flexibility to choose between different alternative fuels for different uses.

Energy is a household necessity, at least below a certain minimum requirement, and according to Deaton and Muellbauer (1980), the share of household total expenditure of a necessity is expected to decline as household income or expenditure increases. At the first stage of household energy expenditure decision making, we expect the share of energy expenditure in total household expenditure to decline as total expenditure increases. The same pattern is expected for both electrified and unelectrified households. At the second stage, when households allocate the energy budget to different fuels, we expect the shares of modern fuels like electricity to increase while the shares of traditional fuels like firewood to decrease for households with access to electricity. For unelectrified households, we expect the share of kerosene to increase as total household expenditure goes up while the share of firewood decreases.

In this study, we use total expenditure as an indicator of household income at the first stage. We use total household expenditure as an indicator of income. The specification of the AIDS model uses total expenditure rather than income. Total expenditure data is also easy to get from household surveys with more reliability than income data. Households are often not willing to disclose their incomes, but are more forthcoming with data on expenditure. At the second stage, according to the AIDS model (Deaton and Muellbauer, 1980), total energy expenditure is used. Total energy expenditure is assumed to increase as total expenditure increases. We follow the AIDS model specification which incorporates total expenditure in logarithmic terms thereby taking care of the decreasing values of the dependent variables as expenditure increases.

Household size is an important demographic demand factor that affects household consumption in general as shown by several studies including Huang and Lin (2000), Elsner (2001). According to Prais and Houthakker (1955), variations in household size have large effects on consumption, and in cases where income does not change very much across households, explain consumption variation more than does income.

We use Engel's observation about the effect of household size on food (Deaton and Muellbauer, 1980b) to formulate the hypothesis on the effect of household size on energy demand. Both energy and food are necessities. According to this observation, a higher share of household expenditure goes to food among larger households than is the case among smaller households at the same level of total expenditure. This is true for necessities and inferior goods (Prais and Houthakker, 1955). This observation is also expected to apply to energy, which is a necessary good. For luxuries, increases in household size leads to a reduction in the share of consumption.

Economies of scale are assumed to exist in energy consumption such that as household size increases, total expenditure increases at a decreasing rate. Elsner (2001) confirms this from Russian household consumption data, indicating economies of scale of living together. Deaton and Paxson (1988) also confirm this trend and the associated economies of scale associated with food expenditures among urban Thai households and indigenous households in South Africa. Accordingly, we expect the share of energy expenditure to increase with household size for households at the same level of total expenditure, but at a decreasing rate. This is true for both electrified and unelectrified households. The hypothesis of economies of scale is tested by including both household size and the square of household size as variables in the estimations. If the hypothesis is true, the coefficient of the variable household squared will be negative (Elsner, 2001).

Different demographic structures also make consumption patterns of households with the same sizes differ. For example, a household made up of adults only differs from a household of the same size but with a different age and sex structure. However, the attribution of energy consumption scales to different ages and sexes is not possible as can be done for example for food. Whereas in food consumption, adults and male adults are assumed to consume more food than children and female adults respectively (Deaton and Muellbauer, 1980), the same cannot be applied to energy consumption. Whereas the amount of energy required to prepare food for an adult is higher, the frequency of preparation of food for children is higher, and when adults can bath in cold water, small children would require their water to be heated. Because of these complications, we use absolute household size rather than break it into components.

We expect very small households to use only one source of energy, with almost all energy expenditure going to that fuel. However, as energy demand grows because of increasing household size, the tendency to add other fuels increases. This is done to both spread risk and meet demand at lower cost by adopting other cheaper, though less preferred fuels. For electrified households, the first choice fuel is assumed to be electricity. Energy consumption patterns in India (Filippini and Pachauri, 2004) show that larger households consume less electricity than smaller households. Evidence from Guatemala (ESMAP, 2003) also confirms this pattern, showing that it is smaller households who more readily abandon wood energy, and are more inclined to purchase ready-made food outside the house, thereby reducing both their energy expenditures and expenditures on fuelwood. Kerosene consumption on the other hand declines as household size increases because the type of kerosene appliances does not support large household sizes. It however does not completely disappear from the household energy mix. It will be used for periods when electricity is not available for electrified households, and for lighting by unelectrified households. Kerosene use will also be restricted to those uses that require fast fuels such as boiling water for tea and bathing in the morning and evening for household members who go to work and for children. When household size initially increases, the decline in the consumption of kerosene for such uses as cooking in larger than the increase in the quantity of kerosene consumed for these other uses such that the share of kerosene initially declines while that of firewood increases. However, as household size continues to increase, the number of household members who need kerosene for the minor uses increases, and the absolute amount of kerosene consumed increases more than the increase in the quantity of firewood such that the share of kerosene in total expenditure starts to rise again while that of firewood starts to decline. Kerosene consumption therefore follows a U curve pattern, while firewood consumption exhibits an inverted U curve characteristic. Therefore, at the second energy budgeting stage, we expect the share of the energy budget allocated to electricity to decrease with household size while the shares of firewood and kerosene expenditure increase with household size. The U shaped curve characteristic in kerosene and firewood consumption in response to changes in kerosene consumption is expected to result in the sign of household size squared being positive for kerosene and negative for firewood. The fact that kerosene is a fuel more suitable for smaller household size because of the types of stoves used, while firewood can be used for larger numbers of people also applies to unelectrified households. Therefore unelectrified households are expected to allocate larger shares of their energy budgets to firewood than to kerosene as household size increases. An inverted U and a U curve is also expected for kerosene and firewood consumption respectively among unelectrified households in response to changes in household size.

We hypothesize that as the **number of rooms** used by a household increases, energy consumption increases, thus increasing the share of energy expenditure for households at the same level of expenditure and size. The number of rooms is used as an indicator of space available. Durrenberger *et al* (2001), Chow (2001) and Filippini and Pachauri (2004) also confirm that amount of space available to a household affects energy demand. According to their studies in Switzerland, Hong Kong and India respectively, larger dwelling spaces increase the requirements for energy. At the first stage of household budgeting, we expect households with more rooms to allocate higher budget shares to energy than similar households with fewer rooms. The response should be higher among electrified households than among unelectrified households. This is because electrified households use more equipment that use energy like radios, heaters, lights etc as space increases, whereas the types of technologies used by unelectrified households do not increase much as the number of rooms increases. At the second stage, we expect only electrified households to respond to changes in the number of rooms while the response of unelectrified households is not significant. For the former, the share of the electricity budget should increase with the number of rooms while the shares of firewood and kerosene decline. This is because electricity is used in several rooms for tasks such as lighting, warming, which do not use firewood or kerosene when electricity is available.

Energy **appliances** affect the extent to which households use energy, and the types of energy they use (Linderhof, 2001; Nesbakken, 1999). Chow (2001) shows that domestic electricity consumption in Hong Kong increased 2.88 times between 1984 and 1997 as a result of increase in the ownership of appliances. This is also confirmed by the findings of Aburas and Fromme (1991) in Jordan, and that by Dzioubinski and Chipman (1999) in a study covering several countries. The ownership of appliances for different fuels enables households to use different fuels. For example, Campbell *et al* (2000) have found that in urban areas, electricity use is constrained by access to appliances. The greater the number of energy using tasks undertaken, the higher the energy consumption thus the higher the expenditure on energy. With other factors held constant, the share of energy in total expenditure increases.

The effect of appliances is incorporated into the analyses by using the value of energy appliances owned by households. Consequently, we expect that, at the first stage of energy expenditure decision making, the value of appliances possessed by households to significantly affect electrified households only. The energy shares of these households, when other factors are the same across households, increase as the value of appliances increases. At the second stage of budgeting, i.e. when households allocate the energy budget to different fuels, electrified households should respond to increases in the value of appliances by increasing the shares of electricity expenditure in their energy budgets while the shares of firewood and kerosene decline. Unelectrified households on the other hand are little affected since the fuels they use require little investments in appliances. For example, firewood can be used without an appliance in the simplest situation, and kerosene can be used with basic, inexpensive stoves.

The level of **education** in a household, measured by that of the household head is a measure of social status (Huang and Lin, 2000; Lippitt, 1959). Thomas (1972) describes educational attainment as a factor affecting psychogenic needs thereby driving demand. Psychogenic needs arise as a result of association with other people and the need for affiliation, achievement and power. As such, people's expenditure patterns depend on their reference groups, which they want to be associated with. In the case of energy demand, educational level determines both the level of exposure of a household to different technologies, styles of life, social class and status in society. While an average-schooled person wants to be associated with the simple use of electricity for lighting and powering a radio, a university graduate wants to be associated with the use of sophisticated cooking methods such as grilling, microwave use etc, thereby influencing their energy expenditure and mix patterns. We therefore expect households with higher levels of education to have higher shares of energy expenditure at the first stage of energy decision making. At the second stage, we expect households with higher levels of education to allocate lower shares of their energy budgets to traditional fuels while higher shares are allocated to fuels like electricity for electrified households. For unelectrified households, educational level is expected to influence households to allocate more of their energy budgets to kerosene. Guatemalan studies by ESMAP (2003) also show that better educated households are more likely to move away from wood than less educated ones. However, at both the first and second stages, education should have a minor effect on the decision-making processes of unelectrified households who are already using fuels perceived to be inferior as their first choice fuels.

The **number of households living** at a particular property is included in the analyses because of the prevalence of multiple dwellership in urban areas. It is common for several households to occupy one house, with each household using at least one room, and also for other households to live in the cottage of the same premises. They share common utilities such as water and electricity. The energy costs depend on the number of households at any property. Multiple dwellership also limits the adequacy of supplies of fuels such as electricity, especially during peak demand periods. For example the use of electricity by several households to cook at the same time may result in the overload of the supply. This may require that households prepare main meals in turn.

We hypothesize that for households with access to electricity, the share of energy expenditure in total expenditure increases as the number of households living at the same premises (multiple occupancy) increases. Box 5.1 gives an illustration of how multiple households living at the same property leads to increased energy spending in the case of electricity, justifying its inclusion as a demand factor, at least as a hypothesis. This will operate only up to a maximum number of sharing households, beyond which the marginal effect of additional households on cost is zero. Multiple occupancy at electrified premises also leads to electricity demand outstripping supply, leading to power overloads. When there are such overloads, households use other sources of energy such as firewood thereby increasing expenditure on these other fuels. For unelectrified households, we expect a decrease in the share of total energy expenditure due to collective purchases of fuels like firewood, which are likely to lower energy budgets. At the second stage of budgeting, we also expect only electrified households to be significantly affected by multiple occupancy. For these households, the share of electricity expenditure is hypothesized to increase with the number of households living at the same premises. The effect of multiple occupancy on unelectrified households, if significant, is likely to reduce the share of firewood expenditure while the share of kerosene increases.

Box 5.1

The sharing of the electricity bill is a common practice among urban households who share the same premises and are connected to electricity through a common meter. Connection of each household to electricity through its own meter is deterred by both the cost of a connection and the fact that some structures especially secondary buildings or cottages are not up to the standard of being electrified. When the bill is shared equally among all households, as is common practice, the fixed cost per household is effectively reduced by a factor equal to the number of the sharing households. However the effective price per unit of energy finally paid by an individual household and the total cost per household needs to be assessed critically in view of the electricity pricing structure in Zimbabwe. We compare two scenarios, one in which three households live at one property and another with only one household.

First consider the electricity pricing structure used by the Zimbabwe Electricity Supply Authority for domestic consumers, with prices for November 2000, for illustration purposes only.

Incremental consumption band	**Unit cost (Z$/KWh)**
Fixed monthly charge	Z$90.37
0 – 50 kWh	Z$0.96
51 – 300 kWh	Z$1.07
301 – 1000 kWh	Z$3.01
> 1000 kWh	Z$3.12

In a case where three households share the same premises, and each household consumes say 300 kWh of electricity per month totaling 900 kWh, the total bill based on the pricing schedule above is Z$2512.87. Each household will pay Z$837.62. If each household had its own meter, consuming the same amount of electricity, they would pay a total of Z$405.87. Thus sharing of a single meter by multiple households results in about double the cost of electricity compared to each household using its own meter.

5.3.1.3 Summary

The expected trends of energy expenditure and fuel choice and mix patterns as a result of these variables are just hypotheses to be tested. Table 5.1a below summarizes the characteristics discussed above. Table 5.1b summarize the hypotheses discussed above, for the probit models, one for the probability of a household living in an electrified area or in an unelectrified area, and the other for the probability that a household living in an electrified area is connected to electricity or not. Table 5.1c summarizes the hypothesized effect of the household characteristics on energy expenditure for electrified and unelectrified households, and at the first and second stages of budgeting.

Table 5.1a: Summary of household characteristics

Characteristic	Description
Household income	Total household expenditure per month in Zimbabwe dollars (Z$)
Household size	Number of individuals in the household
Household size square	The square of household size
Housing space	Number of rooms being used by household
Appliances	Value of energy using appliances owned (Z$)
Education	Educational level of household head (years)
Occupancy	Number of households sharing one property
Employment	Employment status of the head of household (employed =1 or unemployed =0)
Gender	The sex of the household head (male =1 or female =2)
Ownership	Household dwells in own house or in rented accommodation. Owner =1 and Non-owner =0

Table 5.1b: Hypothesized effect of household characteristics on probabilities

Household characteristic	All households	Households in electrified wards
	Probability that household lives in electrified ward	Probability that household is connected to electricity
Income	+	+
Household head employed	+	+
Male headed household	-	-
Education	+	+
Household own house	NA	+

+ positive relationship expected

- negative relationship expected

* weak or no effect expected

NA Not applicable

Table 5.1c: Hypothesized effects of household characteristics on household energy expenditure shares

Household Characteristics	Stage 1		Stage 2				
	Electrified households	Unelectrified households	Electrified			Unelectrified	
	WTEE	WTEE	We	Wf	Wk	Wf	wk
Total expenditure	-	-	NA	NA	NA	NA	NA
Total energy expenditure	NA	NA	+	-	-	-	+
Household size	+	+	-	+	-	+	-
Household size square	-	-	+	-*	+	-	+
Rooms	+	+*	+	-*	-*	*	*
Appliances	+	+*	+	-*	-*	*	*
Education	+	+	+	-	-	-*	+*
Occupancy	+	-*	+	-	-	*	*

+ positive relationship expected

- negative relationship expected

* weak or no effect expected

NA Not applicable

5.3.2 Prices

Under the neoclassical assumption of perfect competition, all consumers at a given location face the same price of a commodity at the same point in time. Therefore cross sectional data shows no variation in prices, making it impossible to incorporate the effect of prices in the demand for goods in most developing countries where time series data are rarely available for long enough periods to enable estimation of price elasticities (Deaton, 1988). The problem is even bigger for goods like wood fuels which are not part of national statistics in most developing countries. While in a few cases own price elasticities for electricity are available, e.g. Hope and Singh (1995) and for energy in general e.g. Dahl (1994),cross price elasticities are rarely available. In the cases that these are available, they are mostly for developed countries e.g. Akmal and Stern (2001). More so, elasticity estimates vary widely by country, depending on the energy mix, the shares of different fuels in household energy expenditures, and the income levels in the different countries. The literature shows that even for the same country, different studies and methods yield different elasticities of demand for energy products. Differences in estimates for the same countries can be explained by the different time periods to which the data used pertains, and failure of the samples used to represent whole populations. We also do not expect elasticities for similar countries to be the same if they have different shares of the same fuels in the expenditures. On the other hand, exclusion of price effects in the estimation of the model specified above would result in specification errors. Price changes are also important for policy analyses. This section describes how the effects of prices are incorporated in the model above.

According to Prais and Houthakker (1955), Deaton (1988) and Elsner (2001), there are price variations in transition and developing economies, due to factors such as regional, seasonal, quality, price discrimination effects. Such price variations, when the demand structure is constant, can be attributed to different supply conditions which, according to Elsner (2001), can be used to identify commodity demand curves. This requires the use of observable indicators to represent such variations in price, since price is often not observed. Most of the literature uses unit values, which are derived by dividing expenditures by quantities, and adjusted for household influences. This assumes that both quantity and expenditure are observed in the data. When demand related influences such as the effect of income on quality purchases are accounted for i.e. households who buy different grades of the same products because of their incomes, unit values can be used as indicators of prices. Thus as long as cross-sectional variation in prices can be identified, and attributed to supply conditions, such variations can be used in cross-sectional demand analyses, indicating the effects of prices. Deaton (1988) illustrates the use of unit values using data from Cote de Ivoire. In Indonesia Deaton, (1990) also investigates the use of unit values for cross sectional demand analyses. In both cases, the analyses involve demand for food.

This study also uses the effect of different supply conditions faced by households to incorporate the effects of prices in the analyses. Because of the inability to identify quantities for all fuels such as electricity in data collection, the application of unit values is not possible, but a similar indicator that mimics different price situations faced by households is used. The supply conditions of fuels subject households to different relative prices for each fuel. For a source of energy, we assume that the cost of its use to a household increases with the difficulty to access it such that even though the observed price is the same, effectively, households with different ease of access face different prices, or relative prices. While the literature e.g. Kebede *et al* (2002) restricts such variations to variations in geographical locations, it is highly probable that supply conditions affect even households within the same locations differently. For example households who take cooking turns to avoid overloading electricity supply face different supply conditions compared to those who do not have such limitations. Incorporation of different supply conditions faced by household in purchasing energy is implemented in the data collection by determining household ease or difficulty of access to each fuel they consume. Using a scale of 1 to 5, households indicate how easy or difficult it is to access each fuel thereby mimicking the prices paid, in relative terms. In the data set, 1 indicates that a household can easily access a fuel, and 5 indicates that the fuel very difficult to access. Thus 1 to 5 become the relative prices of fuels, and are used to assess how household expenditure shares on different fuels change as prices change. This is consistent with the use of unit values discussed above, with the advantage that the access index is directly measurable.

We confirm that this is a consistent indicator of cross sectional price variability, yielding consistent γ_{ij} parameters in the system of demands by calculating price elasticities via equations (5) and (6). We compare these with elasticities from other sources, and their consistency with the expectations of economic theory. The minimum expectation, for example is that own price elasticities for normal goods are negative. Comparisons of elasticities are made with data from countries with similar socio-economic backgrounds. Elasticities differ depending on the shares of different fuels in the total energy budget, and this is also considered when comparing elasticities from different sources. For example comparing the price elasticities of demand between firewood and kerosene for urban households in Zambia and Zimbabwe need to take into account the fact that the Zambian energy mix has more charcoal than firewood while that for Zimbabwe has little or no charcoal.

The advantage of using relative prices is that fuel costs can be compared using the same units. This approach also has the advantage that the restrictions imposed on the model by theory can be tested. However, just as in the use of unit values, the use of this approach will require further empirical application tests.

5.4 Data collection

Household data collected in a questionnaire survey was used to carry out the estimations discussed above. The questionnaire used is attached as an appendix. The data describe household energy and general expenditure in a cross section, together with other household attributes. Data collection centered mainly on the consumption of fuelwood and other sources of energy, together with other household characteristics. Data, especially on fuelwood are very scarce in Zimbabwe. In fact, there are no official statistics on consumption patterns and prices. Primary data collection was therefore used in the analyses. In this section, we outline the data collection process, with detailed focus on household data collection.

5.4.1 Household data

The household survey was carried out in Harare on 500 households in September 2001 using stratified sampling (Leedy and Ormrod, 2000). The questionnaire was administered to a sample of households representing urban Harare households in a cross section. The selection of the representative households is outlined below. The household was used as the enumeration unit because it is the basic consumption unit, and from which meaningful inferences about energy consumption can be made.

Sampling of households to be included in the survey aimed at representing as much as possible all the households in the city, taking into account their heterogeneity. Households in urban areas are distinguished by several factors, including location, household size, ownership of residential property etc. However, the crosscutting distinguishing factor is the level of household income, which largely determines consumption. Income was thus used to stratify the population and ensure representation in the sample. Income tends to strongly influence location of residence by households, and consequently residential areas or suburbs to a very great extent represent assemblages of households in specific income categories, though with some internal variations. The sampling process therefore used residential locations to select the representative households to be included in the survey. The assumption made was that income variation within the residential areas in the same income category is less than variations across residential areas in different income categories.

The first step in the sampling process was therefore to classify residential areas into income categories. Data on income levels by residential area was not readily available. Neither is it easy to get it with a reasonable degree of accuracy from the households themselves. Therefore the design sought to get indicators of incomes of households in different areas using the cost of accommodation. It was assumed that accommodation is more expensive in high-income areas than in low income areas, i.e. rent is higher in high-income suburbs than in low-income suburbs, *ceteris paribus*. Average rent was therefore used as an indicator of the income status of different suburbs. To estimate the average rent, a survey of the rent paid for accommodation in different residential areas was carried out. To do this, first a list of residential areas was obtained from the Central Statistical Office's 1992 Census report, Harare provincial profile (CSO, 1992). This list provides enumeration wards in Harare urban, but does not provide the income status of each ward. Also included in this list is the population and the number of households in each ward as found in the 1992 population census, and updated in 1997. The CSO data is the most reliable basis for drawing a stratified sample, and is the one that we used. However, for inference purposes, the up-to-date population estimates will be used. The rent survey was carried out on 10 households randomly selected from each residential area. Personal interviews were carried out to obtain this information. The survey provided data on the average rent per room per month paid by households renting accommodation and the rent charged by owners of houses for letting accommodation. This was averaged for each ward or residential area.

The data obtained showed that rent (in Zimbabwe dollars, Z$), is Z$1,552 per room per month, ranging from Z$79 to Z$3,415 per room per month. Table 5.2 below shows this data, together with the number of households in each ward, as given by the Central Statistical Office.

Table 5.2: Average rent and population sizes of Harare residential wards

Ward/Residential Area	Average rent /room/month ($)	Number of households
Epworth	$79	17,497
Aspindale	$556	3,275
Hatcliffe	$676	2,102
Dzivarasekwa	$993	10,428
Mabvuku	$698	10,599
Mbare	$730	24,498
Tafara	$740	7,368
Rugare	$745	875
Glen Norah	$754	15,160
Glen View	$765	27,531
Budiriro	$788	8,946
Highfields	$790	25,904
Kambuzuma	$822	9,582
Warren Park	$950	11,895
Kuwadzana	$970	19,170
Mufakose	$984	12,754
Sunningdale	$1,000	4,885
Waterfalls	$1,148	6,131
Greendale	$1,740	9,412
Eastlea	$1,820	8,502
Mt Pleasant	$2,690	5,810
Belvedere	$2,750	5,408
Hatfield	$2,751	6,080
Highlands	$2,980	7,288
Marlborough	$3,108	5,954
Borrowdale	$3,150	8,174
Avondale	$3,171	6,678
Mabelreign	$3,232	8,106
Avenues	$3,415	6,792
Total		296,804

Source of population data: CSO (1992)

From this data, six income categories based on rent data were delineated. The total number of households in each category was computed. The ranges as indicated by monthly rental per room in the different categories are given in table 5.3 below.

Table 5.3: Income categories and wards in these categories derived from rent survey

Category	Rent band: Average rent /room/month ($)	Number of wards
1	Less than $100	1
2	$101 - $500	0
3	$501 - $1,000	16
4	$1,001 - $1500	1
5	$1,500 - $2,000	2
6	More than $2,000	9
Total		29

The table shows that there are no wards in the $101 - $500 category (income band 2). This category was removed, and the lower limit for income categories was raised to $500, without effectively changing the number of wards in the lowest income category. Income band 3 ($501 - $1,000) had 16 wards. This category was split into 2 bands, one ranging from $501 to $750, and the other from $751 to $1,000. This was done to ensure that when selecting wards in which to carry out interviews, the variation in the wards would be adequately represented in the final sample. Similarly, we combined bands 4 and 5 that had only 1 and 2 wards in them respectively. This process resulted in the categories given in table 5.4 below.

Table 5.4: Income categories and the number of households in each category

Income category (rent/room/month)	Wards in category	Number of households in category	Fraction of total number of households
1. Less than $500	Epworth	17,497	0.06
2. $501 - $750	Aspindale, Dzivarasekwa, Hatcliffe, Mabvuku, Mbare, Tafara, Rugare	59,145	0.20
3. $751 - $1,000	Glen Norah, Glen View, Budiriro, Highfields, Kambuzuma, Warren Park, Kuwadzana, Mufakose, Sunningdale	135,827	0.46
4. $1,001 - $2,000	Waterfalls, Greendale, Eastlea	24,045	0.08
5. More than $2000	Mt pleasant, Belvedere, Hatfield, Highlands, Marlborough, Borrowdale, Avondale, Mabelreign, Avenues	60,290	0.20
Total		296,804	1

The fraction of each category formed the basis for the representation of each income category in the sample. A sample of 500 households was used based on the available resources. From each income category, two wards were randomly selected that would represent the category in the sample, and the survey would be carried out in these. The exception was in categories 1 and 4 (table 5.4) in which there were one and three wards respectively. In category 4, one ward was selected. The sample sizes in each income category, and the wards selected are given below in Table 5.5. Table 5.6 gives the number of households in each of the selected wards.

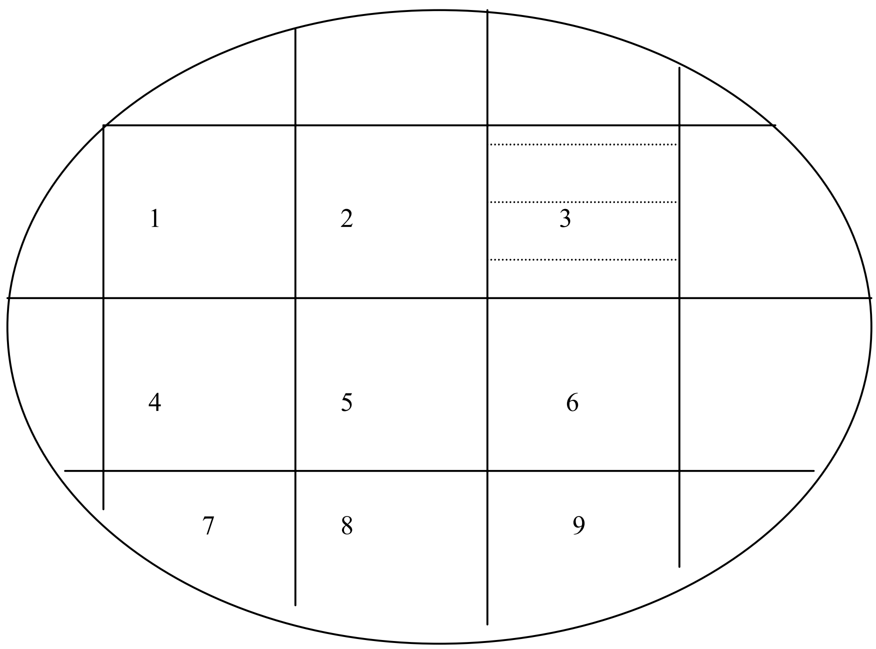
Table 5.5: Sample size by income category and by ward

Income category	Wards in category	Category sample size	Ward	Ward sample size
1	Epworth	29	Epworth	29
2	Tafara, Dzivarasekwa	100	Tafara	50
			Dzivarasekwa	50
3	Highfields, Warren Park	229	Highfields	115
			Warren Park	115
4	Waterfalls	40	Waterfalls	40
5	Marlborough, Mt Pleasant	102	Marlborough	51
			Mt Pleasant	51
Total		500		500

The actual selection of the households to be interviewed was based on blocks randomly selected from the Harare street atlas. Each ward was divided into blocks, and these blocks were numbered. The blocks used are those that make the grid squares or grid references on the street atlas. Blocks were randomly selected and assigned to enumerators. Each enumerator worked in the block assigned to them. In any selected block, a route or road to be followed by an enumerator was selected. All the houses to be encountered in a selected route would be interviewed until the enumerator's allocation was finished. Interviews would start at the first house of selected routes or roads, and continue along the road until either the allocation was exhausted, or until the road came to an end, in which case the enumerator would go to the next road in the same block. Figure 5.1 illustrates the selection of blocks which are defined by solid lines representing grid lines. For example if block 3 is selected (among others) in the hypothetical ward presented in figure 5.1, an enumerator would follow the roads shown in broken lines. The same applies to other blocks randomly selected in the same ward. Households living in the cottages were also interviewed. The head of the household was interviewed.

In the absence of the head, a substantive representative (one who could provide the required information with accuracy) such as spouse or grown up child was interviewed. During the survey, all enumerators worked in one ward at a time to minimize possible bias caused by one enumerator working consistently in one area and others in different areas. However, in each ward, each enumerator was assigned a different block.

Figure 5.1: Illustration of blocks and routes used in interviews



A questionnaire was used to collect data. Enumerators administered the questionnaire through interviews. Before the actual survey, the questionnaire was pre-tested in a ward that was not part of the survey. The enumerators went through a one and half days training that involved understanding the questionnaire, interpretation of meanings and objectives of all questions, translations of questions between English and Shona (the local language), and understanding of different measures and units used in the questionnaire. Practical sessions with each other and with actual households not included in the survey were also carried out during the training. This ensured that enumerators were able to use the questionnaire with confidence, and also to test its practical applicability. Data collected from the practical training session was captured and checked before the actual survey. Problems with both the understanding and capturing of responses by enumerators were rectified.

In the actual survey, an enumerator supervisor made a follow-up in each ward and route to confirm that all households indicated on completed questionnaires had actually been interviewed. All questionnaires were checked as they came in, and all problems rectified before data entry. The data from the survey was captured and stored in SPSS (Statistical Package for the Social Sciences) Version 10.

5.4.2 Energy price data

In the analyses that follow, data on the prices of individual fuels are required to determine the actual quantities of each fuel consumed given its budget share and expenditure. Data on the prices of the alternative fuels was collected separately from the household survey, though the data pertains to the same period as the household survey. Price data was collected in price per unit of the respective fuel i.e. in kilograms for firewood, in kilowatt hour (kWh) for electricity and in liters for kerosene. These were converted into prices per common unit, the mega joule (MJ), allowing comparisons across fuel type. The following conversions from UNEP (1991) were used

Firewood: $1kg = 16MJ$

Kerosene: $1l = 35MJ$

Electricity: $1kWh = 3.6MJ$

The price of electricity was collected from the Zimbabwe Electricity Supply Authority (ZESA), which is the sole electric power supplying parastatal in the country. Electricity price data is available in time series, and is up to date. The price of electricity is available in kilowatt hours (kWh), and comprises of a fixed monthly charge and the cost per kWh

Firewood is sold in open market places at shopping centers in residential areas and along roads and road corners. Firewood price data was collected from the selling points in a cross sectional price survey carried out in the entire city, covering 100 selling points. It was carried out two weeks before the household survey described above such that the prices collected in the market survey roughly correspond to the prices that households were confronted with during the household survey. As with electricity, data on firewood prices was collected using units that traders use (bundles, logs, and bags). At any particular selling point, several samples of a common unit were weighed, the weights averaged and recorded together with the price per unit. The price was then converted to price per kg before converting to price per MJ.

Kerosene is sold at service station pumps, at markets where firewood is sold and in kiosks or tuck-shops found in residential areas. We collected price data from the markets because, kerosene pump prices do not reflect what consumers actually pay. Consumers pay much more than prices ruling at pumps because traders who buy in bulk from service stations at pump prices resell to consumers at higher prices for a profit. This study therefore relies on data collected at points where the consumers buy. This is the price that consumers use for making decisions on the expenditure that they make on kerosene. At the retail selling points, kerosene is commonly sold in 750 ml bottles. The price per 750 ml bottle was converted to price per liter before converting it to price per MJ using the conversions given above. The data was collected at the same time that firewood data was being collected, and at the same markets.

5.4.3 Population data

Population data is used in this study to estimate the total demand for fuelwood in Harare. The data required therefore pertains to Harare only. Household population data was obtained from the Central Statistical Office (CSO)'s national census reports of 1992, 1997 and 2002. The CSO carries out a national census once every ten years, and the last one was in 2002, whose preliminary results are published in 2003. The household survey for this study was carried out in 2001, before the 2002 census. Therefore the sampling process used the 1992 data, updated in 1997 in an inter-censal report. The CSO data gives information on population by province, and breaks it down into wards. Harare urban is one of the provinces. The wards used in the census approximately correspond to the grouping of residential areas or suburbs. Population data is provided in terms of the number of persons, and also in terms of the number of households. The estimation of aggregate demand for fuelwood in our analyses uses the 2002 census results, which have an up to date number of households in Harare.

5.5 Conclusion

This chapter has outlined the overall methodology used in both the analyses and in the collection of data. Data analyses will be based on a two-stage estimation of expenditure shares of energy in general, and specific fuels in particular, based on the almost ideal demand system. A linear specification of the AIDS model is suggested. The fuels considered in the analyses are electricity, firewood and kerosene. The specification has included the incorporation of household factors in demand estimation, in addition to the effects of income and prices. As far as prices are concerned, the chapter has presented the use of an index based on household access to fuels as an indicator of relative prices to enable the calculation of price parameters. Having presented the actual models to be estimated in the first section, the chapter has proceeded to provide the methodology used in collecting the data for the quantification and estimation of the models. The processes used to collect household, price and population data have been described. The results of the estimations carried out using these models and data are presented in the next chapter.

CHAPTER 6

EMPIRICAL FINDINGS

6.1 Introduction

This chapter presents the results of the analyses of data using the household survey data collected in Harare and the empirical models described in the previous chapter. It also gives the policy implications of the empirical results. Section 6.2 highlights the characteristics of households in the sample using descriptive statistics. Section 6.3 presents the models estimated. The energy mix of households in Harare in terms of both expenditure and physical quantities is presented in section 6.4, while estimates of total fuelwood demand in Harare are presented in section 6.5. Section 6.6 presents a summary of simulations that were carried out with results of model estimates. Section 6.7 highlights the main policy implications of the empirical findings while section 6.8 concludes the chapter.

6.2 Descriptive statistics

This section gives a summary description of the population under study. The general household characteristics are presented first, followed by statistics specific to energy consumption. We present statistics for the entire sample, and for electrified and unelectrified households separately. The statistics are based on a sample size of 500 households. Table 6.1 gives a summary of the statistics of household characteristics.

Table 6.1: Descriptive statistics of household characteristics

Household Characteristic		All households combined	Electrified households	Unelectrified households
Sample size		500	443	57
Percentage		100%	89%	9%
Household size		4.9	4.9	5.2
		(2.6)	(2.5)	(3.0)
Number of rooms used		3.7	3.9	2.2
		(2.5)	(2.5)	(1.2)
Sex of household head (% of households):				
Male		82%	83%	75%
Female		18%	17%	25%
Employment status of household head				
Employed		89%	91%	75%
Unemployed		11%	9%	25%
Education of household head (years of schooling)		11.0	11.3	9.2
		(3.6)	(3.6)	(3.0)
Ownership of residence				
Owning (% of households)		58%	59%	47%
Renting (% of households)		42%	41%	53%
Number of families living at one property		2.9	2.9	3.4
		(1.9)	(1.9)	(2.3)
Household total expenditure (Z$ per month)		$18,400	$19,700	7,900
		($20,100)	($20,900)	($5,400)
	Min	$500	$600	$500
	Max	$142,500	$142,500	$30,000
Value of energy-using appliances (Z$)		$64,500	$75,100	$8,500
		($82,300)	($84,200)	($17,400)
	Min	0	0	0
	Max	$432,000	$432,000	$83,000

Figures in parentheses are standard deviations

Of the 500 households in the sample, 443 or 89% live in dwellings connected to electricity while the other 57 households (9%) are not connected to electricity. The sampling procedure did not deliberately select households on the basis of their electrification status; thus the ratios of electrified and unelectrified households in the sample are random outcomes. The percentage of Zimbabwean urban households connected to electricity of 80% found in other studies is lower than the percentage obtained in the sample (Karekezi and Kimani, 2002; Karekezi and Majoro, 2002).

The average size of the household in our sample is 4.9. The difference in household size between electrified and unelectrified households is very small. The respective household sizes for electrified and unelectrified households being 4.9 and 5.2 respectively. On average, a household in the sample uses 3.7 rooms, and the figure is higher for electrified households and lower for unelectrified households. An average unelectrifed household uses about half the number of rooms used by an electrified one. Given the respective household sizes of the two groups, unelectrified households live in more crowded conditions than their electrified counterparts.

In 82% of all cases in the sample, the head of the household is male while females head 18% of households. The pattern does not change significantly when the sample is split into electrified and unelectrified groups of households; there are slightly more households headed by females among unelectrified households compared to their electrified counterparts.

The level of education of the head of household, measured by the years of schooling differs by about 3 years between electrified and unelectrified households. The head of an electrified household is on average more educated than that of an unelectrified household. The average for all households is 11 years, which corresponds to completion of secondary school. While the level of literacy is high among all households, the level of education suggests that the average head of household does not possess a tertiary qualification.

58% of all households are owners of the houses they live in, while 42% live in rented accommodation. The rate of ownership is higher among electrified households than among unelectrified households. More than one household may occupy the same premises at any point, but living independently. Several households may occupy different rooms in the same house, or some households may live in secondary buildings or cottages at the same property. An average of 3 households live at the same property for households in the entire sample. The number of households living at the same property is higher among unelectrified households.

Total expenditure is used as an indicator of household income. The higher the total expenditure the higher the total income. An average household has a total monthly expenditure of Z$18,400. The average total monthly expenditures of electrified households are more than double those of unelectrified households. This shows the wide income disparities between the two groups of households.

In terms of energy appliances, electrified households own assets whose total values are about 9 times the values of those owned by unelectrified households. The appliances of electrified households are dominated by electrical appliances that are expensive, thus have higher values. Higher value appliances are associated with both energy efficiency and the ability to perform sophisticated tasks. On the other hand, the appliances of unelectrified households mostly consists of simple kerosene and firewood stoves.

The use of different fuels by the surveyed households is summarized in table 6.2 below. The most dominant sources of energy for domestic use in Harare are electricity, firewood and kerosene. Of all the surveyed households, 80% mention electricity as their most dominant or mostly used fuel. 18% and 2% respectively mention firewood and kerosene as their most dominant fuels. Other fuels (gas, charcoal, coal and solar) are all cited as dominant fuels by a total of 1% of households (see table 6.2). This pattern of dominance is also exhibited by electrified households, while among unelectrified households, firewood is cited as the dominant fuel by the majority (84%) of households, followed by kerosene (14%).

Table 6.2: Energy use characteristics

Energy use characteristic	All households combined	Electrified households	Unelectrified households
Most dominant fuel (%)			
Electricity	*79%*	89%	0%
Firewood	*18%*	9%	84%
Kerosene	*2%*	1%	14%
Others	*1%*	1%	2%
Total Energy Expenditure	Z$1,600	Z$1,800	800
Energy expenditure as share of total expenditure	0.13	0.13	0.11
Share of electricity expenditure in energy budget	0.73	0.81	0
Share of firewood expenditure in energy budget	0.14	0.09	0.55
Share of kerosene expenditure in energy budget	0.13	0.10	0.45

The energy expenditure patterns show that all households allocate an average of 13% of their total expenditures to energy purchase, with electrified and unelectrified households allocating 13% and 11% of their total expenditures to energy respectively. However, in terms of actual energy expenditure, as the table above shows, electrified households on average spend more than double the amount of money spent by unelectrified households on energy. Given the higher total expenditures of electrified households compared to unelectrified households, this is consistent.

The shares of the different fuels in total energy expenditure show that on average, electrified households allocate most of their energy budgets towards electricity, while firewood and kerosene receive almost equal shares. Among unelectrified households, firewood and kerosene also receive almost equal allocations of the total energy budget. Thus in terms of expenditure, firewood and kerosene have almost the same status, while electricity is dominant among those households who have access to electricity. This implies that both are inferior compared to electricity, but are all needed by households with the same level of necessity. Households cannot use kerosene only, but also need firewood for uses that kerosene cannot satisfy, and vice versa.

6.3 Model Estimations

This section presents the empirical results of estimations carried out using the models presented in the previous chapter. The estimations followed a two-stage budgeting process. At the first stage, households, decide the shares of their total expenditures to allocate to energy expenditure. At the second stage, they decide how to allocate these energy budgets to different fuels. The allocation of energy budgets to different fuels being used depends on the fuels that are available to households. In particular, the consumption of electricity depends on whether a household has access to electricity or not. The use of other fuels like firewood and kerosene is not subject to such conditions. Therefore we estimate the models discussed earlier separately for electrified and unelectrified households. This requires the splitting of the sample into electrified and unelectrified households, and carrying out estimations for the two groups separately. To correct for sample selection bias, the Heckman procedure is used, which requires the estimations of probit models to generate the Inverse Mills Ratio (IMR). The IMR from the probit models is used in the subsequent estimations of household energy budgeting models.

6.3.1 Variables used

Table 6.3 below summarizes all the variables used in all estimations, giving the acronym of each variable, its full name or label, and units of measurement. The hypotheses made about the influence of each variable were discussed in the previous chapter.

Table 6.3: Summary of variables used in estimating models

Variable*	Label	Measure
$Educ$	Educational level of household head	Years of schooling
$Employ$	Employment status of household head	1 Employed 0 Unemployed
$Gender$	Gender of household head (male or female)	1 Male 2 Female
$Hhsize$	Household size	Number of individuals
$Hhsize2$	Square of household size	Square of number of individuals
$Hhslive$	Number of households living at the same property	Number of households
$\ln Asset$	Natural logarithm of value of energy using appliances possessed by household	Zimbabwe Dollars (Z$)
$TE/1000$	Total household monthly expenditure divided by 1,000	Thousands of Zimbabwe Dollars
$\ln TE$	Natural logarithm of total household monthly expenditure	Zimbabwe Dollars (Z$)
$\ln TEE$	Natural logarithm of household total monthly energy expenditure	Zimbabwe Dollars (Z$)
Own	Ownership of house (owning or renting)	1 Owner 0 Non-owner
p_e	Price of electricity	Index
p_f	Price of firewood	Index
p_k	Price of kerosene	Index
$Rooms$	Number of rooms being used by household	Number
w_e	Share of electricity expenditure in total energy expenditure	Ratio
w_f	Share of firewood expenditure in total energy expenditure	Ratio
w_k	Share of kerosene expenditure in total energy expenditure	Ratio
w_{TEE}	Share of total energy expenditure in total household	Ratio

	expenditure	
λ_1	Inverse Mills Ratio for probability that household lives in electrified ward or not	Ratio (probit result)
λ_2	Inverse Mills Ratio for probability the household in electrified ward is electrified or not	Ratio (probit result)

6.3.2 Probit model for electrification status of households

The decisions by households to allocate their total expenditures to energy, and subsequently their total energy expenditures, to different fuels is dictated by the types of fuels they have access to. Specifically, electrified households and unelectrified households have different sets of energy choices, thus respond differently to changes in demand variables. This necessitates the splitting of the total sample into two groups, one of electrified households and the other consisting of unelectrified households, and estimating the models specified in the previous chapters separately for the two groups. This is done by first separating all wards into those that have electricity and those that do not have electricity. All households in unelectrified wards are not connected to electricity. Secondly, households living in electrified wards are separated into those who live in electrified houses and those who live in unelectrified houses. In order to correct for sample selection bias, two probit models are estimated to obtain the Inverse Mills Ratio to correct for this kind of bias (Greene, 2000). The probability that a household is electrified depends on several household factors as discussed in Chapter 5. This probability first depends on whether a household lives in an electrified ward or an unelectrified ward.

The first probit model estimates the probability that a household lives in an electrified ward or not. The results of this probit model are presented in the second column of table 6.4. The estimation of this first probit model generates an IMR ratio which is used as one of the regressors in the second probit model. The second probit model estimates the probability that a household living in an electrified ward is connected to electricity or not. The estimates of this model are presented in the third column of table 6.4, and include the variable λ_1, which is the Inverse Mills Ratio from the first probit model. The estimation of the second probit model generates a second IMR, which is used as one of the regressors (λ_2) in the estimation of energy expenditure shares. Both probit models were estimated using Limdep 7.0.

Table 6.4: Probit model for living in electrified wards, and electrification status of households in electrified wards

Variables	Coefficients	
	All households 1: Living in electrified ward 0: Living in unelectrified ward N=500	Households in electrified wards 1=household connected 0=household not connected N=467
Constant	-.098	-14.075*
	(.597)	(8.226)
$TE/1000$	.025*	.184**
	(.013)	(.094)
Emplyhd	.766***	6.190*
	(.295)	(3.240)
Genderhd	.343	1.599
	(.308)	(1.158)
Educ	.024	.187*
	(.038)	(.098)
Own		.628**
		(.304)
λ_1		27.545*
		(15.041)
Log likelihood function	-86.473	-71.961
Restricted log likelihood	-96.471	-86.672
Chi-squared	19.995	29.422
Significance level	.001	.000

Figures in parentheses are standard errors

*, ** and *** represent significance at the 10*, 5% and 1% respectively

The variables that significantly explain the probability that a household lives in an electrified ward are the total expenditure of a household and the employment status of the household head. As total expenditure increases, the probability that a household lives in an electrified ward increases. As total expenditure is an indicator of income, and with accommodation being more expensive in wards that are connected to electricity, households with higher incomes are better able to pay for expensive accommodation. The probability that a household lives in an electrified area is also higher for households whose heads are employed, with a higher level of significance. This is according to our expectation. Employment gives households assured income such that they can commit themselves to paying the monthly electricity bill, irrespective of their level of income. Electricity is also fast and convenient for those who are employed as discussed earlier. The coefficient of the gender and educational level of the household head are not statistically significant.

For households living in electrified areas, the probability that a household is connected to electricity or not is explained by income, employment status of the household head, the educational level of the head of household and whether the household owns the house or not. As hypothesized, the probability of being electrified increases with both income (as indicated by total expenditure) and the educational level of the household head. The probability of a household being electrified is higher among households whose heads are employed and for households who live in houses they own that those who live in rented accommodation. The gender of the household head does not significantly influence the probability of a household being electrified.

6.3.3 Total energy expenditure

At the first stage of household energy budgeting, households decide the shares of their total expenditures to allocate to energy expenditure. We estimated this share (w_{TEE}) as a function of total household expenditure, in logarithmic form, and other household factors discussed in the previous chapter. The model was estimated separately for electrified and unelectrified households. The Heckman procedure (Greene, 2000; Heckman, 1979) was used to estimate this model. This procedure allows the correction of estimates for the effect of splitting the sample into electrified and unelectrified sub-samples. This procedure uses the IMR from the second probit model discussed above as one of the regressors, using ordinary least squares.

Table 6.5 gives the results of the estimations of the energy expenditure shares, for electrified and unelectrified households. λ_2.is the IMR from the second probit model presented above.

Table 6.5: Total energy expenditure share estimates for electrified and unelectrified households

Variable	Electrified households	Unelectrified households
Constant	.866***	.603***
	(.114)	(.186)
$\ln TE$	-.118***	-.052**
	(.013)	(.261)
$\ln Asset$	.020***	.015**
	(.006)	(.005)
Hhsize	.024**	.010
	(.011)	(.016)
*Hhsize*2	-.001*	-.00003
	(.0008)	(.0010)
Educ	-.001	-.001
	(.003)	(.006)
Rooms	.021***	.003
	(.005)	(.016)
Hhslive	.012**	.012
	(.005)	(.007)
λ_2	-.186*	.122**
	(.114)	(.054)
R^2	.266	.380
Durbin-Watson Statistic	1.853	1.859
Significance level	.000	.024
Akaike Information Criterion	-.874	-1.872
Rho	.073	.070
Diagnostic Log – L	164	49
Restricted Log – L	109	39
LogAmemiyaPrCrt	-3.712	-4.703

Figures in parentheses are standard errors

*, ** and *** represent significance at the 10*, 5% and 1% respectively

For electrified households, all the variables, except the educational level of the household head, have statistically significant coefficients. For unelectrified households, only total expenditure, the value of appliances ($\ln Asset$) and the number of households living at the same property have significant coefficients.

Among both electrified and unelectrified groups of households, $wTEE$ goes down as total expenditure goes up, depicting energy as a necessity for both groups of households. This is consistent with the hypothesis we made about the effect of in come in the previous chapter. However, the absolute value of the coefficient of total expenditure is higher among electrified households than among the unelectrified group, showing that the energy expenditures of unelectrified households are less affected by income than do those of electrified households. Among electrified households, this result signals the existence of wide disparities in energy expenditures as income changes i.e. low income households are expected to have larger values of $wTEE$ while high income electrified households have lower values of $wTEE$. This is consistent with earlier findings in African countries which show that the poor spend higher shares of their budgets on energy than the rich do (Sahn and Ninno, 1994; Kebede *et al*, 2002). On the other hand, the energy expenditure share differences between rich and poor unelectrified households are less compared to those of electrified households because of the smaller coefficient of $\ln TE$ among the unelectrified households.

There is a positive relationship between the value of appliances owned by households and the share of energy expenditure for both electrified and unelectrified groups of households, confirming our earlier hypothesis. The effect is however lower among unelectrified households, who use sources of energy that do not require a lot of investment in appliances for their use. We therefore attribute the increase in the share of energy as the value of appliances increases to the use of electricity.

The share of energy expenditure is higher among larger electrified households, but $wTEE$ increases at a decreasing rate as household size increases. This is shown by the negative sign on the coefficient of the square of household size. This is true for both groups of electrified and unelectrified households. This, according to Elsner (2001) depicts the existence of economies of scale in energy consumption. As the size of the household increases, the additional expenditure on energy due to the additional household member decreases. Though the effect of household size is positive on *wTEE* among unelectrified households, this is not statistically significant, neither is that of the square of household size.

The amount of space available to a household, measured by the number of rooms that are used positively influences *wTEE* such that households with more rooms allocate more resources to energy purchase than households with fewer rooms but with similar other characteristics. The requirement for more energy by households with more space is significant only among electrified households. This variable is not significant for unelectrified households who use mainly kerosene and firewood. These fuels have limited use beyond cooking and lighting (kerosene), and cannot be used in multiple rooms at the same time apart from lighting using kerosene. Kerosene and firewood are also not used for powering appliances such as radios and fans whose use increases with the number of rooms. Electricity can be used in several rooms for such tasks as heating space, powering cooling fans etc.

The number of households living at the same premises also affects only electrified households significantly. For this group of households, the share of energy expenditure increases as the number of households occupying the same premises increases, confirming the hypothesis described in the previous chapter. The increased allocation of the total budget to energy is mainly attributed to the increased electricity bill (see box 5.1 in Chapter 5 for an explanation). For unelectrified households, the coefficient of this variable is not significant. The expectation that households who live together can reduce the cost of fuels like firewood through collective bulk purchases is not supported by the empirical evidence. .Either, these practices are not common, or do not yield significant economic benefit to households.

The differences in the sets of variables that significantly explain *wTEE* between electrified and unelectrified households show that on one hand, both income variables and household characteristics shape the energy expenditure patterns of electrified households. On the other hand, the decisions of unelectrified households are mainly shaped by income variables. The energy consumption level of unelectrified households is still low such that it is still increasing i.e. most are still consuming below necessary levels because their incomes limit them to consume more. Even when other household factors change in such a way that more energy is required, they cannot increase their expenditure on energy without adversely affecting their consumption of other commodities. Only their income levels still dictate their energy expenditure. This is also evident in their expenditure (income) elasticity which is higher than that of electrified households (the expenditure or income elasticities of electrified and unelectrified households are 0.88 and 0.95 respectively according to equation (7) in Chapter 5). The energy expenditure patterns of electrified households on the other hand are affected by changes in other household characteristics in addition to income. From a policy perspective, only a few levers are available to influence the energy consumption patterns of unelectrified households, whereas the energy consumption patterns of electrified households can be influenced through several different policy options.

6.3.4 Allocation of energy budget to individual fuels

The second stage of household energy decision making involves allocating the total energy budget or total energy expenditure (TEE) to individual fuels in the energy mix. This is estimated as a system of equations, determining the shares of each fuel in the energy mix given household total energy expenditure, the relative prices of the fuels paid by different households and other household characteristics described in Chapter 5. Estimations were carried out separately for electrified and unelectrified households. This system was estimated in Limdep 7.0 using the Heckman procedure. Thus the dependent variables are regressed against the standard variables and the IMR, in addition. The IMR, denoted λ_2 in the following results, was obtained from the second probit model discussed earlier. All the equations in the system estimating the w_i shares have the same regressors, and due to this feature, equation by equation estimation of the system using OLS yields the same results as the GLS estimator in the seemingly unrelated regression (SURE) estimation (Greene, 2000; Deaton and Muellbauer, 1980; Edgerton *et al*, 1996). We therefore estimated the model using OLS, constituting a two-stage least-squares estimation together with the probit models that yield the IMR. We present the results for electrified first, followed by those for unelectrified households.

6.3.4.1 Electrified households

Table 6.6 gives the results of the estimations of the energy expenditure shares of different fuels for electrified households, together with the overall statistics and an indication of the variables that are statistically significant. While we recognize the significance levels of the variables in the estimations of shares for different fuels, we also comment on the tendency of the w_i shares in response to those factors that are not significant statistically, and of course take note of this.

Table 6.6: Shares of individual fuels for electrified households

Variable	w_e	w_f	w_k
Constant	-.838***	.775***	1.063***
	(.190)	(.147)	(.151)
$\ln TEE$	.096***	-.021*	-.076***
	(.018)	(.014)	(.015)
$\ln Asset$	.058***	-.044***	-.014*
	(.012)	(.009)	(.009)
$Hhsize$	.055***	.015	-.071***
	(.020)	(.015)	(.016)
$Hhsize2$	-.004***	-.0007	.005***
	(.001)	(.001)	(.001)
$Hhslive$	.004	.013*	-.016**
	(.009)	(.007)	(.008)
$Rooms$	-.013*	.009	.004
	(.008)	(.006)	(.007)
$Educ$	.019***	-.017***	-.002
	(.005)	(.004)	(.004)
p_e	-.470***	.191*	.279**
	(.143)	(.111)	(.114)
p_f	.281***	-.172***	-.109*
	(.079)	(.061)	(.063)
p_k	-.222*	.226**	-.004
	(.122)	(.095)	(.097)
λ_2	.330*	-.544***	.214
	(.194)	(.150)	(.155)
R^2	.444	.318	.320
Durbin-Watson	1.529	2.000	1.635
Significance	.000	.000	.000
Akaike Information Criterion	-.105	-.616	-.558
Rho	.236	-.0002	.182
Diagnostic Log – L	25	91	83
Restricted Log – L	-50	42	34

LogAmemiyaPrCrt	-2.942	-3.454	-3.400

Figures in parentheses are standard errors

*, ** and *** represent significance at the 10*, 5% and 1% respectively

The share of electricity in the energy budget increases as total energy expenditure increases, while the shares of firewood and kerosene decrease. Thus electricity is the normal good for electrified households while firewood and kerosene are inferior products (Deaton and Muellbauer, 1980). In all cases for this variable, electricity is the most sensitive to changes in energy expenditure, followed by kerosene. As TEE is expected to increase with income, the share of electricity increases as income rises, while the shares of kerosene and firewood fall, with the share kerosene falling faster than the share of firewood. Total energy budget elasticities were calculated using equation (7) in Chapter 5. The energy budget elasticities of electricity, firewood and kerosene are 1.10, 0.98 and 0.92 respectively. Thus as TEE increases, the quantity of electricity increases by more than the percentage increase in TEE, while the quantities of firewood and kerosene increase by less than the percentage increase in TEE i.e. they are inelastic to changes in TEE. This is explained by the fact that electricity is a normal good, and that households prefer electricity to firewood and kerosene. The order of preference for the three fuels is also evident in the order of magnitude of the elasticities.

The share of electricity increases that as the value of energy appliances used by households increases, while the shares of kerosene and firewood in total energy expenditure decrease. Thus access to appliances, when all other factors are kept constant, enables households to use more electricity, thus reducing their use of fuelwood and kerosene. This is consistent with the literature cited earlier e.g. Campbell *et al* (2000). Increase in the value of appliances is mainly attributed to electrical appliances, whose use substitutes the use of fuelwood and kerosene, while increasing the use of electricity. This variable is significant for all the three fuels under consideration. As households have more access to these appliances, more tasks are undertaken using electricity thereby shifting expenditure from firewood and kerosene to electricity.

Increase in the size of the household leads to an increase in the expenditure shares of electricity and firewood, while the share of kerosene decreases. The increase in shares is higher for the share of electricity and lower for the share of firewood, while the decrease in the share of kerosene expenditure almost totally compensates for the increase in the shares of the other two. However, the coefficient of the variable $Hhsize$ has low statistical significance for w_f. This because the quantity of firewood required for tasks such as cooking do not change much with additional household members. The minimum amount of firewood required to prepare a meal for one person does not increase much when an additional person comes to a household. Because of the time and effort required to use firewood such as starting and putting out fires, households adopt the practice of cooking one meal for all households at the same time. For electricity and kerosene, it is easy to prepare meals for different household members separately e.g. early cooking for children and late cooking for household members who get home from work late. While the addition of new household members leads to an increase in the consumption of electricity and firewood, the use of kerosene, especially kerosene stove, does not support large household sizes for tasks like cooking. Thus as household size increases, households cut back on kerosene and reallocate their energy budgets mainly to electricity.

The hypothesis of economies of scale is confirmed in the expenditure on individual fuels as it was confirmed for TEE, with the shares of household size squared having a negative coefficient for both firewood and electricity. However, the significance of household size squared is lower for w_f both in magnitude and statistically. Thus as household size increases, the shares of energy expenditures allocated to electricity and firewood increase at decreasing rates. The marginal energy requirement of an additional member is declining. The coefficient of $Hhsize2$ for w_k on the other hand is positive, and consistent with the expectation of a U curve characteristic. As household size increases, the cost of kerosene rises sharply such that households cut on its use, thus the decline in its expenditure share. At larger household sizes, kerosene is used only as a supplement to other fuels, and for periods when there are shortages of other fuels such as when there are power cuts. The negative coefficient of $Hhsize2$ on w_f is also consistent with the hypothesis of an inverted U curve pattern for household size.

The shares of both electricity and firewood increase as the number of households living at the same property (*Hhslive*) increases, while the share of kerosene decreases. The sign of the coefficient of *Hhslive* on w_e is consistent with our hypothesis. According to this hypothesis, the more the number of households sharing the same premises, the higher the cost per unit of electricity because of the electricity pricing structure. However, the coefficient is not statistically significant, and the magnitude of the coefficient is very small. w_f increases as the number of households occupying the same premises increases, while w_k decreases, and the coefficients are significant. The previous (first stage) model has shown that indeed, the share of energy expenditure in total expenditure goes up with *Hhslive*, confirming that there is an additional energy cost associated with additional households at one property. In the previous chapter, we noted that this variable is supposed to influence mostly electricity expenditure, which is supposed to increase as *Hhslive* increases. However, in the same hypothesis, we also noted that this marginal cost levels off at increasingly higher levels of consumption. This thus reduces the impact of *Hhslive* on w_e thus the low level of significance. The failure of the data to significantly confirm the hypothesis that w_e increases with *Hhslive* is also explained by the fact that households at crowded premises diversify to other sources of energy in response to electricity overload as explained below. Apart from the cost of energy associated with increased numbers of families at the same property, the electricity supply also gets overloaded as more households sharing the same property push demand up such that households increase their consumption of other fuels. Electricity overload usually occurs during peak energy use times such as times of cooking in the morning and in the evening. This forces households to use other fuels in place of electricity. Thus they increase the share of the energy budget allocated to firewood, cutting on kerosene expenditure, which is more expensive.

The results show that as the number of rooms increases, the share of electricity expenditure in total energy expenditure decreases while the shares of firewood and kerosene increase. The coefficients are not statistically significant, and do not confirm the hypothesis that as the number of rooms increases, the share of electricity increases while the shares of firewood and kerosene decrease. The main explanation to the trend shown by the data is that at the minimum number of rooms, electrified households spend almost all their energy budgets on a single fuel, which is electricity. As the number of rooms increases *ceteris paribus*, household energy requirements increase for purposes like lighting, warming space etc. For example, households with many rooms cook in a different room from the lounge or family room. Extra energy is required for warming. Houses with separate lounges are often fitted with fireplaces that use firewood. This brings firewood into the energy mix. Also as energy requirement increases, the risk of relying on one fuel increase, thus households diversify to firewood and kerosene to reduce the risk. While total energy expenditure increases, the shares of fuels such as firewood and kerosene increase while that of electricity declines. The fact that the coefficients of w_f and w_k are not statistically significant show that the effect is weak, and other factors have a bigger role in explaining the observed pattern.

The educational level of the household head, measured by the number of schooling years, is positively related to w_e, and negatively related to both w_f and w_k, but the coefficient is not statistically significant for w_k. The perception of firewood as an inferior fuel is higher among more educated households than among less educated ones, while electricity is perceived as a more modern fuel, to be used by households with high status. This is consistent with the hypothesis of psychogenic needs (Thomas, 1972). Kerosene is also perceived to be inferior to electricity, but the level of significance is low. Therefore as the level of education increases, households allocate more of their energy budgets towards the purchase of electricity, reducing the budget share of firewood by an almost equal amount, while reducing the share of kerosene marginally.

The price of electricity is significant in explaining all of w_e, w_f and w_k. The signs of the coefficients of p_e on w_e, w_f and w_k are also consistent with our *a priori* expectations. An increase in the price of electricity increases the shares of both firewood and kerosene while reducing the share of electricity in total energy expenditure. A greater portion of the expenditure saved from reduced electricity expenditure is reallocated to kerosene.

The share of electricity increases with increases in the price of firewood, while the shares of firewood and kerosene decrease. Households cut back on firewood as expected, and reallocate the savings made on reduced firewood expenditure to electricity. They also cut on their expenditure on kerosene, which, together with firewood, is inferior, compared to electricity, and increase their expenditure, thus their consumption of electricity. The coefficients of p_f are significant for all fuels.

An increase in the price of kerosene results in the decrease in the shares of kerosene and electricity, while the share of firewood goes up. The share of kerosene hardly changes when its price changes, and the coefficient is not statistically significant. Households respond to increases in the prices of kerosene by increasing the share of firewood expenditure. The increased firewood budget enables households to use it more frequently and for tasks normally done using electricity, such as ironing, cooking and warming space thereby reducing the expenditure on electricity. Because of the high price of kerosene relative to electricity and firewood small changes in the price of kerosene have larger effects on the levels of consumption of other fuels other than itself. For example, when the price of kerosene increases, households reduce the amount of kerosene they consume. The savings from this reduction in kerosene are reallocated to firewood, enabling households to buy more units of firewood because of its relatively low price compared to kerosene.

The order of substitution of the three fuels for each other in terms of expenditure partly shows the order of preference of use of the three fuels. When the price of kerosene increases, households increase the share of firewood in the energy budget. When the price of firewood increases, households increase the share of electricity, and when the price of electricity increases, households increase the budgets of both firewood and kerosene. This shows that the combination of firewood and kerosene is an inferior substitute of electricity. Between themselves, firewood and kerosene are direct substitutes, and this is evident when the price of kerosene changes.

The effect of price changes on quantities of fuels consumed is assessed using price elasticities derived from the table above using equations (5) and (6) in chapter 5. Elasticities are important for assessing the impact of policies on quantities demanded. The own and cross price elasticticities of demand for electricity, firewood and kerosene are given in table 6.7 below. These are compared with elasticities obtained from urban households in Ethiopia, covering several urban areas and several fuels (Kebede *et al*, 2002). These are presented in table 6.8, showing only electricity, firewood and kerosene.

Table 6.7: Price Elasticities of demand in electrified households

Quantity Changes ↓	Price Changes →		
	Electricity	Firewood	Kerosene
Electricity	-1.67	.33	-.28
Firewood	2.29	-2.88	2.51
Kerosene	3.61	-.1.08	-.97

Table 6.8: Price Elasticities from Ethiopia

Quantity Changes ↓	Price Changes →		
	Electricity	Firewood	Kerosene
Electricity	-0.74	0.59	-0.84
Firewood	0.36	-1.17	1.14
Kerosene	-2.14	-0.63	-1.64

Source: Kebede *et al* (2002)

The own price elasticities of all fuels are negative, in conformity with theoretical expectations. This also agrees with findings by Kebede *et al* (2002) in Ethiopia, which shows own price elasticities to be negative. However, the own price elasticity estimates from our study have higher magnitudes than those from Ethiopia in most cases. The larger magnitudes are partly because our elasticities are calculated using total energy expenditure budget shares instead of total household expenditure shares. Quantities of fuels are more sensitive to changes in total energy expenditure than to changes in total household expenditures. However, our estimates are consistent with existing data on the aggregate energy price elasticity for domestic energy for Zimbabwe which show energy to be price elastic i.e. less than minus one (Dahl, 1994). The elasticity of energy demand for Tanzania is also less than minus one (Dahl, 1994). Cross price elasticities from our data also compare well with those from Ethiopia given the high variability in elasticity data from different sources. The only price elasticity figure that is not consistent with Ethiopian data is that of kerosene in response to changes in the price of electricity. In our results, kerosene consumption increases with electricity price increases. Ethiopian data shows this to be the opposite. Our data gives a more consistent result in this case as kerosene, together with firewood, are substitutes for electricity. Firewood is highly sensitive to changes in the prices of all fuels, with absolute values of own and cross price elasticities being greater than one. When the prices of electricity and kerosene increase, the quantity of firewood increases by more than the proportionate increases in these other fuels. It is the response of firewood to changes in prices that has the most important policy implications for our study that aims to study the demand for firewood by urban households. Therefore the prices of both firewood and other fuels are important policy variables for managing fuelwood demand.

According to the results for electrified households, the most significant variables affecting firewood demand are income, the ownership of electric appliances, the educational level of the head of household and prices of firewood and alternative fuels. The index used to represent the relative prices of fuels in the estimations is a reliable indicator of price. The majority of the coefficients of prices are statistically significant and the associated price elasticities compare well with elasticity data from elsewhere.

6.3.4.2 Unelectrified households

The energy choice set of unelectrified households is made up of firewood and kerosene. The results of the estimation of the model for unelectrified households are presented in table 6.9 below. We discuss the effect of each variable in turn, under the *ceteris paribus* assumption.

Table 6.9: Shares of individual fuels for unelectrified households

Variable	w_f	w_k
Constant	-.315	1.236**
	(.676)	(.599)
$\ln TEE$	.088	-.074
	(.071)	(.063)
$\ln Asset$	.041	-.052*
	(.032)	(.028)
$Hhsize$	.076	-.096*
	(.058)	(.052)
$Hhsize2$	-.003	.004
	(.004)	(.003)
$Hhslive$	-.010	.010
	(.025)	(.022)
$Rooms$	-.064	.096*
	(.058)	(.051)
$Educ$	.005	-.009
	(.022)	(.020)
p_f	-.159	.365
	(.018)	(.282)
p_k	.659*	-.721**
	(.371)	(.328)
λ_2	.225	-.255
	(.214)	(.189)
R^2	.316	.415
Durbin-Watson	1.757	1.914
Significance	.308	.087
Akaike Information Criterion	.713	.469
Rho	.121	.043
Diagnostic Log – L	-3	2
Restricted Log – L	10	-8
LogAmemiyaPrCrt	-2.108	-2.352

Figures in parentheses are standard errors

*, ** and *** represent significance at the 10*, 5% and 1% respectively

The results of the estimations of the AIDS demand model show the two fuels to be direct substitutes of each other among unelectrified households. However, most variables are not statistically significant at the 10% level, mostly owing to the small sample size of unelectrified households. We however discuss the results on the basis of the signs of the coefficients.

The share firewood in total energy expenditure (w_f) increases with total energy expenditure while the share of kerosene, w_k, decreases, though in both cases, the coefficients are not significant at the 10% level. The signs of the coefficients show firewood to be the normal good while kerosene is inferior. The energy expenditure elasticities of 1.09 and 0.93 based on equation (7) in Chapter 5 for firewood and kerosene respectively show that as energy expenditure increases, quantities of both fuels increase, but kerosene demand increases at a lower rate.

The value of appliances ($\ln Asset$) has opposite effects on w_f and w_k, and is significant for w_k and insignificant for w_f. The share of firewood increases as the value of appliances increases while the share of kerosene decreases. In our hypothesis, we had expected $\ln Asset$ not to have a significant effect on both w_f and w_k. While the low level of significance of $\ln Asset$ on w_f is consistent with the low level of technology required to use firewood, the positive coefficient is attributed to such simple appliances as tripod cooking stands and pressing irons that use firewood. Kerosene on the other hand is not used for such tasks as pressing clothes, thus its share decreases. The use of kerosene is restricted to just cooking and lighting. Therefore households who have invested in appliances allocate more of their budgets to firewood which can be used for several purposes, while the share of kerosene declines.

The effect of household size on firewood and kerosene expenditure is consistent with our expectation, with the share of firewood increasing with household size while the share of kerosene decreases, and both are statistically significant at the 10% level. The signs of the coefficients of $Hhsize2$ on w_f and w_k exhibit a U curve characteristic for kerosene and an inverted U for firewood. Thus, as household size increases, the kerosene share initially decreases and then increases. For firewood, w_f initially increases and than decreases. As the number of household members increases, the use of kerosene for common uses like cooking meals becomes too costly, and households reallocate their energy budgets to firewood thereby reducing w_k and increasing w_f. Kerosene use gets limited to such uses as lighting, and for uses that require fast fuels such as boiling water for bathing and tea early in the morning and in the evening for household members who go to work and for children. At small household sizes, the reduction in kerosene consumption for the main uses like cooking meals is substantial compared to increases in its consumption for the minor uses of lighting and boiling water and warming food. However, as household size gets bigger, the number of members using kerosene for the minor uses also increases thereby increasing the absolute quantity of kerosene consumed. This leads to a gradual increase in the share of kerosene expenditure in total energy expenditure, while the share of firewood declines. However, this later change in the shares of kerosene and firewood are minor, and are not statistically significant.

The coefficient of the number of households living at the same property ($Hhslive$) has a very low level of statistical significance. This supports our hypothesis in the previous chapter, that the number of households living at the same property has no effect on energy expenditure patterns of unelectrified households. However, the observed pattern, in which the share of kerosene increases and the share of firewood decreases when $Hhslive$ increases could be explained by the fact that limited space at crowded premises does not allow each household to use firewood. When one household is using the cooking place, other households resort to the use of kerosene, which they can use in their rooms. Cooking with kerosene is possible in rooms that are used for other purposes like in living rooms, while cooking with firewood is only possible in open spaces or rooms specifically set aside for cooking. Also, when the number of households living at a property increases, the chances that some households live in cottages made from wood and plastic increases, and firewood cannot be used in these rooms. Therefore households allocate more of their energy budgets to kerosene, explaining the observed patterns.

The share of kerosene increases with the number of rooms used by households, and the coefficient of *Rooms* is statistically significant. The more the number of rooms used by households, the more the kerosene is required for tasks such as lighting in the several rooms. This increases the budget of kerosene thereby reducing the budget for firewood. The coefficient of *Rooms* on w_f is therefore negative, but not statistically significant. In our hypothesis however, we did not expect *Rooms* to have any significant effect on the energy allocations of unelectrified households.

The level of education of the household head is not significant among unelectrified households. Since both firewood and kerosene are perceived as inferior fuels compared to a fuel like electricity, the effect of psychogenic needs expressed through the educational level of the household head does not have a significant bearing. The indifference in preference for the two fuels by households is also evident in their actual shares in total energy expenditure of 55% and 45% for firewood and kerosene respectively, which are almost equal (see table 6.2). Moreover, the educational level of household heads among unelectrified households does not have wide variation.

The expenditure shares of both firewood and kerosene respond to changes in prices in accordance with theoretical expectations. While the level of significance of the price of firewood on both w_f and w_k is low, the price of kerosene is significant for both w_f and w_k. Increases in the price of firewood increases the share of kerosene while the share of firewood decreases. A change in the price of kerosene on the other hand has the opposite effect. The consistency of this result with economic theory is also evident in the values of their own price and cross price elasticities of demand for the two fuels. Table 6.10 presents the price elasticities of demand for firewood and kerosene derived from the estimates in table 6.9 above.

Table 6.10: Price Elasticities of demand in unelectrified households

Quantity Changes	Price Changes	
	Firewood	Kerosene
Firewood	-1.37	1.12
Kerosene	.95	-2.61

The own price elasticities of demand for both firewood and kerosene are negative, with magnitudes of greater than minus one (elastic). At least the negative values of these figures are consistent with elasticity estimates from Ethiopia presented earlier in table 6.8 (Kebede *et al*, 2002), except that the magnitude of kerosene's own price elasticity is very high, showing that its consumption is very sensitive to its own price. The cross price elasticity estimates from our data are both positive, showing that firewood and kerosene are substitutes of each other. The response of the demand of the commodities to changes in the price of its alternative is high, shown by the elastic demands. This has important implications for policies aimed at managing fuelwood demand.

The results of the model estimations show firewood and kerosene to be direct substitutes of each other among unelectrified households. A change that results in an increase in the budget of one fuel results in a decrease in the share allocated to the other in all cases. However, the energy consumption patterns of unelectrified households are influenced by only a few variables. The small sample size for unelectrified households partly explains the low levels of significance of most variables. This confirms the earlier finding about variables explaining the share of total expenditure allocated to energy at the first stage of decision making. Variables other than those related to incomes of households had little significance at that stage, and even in the case of changes in total income (expenditure) the response of energy expenditure was very low.

6.4 Household energy mix

The model results presented above describe the behavior of households in their energy decision-making processes, in response to changes in several variables. In this section, we provide a static analysis of the actual consumption of the different sources of energy. Specifically, we present the household energy mix of households in the sample. The energy mix is presented in terms of expenditure shares and also in form of actual quantities of different fuels. The analysis is carried out for households in the electrified and unelectrified categories separately, and also for households in different income categories. For each group of electrification status, the sample is split into three groups of households based on total expenditure, each representing low, medium and high income (see table 6.11 below). This analysis provides support for policy discussions to be made based on model results.

The average expenditure shares of electricity, firewood and kerosene in the total household energy budget are given in table 6.11 below. These are presented for different electrification groups and for different income levels. The income levels were determined separately for electrified and unelectrified households using expenditure data from the household survey. Thus the range of expenditure that defines low income for electrified households does not necessary define low income among unelectrified households.

Table 6.11: The expenditure mix of electrified and unelectrified households at different levels of income

Income group	Average w_i shares						
	Electrified households				Unelectrified households		
	Expenditure range (Z$)	w_e	w_f	w_k	Expenditure range (Z$)	w_f	w_k
Mean	$19,700	0.89	0.09	0.10	$5,400	0.55	0.45
Low income	Less than $10,000	0.76	0.11	0.13	Less than $5,000	0.53	0.47
Medium income	$10,000 - $50,000	0.93	0.03	0.04	$5,000 - $10,000	0.56	0.44
High income	More than $50,000	0.99	0.01	0.00	More than $10,000	0.84	0.16

The actual quantities of each fuel in the energy mix are computed by dividing the actual expenditure on each fuel by its price. This is converted from the unit of the fuel to a common unit, the mega joule (MJ) to enable comparison across different fuels. The conversion factors for kerosene, firewood and electricity, together with their prices in their original units, and in the common unit are given in table 6.12 below. The unit price of electricity is an average, reflecting the tariff structure by taking into account the fixed monthly charge and the prices of units of electricity at different consumption levels. An average consumption level in Harare is used to arrive at the price given in the table, using prices that were prevailing at the time of data collection.

Table 6.12: Prices of firewood, kerosene and electricity, energy conversion factors to MJ and prices of these fuels per MJ

Fuel	Common unit	Price per unit (ZWD)*	Conversion factor (MJ per unit)**	Price per MJ (ZWD)
Electricity	Kilowatt hour (kWh)	2.95	3.6	0.82
Firewood	Kilogram (kg)	7.12	16	0.45
Kerosene	Liter (l)	104.44	35	3.12

* Source: Data collection in this study

**Sources: UNEP (1991)
Attwell *et al* (1989)

The relatively high price of kerosene is a reflection of the scarcity of the commodity on the market. The scarcity of petroleum products make consumers pay black market prices which are higher than gazetted prices. Only a few persons are able to buy kerosene from fuel stations in bulk because of supply shortages. These in turn sell to consumers in small quantities of 0.75 liter bottles at prices much higher than the normal price had supplies been adequate.

Using the expenditure shares and the conversion factors and prices in table 6.12, the actual quantities of electricity, firewood and kerosene in the consumption mix of the surveyed households are calculated by dividing total expenditure with price. These are given in table 6.13, together with the shares of each fuel in the consumption mix. To arrive at the actual energy consumption figures in table 6.13, the expenditure share of each fuel is multiplied by the total energy expenditure to get the expenditure for each fuel. This is divided by the unit price of the respective fuel in table 6.12 to get actual consumption for respective fuels. The actual consumption figures are converted to a common unit using the conversion factors given in table 6.12.

Table 6.13: Average actual quantities of different fuels consumed by a household in MJ and the share of each fuel in the energy or consumption mix

Fuel	Contribution to total energy consumption			
	Electrified households		Unelectrified households	
	Actual energy consumption (MJ)	share of total actual energy consumption	Actual energy consumption (MJ)	share of total actual energy consumption
Electricity	1736	0.81	0	0
Firewood	355	0.16	994	0.90
Kerosene	56	0.03	116	0.10
Total	2147	1	1110	1

An average electrified household consumes a total of 2147 MJ of energy per month, this being made up of 81% electricity (1736MJ), 16% firewood (355MJ) and 3% kerosene (56MJ). Electricity still maintains its dominance in actual consumption. The contribution of kerosene in the actual energy or consumption mix is much lower compared to its contribution to energy expenditure, while that of firewood is considerably higher. For unelectrified households, 90% of total energy consumption is made up of firewood, while kerosene makes up 10%. This gives a total of 1110MJ of energy consumed by a typical unelectrified household per month. Thus unelectrified households consume 52% of the energy consumed by electrified households per month. In welfare terms, the relative welfare of electrified households is higher than that of their unelectrified counterparts when energy is considered.

Using the same approach, we calculated the average expenditure and physical energy mixes in different income groups. The sub-samples of electrified and unelectrified households were each split into three equal groups of increasing expenditure. The categories low, medium and high income refer to different income ranges for the electrified and unelectrified groups of households as discussed earlier i.e. the income range representing high income for electrified households is different from the range representing high income for unelectrified households. These are given in table 6.14 below.

Table 6.14: Actual quantities of different fuels (in MJ) consumed by households in different income and electrification categories

Income group	Actual quantities of fuel consumed measured in MJ						
	Electrified households				Unelectrified households		
	Electricity	Firewood	Kerosene	Total	Firewood	Kerosene	total
Low	952	254	43	1249	716	91	806
Medium	3233	192	32	3462	1235	138	1373
High	5711	74	2	5787	1956	53	2009

Energy consumption is higher among higher income groups for both electrified and unelectrified households. However, electrified households consume more energy than their unelectrified counterparts in the respective income groups. In fact the differences are so high that on average, a high income electrified household consumes more than double the amount of energy consumed by a high income unelectrified household. The welfare of electrified households is therefore high when measured in terms of energy consumption compared to unelectrified households.

The energy consumption and expenditure mixes of households in different income groups are given in tables 6.15 for electrified and unelectrified households. The figures given are averages of each of low income, medium income and high income groups.

Table 6.15: Energy quantity shares of different fuels for households in different income groups

Income group	Quantity shares*				
	Electrified households			Unelectrified households	
	Electricity	Firewood	Kerosene	Firewood	Kerosene
Low income	0.76	0.20	0.04	0.89	0.11
Medium income	0.93	0.06	0.01	0.90	0.10
High income	0.99	0.01	0.00	0.97	0.03

*Quantity shares denote the contribution of the different fuels to the actual consumption mix in mega joules. The quantities are taken from table 6.14.

Among electrified households in all income groups, electricity is the dominant fuel in terms of physical consumption, with a higher share among households in higher income categories. The contribution of firewood in actual energy consumption is much higher among low income households than it is in expenditure terms i.e. the share of firewood in actual energy consumption is 20% while its contribution to total expenditure is 11% in low income households. Its contribution to both energy expenditure and actual consumption is very negligible among high income households. The share of firewood in terms of actual consumption is higher among unelectrified households in higher income groups, while the shares of kerosene expenditure and consumption are lower for higher income groups. In each income group, the contribution of firewood to total energy consumption is much higher than its contribution to total energy expenditure. Thus among unelectrified households, the contribution to firewood consumption is higher among high income households.

In summary, the energy mix statistics show the dominance of electricity in terms of both expenditure and actual consumption among electrified household. The shares of electricity expenditure and actual consumption are highest among high income groups. While kerosene completely disappears from both expenditure and actual consumption among high income households, firewood still remains in the mix, though with a very low contribution. Among unelectrified households, the quantity share of firewood is high among high income households. Among all groups of unelectrified households, the share of firewood in actual consumption is much higher than its share in energy expenditure, owing to its lower price compared to kerosene.

6.5 Firewood consumption

The preceding two sections presented the results of model estimations showing the behavior of households in their energy expenditure patterns, and the energy mixes of households in terms of expenditures and actual quantities consumed. The ultimate effect on the environment works through fuelwood consumption, whose total demand for Harare we estimate in this section. The actual quantities of firewood consumed by households in Harare were calculated on the basis of the share of firewood expenditure in the energy budgets of households and the unit price of the fuel. The following equation was used to calculate the quantity of firewood q consumed by a household whose share of firewood expenditure in TEE is w_f when the price of firewood per kg is p_f.

$$q = \frac{w_f .TEE}{p_f}$$

Using this formula and the average values of w_f and TEE, an average household was found to spend Z$179 per month on firewood for all households taken together. Electrified households spend and average of Z$108 per month on firewood while unelectrified households spend Z$412 per month. Given the average firewood price at the time of the survey of Z$7.12 per kg, this expenditure translates into 15kg of firewood per month and 58kg per month for electrified and unelectrified households respectively. Per annum, the respective quantities consumed per household are 185 kg and 695 kg for electrified and unelectrified households. Table 6.17 gives the monthly and annual expenditures on firewood, and the actual quantities of firewood consumed by a household for the two categories of electrification status.

Table 6.16: Household monthly firewood expenditure and consumption by electrification status

Measure	Electrified households	Unelectrified households
Monthly expenditure on firewood (Z$)	108	412
Household monthly firewood consumption (kg)	15	58
Household annual firewood consumption (kg)	185	695

When the survey sample is broken into different income categories, consumption of firewood by households in the different categories can be compared. This is provided in table 6.18 below.

Table 6.17: Annual energy demand by households in different electrification and income categories

Income category	Quantity of firewood consumed (kg/household/year)	
	Electrified households	Unelectrified households
Low income	190	537
Medium income	144	926
High income	56	1467

Firewood consumption is high among low income electrified households, and is very low among high income households in this category of electrification. In fact, an average low income electrified household consumes more than three times the quantity of firewood consumed by a high income electrified household. The opposite is true for unelectrified households. In this category of households, an average high income household consumes almost three times the amount of firewood consumed by a low income household. Thus it is the low income electrified, and the high income unelectrified households who make the highest contribution to firewood consumption in Harare, according to the survey data.

Using the number of households in Harare of 405,861 (CSO, 2003), and the observed proportions of electrified and unelectrified households in Harare of 78% and 22% respectively (Campbell et al, 2000), 316,572 and 89,289 households are electrified and unelectrified respectively. Using the average household fuelwood consumption rates given above, we calculated the total firewood consumption by all electrified and all unelectrified households in Harare. Total annual firewood consumption is estimated at 58,600 tones and 62,000 tones for electrified and unelectrified households respectively, giving a total of 120,600 tones for the whole of Harare. According to these results, electrified households account for 49% of total firewood consumption in Harare, while unelectrified households account for 51%. The high aggregate contribution of electrified households is due to their high contribution to total population.

Frost (1996) shows that the average harvestable wood (on a dry matter basis) from miombo woodlands is 66.43t per hectare. The harvestable wood refers to total dried biomass that can be used for firewood i.e. tree trunks and branches, excluding leaves and twigs. Therefore the annual average hectrage required to meet the demand for firewood in Harare is 1,488 (see table 6.19 below). Table 6.18 also gives the woodlands requirements to meet demand for firewood by electrified and unelectrified households separately.

Table 6.18: Total annual firewood demand in Harare by electrification status

Measure	Electrified households	Unelectrified households	All households
Annual firewood consumption (t)	58,600	62,000	120,600
Annual firewood consumption (ha)	1,800	900	2,700
% contribution to total consumption	49%	51%	100%

Our estimates of total fuelwood demand are comparable to estimates from earlier studies. For example, Attwell *et al* (1989) estimated the total annual demand for fuelwood in Harare in 1989 at 93,329 tones. Their adjusted figure based on an average annual consumption by high density households of 524 kg is 120,454 tones. Our figure of 120,600 tones of firewood consumed annually only refers to firewood acquired through purchase and excludes firewood that households collect on their own. In fact, in our sample, some 25% of all households report collecting their own firewood. Incorporating wood that households collect on their own from the bush (not bought on the market) would result in even higher demand figures compared to estimates from earlier studies, showing that that total firewood demand in Harare has increased over the years.

6.6 Simulations

The model results were used to simulate the behavior of households in response to changes in selected demand factors, and determine how this ultimately affects household expenditures on different fuels and total fuelwood demand. The results of the simulations are presented in this section. The effects of changing the following variables, which can be used as policy levers, were investigated:

- Household total energy expenditure
- The value of appliances possessed by households
- The educational level of the household head
- Prices of electricity, firewood and kerosene
- The proportions of electrified and unelectrified households

The simulations were carried out on a spreadsheet in Microsoft Excel. The effect of changing each variable is considered while all other variables are held constant at their average values. The effects considered are on the shares of electricity, firewood and kerosene in total energy expenditure, the total fuelwood consumed in Harare and the contributions of electrified and unelectrified households to total firewood consumption. The results are given in table 6.19 for the first four variables, and in table 6.20 for changes of proportions of households in the population who are electrified.

Table 6.19: Effect of changing values of selected demand variables on fuel expenditure shares, total firewood consumption and the contributions of electrified and unelectrified households to total firewood demand

Variable	Fuel expenditure shares					Total firewood consumption in Harare		
Direction of change	Electrified households			Unelectrified households		Actual (ton/year)	% contribution of electrified households	% contribution of electrified households
	w_e	w_f	w_k	w_f	w_k			
Base scenario (this study)	**0.81**	**0.09**	**0.10**	**0.55**	**0.45**	**120,600**	**49%**	**51%**
TEE increased by 10%	0.83	0.08	0.09	0.56	0.44	132,200	48%	525
TEE decreased by 10%	0.80	0.09	0.11	0.54	0.46	109,000	50%	50%
$Asset$ increased 10%	0.82	0.08	0.10	0.56	0.44	118,100	47%	53%
$Asset$ increased 50%	0.80	0.10	0.10	0.55	0.45	123,300	50%	50%
$Educ$ increased by 10%	0.83	0.07	0.10	0.56	0.44	107,400	42%	58%
$Educ$ decreased by 10%	0.79	0.11	0.10	0.54	0.46	133,800	54%	46%
p_e increased by 10%	0.77	0.10	0.13	0.55	0.45	133,100	53%	47%
p_e decreased by10%	0.86	0.07	0.07	0.55	0.45	106,800	42%	58%
p_f increased by 10%	0.84	0.07	0.09	0.53	0.47	107,600	0.44	0.56
p_f decreased by10%	0.79	0.10	0.11	0.58	0.42	134,900	53%	47%
p_k increased by 10%	0.79	0.11	0.10	0.62	0.38	142,400	51%	49%
p_k decreased by10%	0.83	0.07	0.10	0.48	0.52	96,500	44%	56%

Small changes in household total energy expenditures is associated with equal percentage changes in the total amount of firewood consumed. The contribution of electrified households to total firewood demand decreases when TEE increases while that of unelectrified households increases. The opposite is true when TEE decreases.

Increasing the value of appliances results in less than the proportionate changes in the total demand in firewood i.e. a 10% increase or decrease in the value of appliances results in less than 10% decrease or increase in total firewood demand respectively. The shares of fuels in total energy expenditure for both electrified and unelectrified households change only marginally, as do the shares of electrified and unelectrified households in total firewood demand.

Increasing and decreasing the level of education of the household head have larger effects on both total firewood demand and the shares of the different fuels in *TEE* . 10% changes in the level of education of the household head either upwards or downwards results in slightly higher than 10% changes in total firewood demand.

As shown on table 6.19, changes in prices of the different fuels result in large changes in the shares of all fuels and total firewood demand. The largest reduction in total firewood demand results from a 10% decrease in the price of kerosene, while a 10% increase in the price of kerosene results in the largest increase in total firewood consumption compared to 10 % points changes in the prices of other fuels. This makes kerosene price an important policy tool in influencing the demand for firewood, together with other variables.

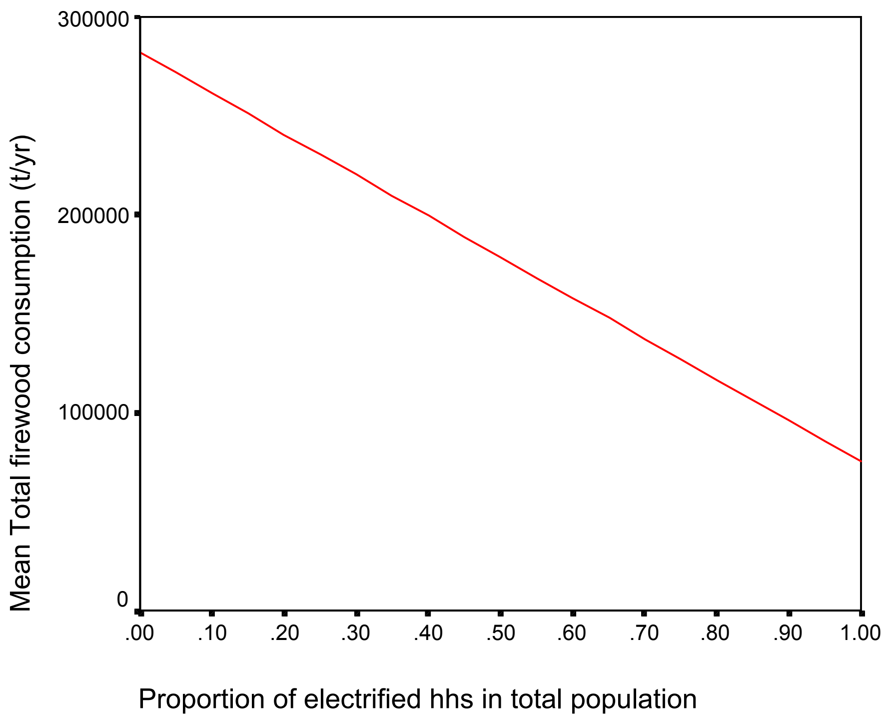
The rate of electrification in a city, as indicated by the proportions of electrified and unelectrified households, is an important factor that determines the ultimate total demand for firewood. The scenario just presented represents the total demand for firewood in Harare using the proportions of electrified and unelectrified households in Harare given by Campbell *et al* (2000). However, this may vary as other studies show that only about 80% of urban households in Zimbabwe are electrified (Karekezi and Majoro, 2002; Karekezi and Kimani, 2002). We computed the total demand for firewood in Harare under different assumptions of the proportions of electrified and unelectrified households in the total population. The results are presented in table 6.20 below. The different scenarios assume that when a currently unleectrified household gets electrified, its income level also changes to the level of that of an electrified households. However, this may not be the case. The level of energy expenditure and consumption, and the energy mix of currently unelectrified households will be different from those of currently electrified households. The same happens when currently electrified households get unelectrified. Having taken note of this assumption, we assume the outcome of this simulation will still have the same policy implication.

Table 6.20: Effect of changing population proportions of electrification status groups on total energy demand

% of electrified households in total population	% of unelectrified households in total population	Total annual firewood demand (tones)
78% (this study)	**22% (this study)**	**120,600**
75%	25%	126,800
80%	20%	116,500
85%	15%	106,100
90%	10%	95,800
95%	5%	85,400
100%	0%	75,100

The electrification of all households in Harare reduces total firewood consumption by 38%. Different levels of total firewood demand in Harare under different proportions of electrified and unelectrified households are presented in figure 6.1 below. Both the figure and the table above show that total electrification of households in Harare reduces fuelwood demand only to a certain level, below which other factors apart from electrification status influence demand.

Figure 6.1: Levels of total firewood demand in Harare as the rate of electrification increases



From these results, we can deduce that proportions of household under the electrified and unelectrified categories are an important policy variable in influencing firewood demand in Harare.

6.7 Policy implications of the results

The results just presented have important policy implications, and in this section, we highlight the general policy considerations that they generate before we suggest specific policies for the management of urban fuelwood demand.

6.7.1 General considerations

The consumption of fuelwood in particular, and energy in general in urban areas has environmental and welfare dimensions. On one hand, energy mixes that have high proportions of fuelwood have negative environmental consequences. Factors that increase the consumption of fuelwood therefore tend to accelerate environmental problems. On the other hand, a welfare scenario also exists as far as overall energy consumption is concerned. For any household with a specific fuel mix, increase in energy consumption increases its utility up to a certain extent thus its welfare while an across the board reduction of energy consumption has negative welfare impacts. Welfare can also be considered in terms of the share of total expenditure that is allocated to energy. The higher the share of total expenditure allocated to energy, the lower the welfare of households as this reduces the amount of expenditure for other household commodities *ceteris paribus*. The results just presented show that low income electrified households spend more of their total budgets on energy, and have higher shares of their energy budgets going to the purchase of fuelwood than do high income households. Unelectrified households on the other hand consume just about half the amount of energy consumed by an average electrified household, thus have relatively low welfare compared to electrified households. They also have higher shares of fuelwood in their energy mixes, indicating that on a per household basis, they contribute more to environmental damage. While high income unelectrified households consume more energy units than low income unelectrified households, their shares of fuelwood are higher, thus contribute more to fuelwood demand. The general aim of policies should be to generate win-win scenarios by both improving household access to energy while reducing the contribution of biomass fuels in the mix.

Urban fuelwood consumption decision making takes place within the overall framework of energy consumption, and is therefore affected by household decisions on overall energy consumption and specific fuel choice. This should also form the basis on which policies to manage or study urban fuelwood demand are made. Thus options for demand-side management of urban fuelwood consumption should be developed accordingly, aimed at influencing the whole energy system. This will determine the amount of wood that is ultimately harvested from the environment. Direct control of either the marketing or harvesting system will have limited impact because of non - compliance by players in the fuelwood business and weaknesses in the enforcement system. This is evidenced by the fact that despite the illegality of cutting down trees and selling firewood, even in designated areas, the practice still continues because enforcement is weak. Firewood is often brought to the city by trucks at night. At the same time, arresting those who sell firewood in urban areas is politically costly since the business employs many urban voters. This is compounded by the fact that the fuelwood system is difficult to influence in isolation or from the supply side because of its rather informal and semi-illegal nature.

The analyses have shown that household energy decision making takes place at two levels, which are key for considerations when policies are being made. The one level is when households decide to allocate their total expenditures to energy in general. Specific household circumstances should reflect the share of total expenditure that goes to energy. Such factors and their influence on household decision-making have been discussed in the results. The second level is that at which households allocate their energy budgets to specific sources of energy. The feasible sets of energy choices available to households should be considered for effectiveness of policies.

Energy expenditure and choices of electrified and unelectrified households differ significantly. The expenditure shares and the mixes of fuels differ as well as the sets of factors affecting such patterns. For example an increase in total energy expenditure reduces the share of fuelwood among electrified households while such an increase tends to increase the share of fuelwood expenditure among unelectrified households. The differences in energy expenditure shares, w_{TEE}, are smaller among unelectrified households with different incomes compared to electrified households, whose variations in w_{TEE} are larger between households in different income groups. The relevance of this finding is that energy policies should be targeted at electrified and unelectrified households separately. Blanket types of policies will result in unintended results. An example of a blanket policy in Zimbabwe in the past has been a subsidy on the price of kerosene intended to benefit households without electricity. This tended to be abused by truckers who bought kerosene at low prices for fueling their trucks, leading to shortages of the product. The intended beneficiaries had to resort to firewood. Similarly, subsidies on kerosene by the government in Ecuador did not help the poor as retailers diverted the bulk of supply to the more profitable transport sector (Barnes, 1995). The different responses of electrified and unelectrified households to different stimuli, and the differences in their energy choice sets therefore requires the use of directed policies and strategies to yield meaningful results. In some cases, combinations of strategies should be used.

Similarly, the results of model estimations show that the sets of variables that significantly influence the energy expenditure patterns of households differ between the electrified and unelectrified groups. While economic, social and demographic factors are significant determinants of household energy expenditure patterns among electrified households, the energy expenditure patterns of unelectrified households are mainly shaped by their incomes. Consequently, different policy levers should be used to the two groups of households.

The demand for fuelwood in Zimbabwe has been downplayed owing to the high levels of electrification in the urban areas (see for example Campbell *et al*, 2003), and total electrification is seen as the end of fuelwood consumption in urban areas. However, this study has shown that total electrification of Harare by ensuring that all households get access to electricity, alone reduces total fuelwood demand by about 38%. Indeed, electrification explains the wide margin in fuelwood consumption between electrified and unelectrified households, but neglects the fact that other factors contribute to the continued presence of fuelwood in the household energy mix of electrified households. This is especially true among low income electrified households. This has both environmental and welfare impacts as discussed above. Thus urban fuelwood management should go beyond just electrification, but should also address those factors that force households to retain energy mixes with high ratios of fuelwood.

The results of this study have also identified welfare implications of the existing energy consumption patterns. Specifically, low income households spend more of their incomes on energy i.e. the share of household budget that goes to energy decreases with income among both electrified and unelectrified households. The expenditure shares of low value fuels like firewood also increase as income decreases. Apart from their poor energy values, fuels such as firewood also have negative health consequences, exposing low income electrified, and all unelectrified household to health risks.

The role of the economic environment in affecting the natural environment through urban fuelwood consumption is evident from this study. Most of the factors influencing household decision-making on energy expenditure and fuel choice are driven by factors operating at the economy level. These include the ownership of dwelling places, affordability of appliances, employment, residence conditions such as sharing and numbers of rooms used, prices etc. A deterioration of the economic environment has negative consequences on the energy welfare and energy choices of urban households who are more integrated into the market economy than their rural counterparts. Adverse economic conditions make poor households spend more of their incomes on energy, and mostly on inferior fuels, restrict household energy choices because of unavailability of alternatives, create unemployment which drives the fuelwood market etc. Poor economic conditions also limit investment in the modern energy sector such that supply is not likely to meet demand. This in turn limits the possibility of expanding electrification in urban areas. The main policy implication of this is that there is a strong connection between the economy and the environment through urban fuelwood consumption. In a country like Zimbabwe where urban electrification that is above average Sub-Saharan levels, disappearance of fuelwood from the urban consumption mix over time can only be assumed in a positive economic environment.

The high level of sensitivity of households to changes in prices of different fuels provides an opportunity to influence household fuel consumption patterns. The magnitudes of most of the price elasticities of demand are high such that changing prices will result in large changes in quantities consumed. This also has high risks associated with it when prices move in unintended directions. Increasing the price of electricity for example decreases its share in total energy expenditure, and consequently its quantity, while increasing the shares of firewood and kerosene. Policies that keep prices of electricity stable are therefore more preferred. On the other hand, firewood and kerosene are substitutes of each other, and demand for firewood can be managed by influencing the price of kerosene. Among unelectrified households, this has a direct effect on firewood demand.

6.7.2 Recommendations

The recommendations we make below follow from the policy considerations presented above. As these are suggestions based on the findings of this study, their implementation need to be preceded by further discussions and investigations of their feasibility. The general aim of the policies is to manage urban energy demand so as to minimize environmental degradation caused by deforestation as well as improving urban household welfare through energy consumption. They are not based on the notion of an energy crisis or an environmental crisis in Harare, but on the likely trends based on our findings. Fuelwood demand is best managed by influencing the whole urban energy system, and not necessarily targeting fuelwood specifically.

A total electrification policy for urban areas should be pursued. This both increases household energy welfare as well as minimizes the contribution of fuelwood in household energy consumption. Total electrification also makes it easier to develop policies and strategies that address just one group of households i.e. electrified households without negatively affecting the welfare of other households without access to electricity. The main challenge to total electrification in cities of developing countries is the nature of accommodation among some electrified households. Many urban households live in illegal or informal settlements that are not serviced with electricity. Some households, though they live in electrified areas, occupy structures whose electrification may result in safety hazards, such as cottages made from plastic, wood etc. Connections of electricity to these are almost impossible. With shortages of accommodation, total electrification will be difficult to achieve. Another obstacle to total electrification is the cost of installation, which has been cited by several studies such as Campbell *et al* (2003), Mapako and Dube (2002) as a big constraint to electrification. Both residence in an electrified ward, and residence in an electrified house were seen to be mainly dependent on income. While households may be able to pay for their electricity consumption or to manage their consumption to make it affordable once they are electrified, they may be constrained by the overheads. Also, while achieving total electrification by improving the incomes of all households may not be feasible in the near term, it is suggested that strategies that enable households to overcome the barriers to electrical installations be removed. These involve supplying electricity to unelectrified wards or residential areas, and developing terms of payment that enable low income households install electricity in their dwellings.

We also recommend a strategy that reduces the overall energy budget by reducing the cost of electricity to electrified households. Reduced electricity costs will increase its use thereby reducing the contribution of other fuels like fuelwood in the energy mix. This strategy should be targeted at electrified households who share the same premises. The results of this study show that the higher the number of households at a property, the higher the share of energy in total expenditure. Cottage dwellers mainly get a cable extension from the main house for simple purposes like lighting such that even though they are electrified, they cannot use their limited supply for several purposes. Many households sharing the same meter also results in the overloading of power supply such that during peak periods like evenings and mornings, some electrified households use alternatives like firewood for tasks like cooking. We suggest that separate meters be installed for different user households as far as is possible, such as for main houses and cottages thereby reducing the cost of electricity to individual households, and also ensuring unlimited supply of electricity for all domestic uses. As in the case of electrification discussed above, the major challenge is the suitability of some secondary dwellings for separate installations, and the cost of new installations. While some residents of these secondary dwellings are willing to pay for installations, they do not have security of tenure at their current residences. Most households who rent accommodation do not sign legal leases specifying how long they are to stay, and they run the risk of being evicted any time by the landlords. Thus investments in separate installations are risky and without a specified period or residence, returns to such investments are not guaranteed. Consequently, we recommend formal lease agreements for renting accommodation.

The energy choice set of urban households should be widened in view of the diversity of the urban community in developing countries. Widening of the choice set should be accompanied by the ease of availability of these fuels so that they become realistic options for households in all areas and income groups. This includes the availability of equipment that use these sources of energy at affordable prices. Technologies such as LPG have rarely been promoted as real energy options for most households in the urban areas of Zimbabwe such that their potential is not tapped. These become ready alternatives in cases of electricity shortages. They are also ideal for households who change residences frequently because they are portable. Gas refilling facilities should also be easily accessible to consumers. Only firewood and kerosene are the main sources of energy for unelectrified households in Harare, and in the shortage of kerosene, firewood becomes the only option. If other sources of energy are available, some households will allocate their energy expenditure towards these fuels.

Basic energy appliances for modern fuels should be made readily available to households at affordable prices. This enables low income households to utilize fuels such as electricity for basic tasks such as cooking. The availability of appliances has shown the tendency of increasing the share of modern fuels in the energy budgets of both electrified and unelectrified households. For electrified households, more resources are put towards electricity, and towards kerosene by unelectrified households. Such appliances as basic electric hot plates, kerosene pressure stoves, gas stoves and cylinders should be considered for subsidies for the benefit of low income households. Such targeted subsidies, on basic appliances are not subject to abuse by high income households who already have more sophisticated appliances. The current electricity pricing structure provides an opportunity to generate resources to finance such subsidies without jeopardizing the financial viability of the power supplier. Increasing the price paid for additional units of electricity beyond a certain level, such as the subsistence level, will provide the required resources. This levy does not affect low income households who consume below the subsistence level. This does not conflict with the recommendation made earlier about reducing the cost of connecting households to electricity.

In the long term, investments in energy generation should be promoted at national level to cater for increasing energy demand. This can be achieved by creating a conducive environment for such investments. In the case of other conditions discussed above being met, demand for energy will increase, more so with increasing urban populations thereby pushing up the demand for fuels such as electricity. This requires that supply be adequate to meet demand. With about 40% of electricity having to be imported, investment in local generation should be given high priority.

A positive overall economic environment should be promoted, accompanied by reduction in unemployment and increasing real incomes for urban households. This both enables households to reduce the shares of traditional fuels in the energy mix, and also reduces the tendency by the unemployed to engage in the fuelwood business that makes the commodity readily available. This will constrain its demand in urban areas thereby minimizing environmental damage. A positive national economic environment also promotes investment in the energy sector, which improves the availability of modern fuels.

Finally, we recommend that urban fuelwood consumption be incorporated in the overall energy policy, with such policy taking into account the relationship between urban energy consumption and the environment. The traditional focus on electricity and liquid petroleum fuels as far as energy consumption is concerned has not only neglected the negative consequences of fuelwood consumption, but has also ignored the energy welfare of several urban unelectrified households who cannot access the conventional fuels. Energy policy should not only stop at total electrification and assume that this ensures maximum energy utility, but should look into the energy consumption dynamics of urban households, particularly the energy mix.

6.8 Conclusion

The empirical analyses of energy consumption behavior of urban households using a multi-stage decision making framework, and as a system of demands for several sources of energy has provided an indication of the significant factors at play in energy consumption decision making in general, and in fuelwood consumption in particular. This enables a more reliable way of estimating the demand for fuelwood in urban areas, and provides a wider choice of policy options that are not limited to just fuelwood. The separation of households into electrified and unelectrified households, and the associated results also enables the formulation of more reliable policies, whose outcomes can be predicted with relatively high degrees of certainty. Specifically, the results have highlighted the fact that the energy consumption patterns of electrified households depend on a wider array of variables, while those of unelectrified households are mainly shaped by incomes and prices. The results have also highlighted differences in energy consumption patterns of households in different electrification and income categories, which have welfare implications on households. The results presented in this chapter formed the basis for the policy discussions that followed. The overall approach suggested in the policy discussions considers the environmental implications of energy consumption as indicated by the demand for fuelwood as well as the welfare of households. Overall, demand side management of fuelwood consumption in urban areas is best achieved within the framework of the entire urban energy system, from which policy influencing the environment should be derived.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Introduction

This chapter gives a summary of the study and the main conclusions from the results. It also highlights the limitations of the study in terms of both scope and methodology, and suggests areas of further research. Section 7.2 summarizes the background of the study with respect to fuelwood consumption in Africa and Zimbabwe. Section 7.3 highlights the main conceptual and theoretical aspects, and section 7.4 gives a summary of the empirical results and the policy implications of these findings. Section 6.6 concludes the chapter by highlighting its contribution, weaknesses and areas requiring further research.

7.2 The fuelwood problem

Deforestation is one of the most pressing environmental problems in Africa. It has both local and global environmental consequences as well as implications for human health and livelihoods. Deforestation results in loss of biodiversity, disturbance of ecosystem functions, siltation of rivers and dams, loss of topsoil resulting in poor agricultural yields, flooding etc. This often results in loss of the support base for human livelihoods at the local level, and negative environmental consequences such as global warming when effects are aggregated over large areas. In most sub-Saharan African countries, the rate of deforestation exceeds the global annual average. The key driver of deforestation in Africa is human activity, and one of the most significant activities is removal of wood for energy. According to FAO data, fuelwood consumption accounts for about 90% of total African energy consumption. This makes wood fuel consumption a major local and global environmental issue in Africa. Because of the current high consumption levels, the dependence of African populations, and therefore the deforestation problem, is likely to continue in the foreseeable future. In fact, Africa has the highest per capita fuelwood consumption of 0.89 m^3 per year compared to any other continent. Available data also show that total fuelwood consumption in Africa increased by about 106 million m^3 between 1980 and 1996.

While the contribution of fuelwood consumption to deforestation varies from site to site, its most significant impact is associated with supplying wood to urban areas. The harvesting of wood to supply fuel to urban areas often implies felling whole, live trees. This contrasts it with harvesting wood to meet the needs of rural residents, which often involves selective collection of dead wood. The contribution of urban areas to deforestation through fuelwood consumption is one aspect of the overall urban energy consumption context. The urban areas of African countries are major consumers of energy compared to rural areas. The high population densities of urban areas make them centers of concentrated energy consumption. Because of their higher integration in the market economy, their energy needs are often met by market arrangements. Their high levels of energy consumption makes urban areas have significant contributions to energy related problems such as deforestation and indoor air pollution.

Urban areas in Africa have rapid population growths, which, in Southern Africa, are causing unsustainable demands on natural resources. For most sub-Saharan African cities, urban population growth rates are double national averages. For example, the urban population growth rate in Southern Africa is expected to average 3.5% for the next 15 years. Consequently, the rate of growth of demand for energy of all types is also set to increase in these areas, and should be matched by increased supply.

Generally, African urban areas are associated with the use of modern fuels like electricity. However, the consumption of electricity depends on the adequacy of supply and the incomes of consumers. In cities with rapidly growing populations, supply often gets limited. On the one hand, declining economic conditions in most African countries limit investments in the generation of modern fuels. On the other hand, high population growth rates are not matched by economic growth. As a result, real incomes of urban residents are falling, limiting their ability to afford the modern fuels. In fact, the literature has shown that urban poverty in Africa is growing, with the gap between the poor and rich getting wider, and the proportion of the poor getting bigger. Income distribution shows that most African urban households are poor. The poor tend to depend more on fuelwood to meet their energy requirements thereby contributing to the problem of deforestation. In most African cities, the most common energy source for low-income people is fuelwood.

The dependence of cities on fuelwood is determined mainly by the access of the residents to alternative, modern fuels like electricity. While urbanization increases, and urban populations increase, the proportion of urban residents without electricity increases. Between 1970 and 1990, the number of urban inhabitants without electricity in Africa increased from less than 40 million to 100 million (Karekezi and Majoro, 2002).

All current trends in Africa indicate that as urban population growth drives energy consumption upwards, this consumption will mainly be in the form of wood fuels. The transition from fuelwood in urban areas will be largely determined by trends in real incomes and the increased supply of alternatives at prices that consumers can afford.

Since wood fuels are likely to remain a major source of energy and an important environmental and development issue in Africa in the medium to long term future, the management of fuel resources should be considered a major issue in energy planning processes (Amous, undated). There have been few attempts in Africa to include wood fuels in the energy sector planning processes. According to Amous (undated), these are mainly hampered by the scarcity, limited scope, and poor quality of existing data. Conclusions and policy prescriptions are mainly based on perceptions instead of facts. Moreso, the focus of most policies in the energy sector is on modern fuels such as electricity and liquid fuels, which have, direct macroeconomic implications such as requirements of foreign currency. Traditional fuels such as fuelwood on the other hand has remained informal and unregulated. In this study, we focus on the consumption of energy in Zimbabwean urban areas in studying the demand for fuelwood.

The demand for fuelwood in Zimbabwean urban areas has attracted fragmented policy and research attention. Some research on urban fuelwood consumption in Zimbabwe has concluded that the fuelwood sub-sector requires no major attention owing to the high rates of electrification in the urban areas. In fact, due to the successful urban electrification program in Zimbabwe compared to most African countries, the fuelwood sub-sector has been overshadowed in terms of research attention. Recent literature however suggests that the economic and demographic trends in Zimbabwean urban areas puts them in the general African framework, which is characterized by increasing dependence on traditional fuels. The demographic and economic trends include high rates of urban population growth, declining real incomes, emergence of unplanned settlements. The population growth rate is very high compared to the economic growth rate of 0.8%. The demand for electricity, though growing, is not matched by supply. Generation of electricity has not been growing to meet increasing demand. Excess demand is being met by imports. About 40% of Zimbabwe's electricity is imported while liquid fuels and gas are imported in their entirety.

The main form of fuelwood used in Zimbabwean cities is firewood, with charcoal being used in very limited cases. At household level, firewood is mainly used for cooking and heating space for warmth. The technology for the use of firewood in most urban areas is basic. In most cases, no stove is used when households use firewood. The three-stone technology is the most common, though in some cases households invest in metal grates, which are more of stands for cooking pots than energy-saving technologies. The uses of firewood include preparation of regular family meals, preparation of special dishes, heating space for warmth, pressing or ironing clothes, to special functions such as parties and other gatherings.

There are several alternatives to fuelwood in urban areas. In Zimbabwe, the most common alternatives are electricity and kerosene. Gas, coal, and charcoal are very rarely used by households, mainly because they are not readily available to most households.

Most households buy the firewood from vendors either along main roads leading to residential areas or from small markets or stalls located on the sides of roads and at shopping centers of residential areas. The markets are mainly informal. They are operated either by individuals, families or groups of individuals. These vendors either buy their supplies from whole-sellers, or from sources mainly located in farming areas.

The urban fuelwood problem is a typical case that relates the economy to the environment. It identifies the energy consumption patterns of urban households as one of the causes of deforestation. The consumption patterns of households on the other hand are largely shaped by their decision variables, which in turn are shaped by higher level policies and economic trends. The choice variables of the consumers provide the most ideal levers that can be influenced to manage the demand for fuelwood in urban areas. Household consumption patterns are on one hand driven by their utility maximizing behavior, while the environment is affected through households' demand for environmental goods. Accordingly, urban fuelwood consumption has both environmental implications and welfare implications on households. The management of environmental problems due to urban fuelwood consumption is therefore best approached from the demand side. Demand side management complements supply side management strategies, which include sustainable harvesting methods such as selective harvesting and lopping branches instead of whole trees, and post-harvesting management of woodlands. Demand side management requires an understanding of energy consumption dynamics in the urban areas, an area that has not attracted much research attention. The lack of data and appropriate analytical tools in the African urban context has weakened the premise on which policies for the management of urban fuelwood management are made.

The broad objective of this study was to make economic analyses of urban household fuelwood demand within the context of overall energy consumption. The study developed a framework for household energy demand analysis and applied economic theory models to analyze household energy expenditure data for Zimbabwean urban areas using Harare as a case study. The specific objectives of the study were to:

1. Develop an urban household energy consumption framework within which to analyze household fuelwood demand.
2. Use empirical data to estimate the energy mix for households in Harare using household energy expenditure data thereby estimating the demand for fuelwood.
3. Investigate the factors that significantly affect the demand for fuelwood in urban areas.
4. Highlight the policy implications of the energy demand patterns on household energy welfare and fuelwood demand.

The main questions that we sought to answer are:

1. What is the proportion of energy expenditure in total household expenditure?
2. What are the respective proportions of the main sources of energy expenditure in Harare?

3. What are the factors that affect the observed expenditure patterns observed in questions (1) and (2) above?
4. What is the ultimate impact on fuelwood demand?
5. What are the policy implications of the observed patterns?

7.3 Conceptual and theoretical approach

7.3.1 Conceptual framework

The conceptual approach developed in this study uses the energy ladder hypothesis, which is the main model used to describe fuel choices in developing countries, as the starting point. The understanding of urban household energy consumption in developing countries is mainly built on the concept of fuel substitution, or more commonly, the energy ladder hypothesis. The hypothesis has been mainly advanced by Richard Hosier in characterizing energy consumption patterns in Africa in the 1980s and 1990s. Subsequent models such as the inverted – U used by Foster *et al* (2000) basically use the energy ladder model as the starting point. The inverted – U hypothesis describes the relationship between energy consumption and per capita income, showing for example in Guatemala gross energy consumption increasing with per capita income to a certain income level before declining.

The energy ladder model hypothesizes that as households gain socio-economic status, they abandon technologies that are cheaper, and start using more modern technologies. This is mostly dictated by the preferences of consumers for more modern fuels. The underlying assumption of the model, according to Hosier (1987) is that households are faced with an array of energy supply choices, which can be arranged in order of increasing technological sophistication. At the top of the list is electricity, and at the bottom are traditional fuels such as fuel wood, dung and crop wastes. As a household's economic well being increases, it is assumed to move up the ladder to more sophisticated energy carriers, and it moves to less sophisticated energy carriers as economic status decreases through either a decrease in income or an increase in fuel price.

The energy ladder hypothesis, in its current specification just gives an indication of the fuel being used at each stage. The hypothesis also fails to account for the fact that in any period, households may be using several fuels, but in different proportions. These realities have been noted in some empirical studies on fuel substitution. These and other weaknesses of the energy ladder hypothesis led this study to suggest an alternative model for describing household energy consumption in urban areas, the energy mix model.

The energy mix model takes into account the reality that households use several fuels in a particular period. Households embark on this practice for several reasons, including using different fuels for specialized tasks and functions, to spread risk, to reduce cost and to cater for periods when other fuels are unavailable. The extent to which households mix fuels depends on individual household characteristics and the prices and availabilities of alternative fuels. The decisions that households make are on the expenditures to allocate to different fuels in a specified period, giving an energy mix in terms of expenditure. The models enable us to link urban energy consumption decisions with the environment. This fits well with the motivation of this study i.e. fuelwood consumption in urban areas and its contribution to deforestation. We therefore developed and adopted the energy mix model as the conceptual framework of this study.

7.3.2 Theoretical basis

Consumer theory forms the basis of the empirical models used to estimate the demand for fuelwood in urban areas. The relevance of this theoretical approach is based on the assumptions that we made about energy consumption in urban areas. First, fuelwood is taken as one of the several sources of energy available to urban households i.e. it is one option among other alternatives. Second, the literature shows that the majority of urban households obtain fuelwood by purchasing on the market. Therefore fuelwood is a market good among other sources of energy that households also buy. Based on the conceptual framework i.e. the energy mix model, households are taken as economic agents, who make economic decisions on quantities of each source of energy to buy to maximize their utility. Consumer theory is therefore used as the underpinning theoretical framework.

The theory of the consumer is developed starting with consumer preferences. When the properties of preferences are met, a continuous utility function may be assumed. The consumer is assumed as striving to maximize utility, and is constrained by a budget constraint. Imposition of a budget constraint on consumer preferences yields Marshallian demand functions, which represent the problem of the consumer. Maximization of the utility function subject to the budget constraint yields the decisions of the consumer. In the typical case, we have income (or expenditure) and prices as the main variables determining quantities consumed. The incorporation of other household factors is suggested as giving a more complete description of consumer decisions. The main postulations of this theory relate to responses of consumption decisions to changes in prices and total outlay.

The empirical application of both the conceptual framework and the theoretical model follows a multi-stage budgeting process. At the first stage, households decide how much of their total expenditure to allocate to different groups of goods, energy being one group. At the second stage, households decide how much of their energy expenditure to allocate to each source of energy to maximize utility. In using this approach, we assumed that the principle of separability of preferences holds, i.e. preferences within one group can be described independently of preferences in other groups. The sub-utilities associated with consuming individual fuels at the second stage add up to the total utility from energy consumption, among other goods. Thus the use of a multiple budgeting process is consistent with consumer theory. The multi-stage budgeting process is also used in the estimation of the empirical models.

Going along with the conceptual framework that takes fuelwood as one of the fuels in the consumption set of households, we suggested the use of systems of demands, which enables the estimation of the demands for all fuels in the consumption set as a system. This approach allows the incorporation of household decisions on the consumption of alternative sources of energy in their fuelwood consumption decisions. Specifically, the Almost Ideal Demand System (AIDS) model is adopted on the basis of its flexibility and amenability to the testing of theoretical restrictions. Because complete demand systems are derived from stringently applying the microeconomic theory of consumer behavior to the multi-good case i.e. utility maximizing behavior, they are embedded in a theoretically consistent framework. Demand systems derived from neoclassical theory have the properties that characterize the Hicksian and Marshallian demand functions. The AIDS model specifies expenditure shares of goods with respect to their prices and total household expenditures in logarithmic form. The incorporation of household characteristics into the linear approximate specification of the AIDS model in recent works has made it more relevant especially where significant variation in household expenditure patterns are explained by differences in household characteristics in addition to income and prices. In terms of practical significance, this suggests other variables that can be targeted for policy influence. The estimation of demand for goods using the AIDS approach uses the expenditure shares of all the goods in the consumption set as the dependent variables in the respective equations in the system.

7.4 Empirical results

The results of this study are based on a survey carried out in Harare, the capital city of Zimbabwe, on a sample of 500 households. 89% of the households in the sample live in dwellings connected to electricity while another 11% live in houses not connected to electricity. The probability that a household is connected to electricity increases with the total income of a household, as measured by total expenditure, and with the level of education of the household head. The probability is also higher among households whose heads are employed, and who own the dwellings they live in. The average size of the household in the sample is 5, with each household using an average of 4 rooms. The number of rooms used is higher among electrified households than among unelectrified households.

The model estimated for the first stage of decision making estimated the share of total energy expenditure to total household expenditure, thereby answering our first research question i.e. What is the contribution of energy expenditure to total household expenditure? The variables in this model are the total expenditure of the household, the value of appliances it owns, the size of the household and its square, the educational level of the household head, the number of rooms used and the number of households living at the same premises. The model was estimated separately for electrified and unelectrified households. The Heckman procedure was used to correct for sample selection bias caused by splitting the sample into electrified and unelectrified households. In both cases (electrified and unelectrified households), energy assumes the properties of a normal good, with its share in total expenditure decreasing as total expenditure increases. Energy expenditure shares are higher among households who have higher investments in appliances, and for larger households. Economies of scale operate in energy consumption, with the model results showing that as household size gets bigger, the additional expenditure allocated to energy gets smaller i.e. the coefficient of the square of household size is negative. The share of energy expenditure is higher among households using more rooms than among those with fewer rooms. The share of the energy budget is also positively related with the number of households living at the same property. In these results, it should be noted that only total expenditure and appliances are significant at the 10% level for the unelectrified group of households. For electrified households, the only variable that is not statistically significant is the level of education of the household head. The summary statistics show that energy forms 13% of the total budgets of all households in the sample. The respective figures of the share of energy in total expenditure for electrified and unelectrified households are 13% and 11%. Since the share of energy expenditure goes down as total expenditure increases, low-income households spend higher shares of their incomes on energy than high-income households do.

The respective second and third research questions outlined in our objectives are: *What are the respective contributions of the main sources of energy to total energy expenditure in Harare?* and, *What are the factors that affect the observed expenditure patterns?* These questions are addressed in the models representing the second stage of household decision making, when they allocate the energy budget to different fuels. The data show that electricity, firewood and kerosene are the main sources of energy in Harare, accounting for 73%, 14% and 13% respectively of all households in the sample. The respective shares of the three fuels to total energy expenditure among electrified households are 81%, 9% and 10% while for unelectrified households these are 0%, 55% and 45%.

Among electrified households, the shares of firewood and kerosene decline as total energy expenditure goes up, while the share of electricity goes up. The same pattern is also true for the value of energy using appliances or assets. Both electricity and firewood shares increase when the size of the household increases, while the share of kerosene decreases. The negative sign on the coefficient of household size squared for firewood shows that its expenditure follows an inverted U shaped curve. The expenditure share for kerosene on the other hand follows a U shaped curve, with the sign of household size squared being positive. However, both household size and its square are not statistically significant for the share of firewood expenditure. The share of electricity increases (not statistically significant) when the number of households living at the same property increases, so does that of firewood, while that of kerosene decreases, both with statistical significance. The number of rooms is only significant for electricity, and not significant for firewood and kerosene shares. The share of electricity goes down when the number of rooms increases, contrary to *a priori* expectations. On the other hand, the shares of firewood and kerosene increase as the number of rooms increases. This arises from the fact that households diversify to their fuel mixes to include firewood and kerosene because of the increased demand for energy, and the increased diversity of uses as the number of rooms for specialized uses increases. Households also want to reduce the risk of relying on only one fuel, thereby introducing other fuels. Consequently, the share of electricity in the budget decreases. The share of electricity in total energy expenditure increases as the level of education of the household head increases, while the shares of firewood and kerosene decreases. The share of electricity decreases when its own price and the price of kerosene increase, while it increases when the price of firewood increases. The firewood budget on the other hand decreases only when its own price increases, but increases when the prices of both electricity and kerosene increase. The share of kerosene decreases when its own price and that of firewood increase, but increases when the price of electricity increases. The results show the combination of firewood and kerosene to be a substitute of electricity among electrified households. On its own, firewood is a substitute of both kerosene and electricity when prices are considered.

Among unelectrified households, kerosene and firewood are direct substitutes of each other. Increases in total energy expenditure are associated with an increase in the share of firewood and a reduction in the share of kerosene. Similar patterns exist for the value of appliances, household size and the educational level of the household head. The inverted U shaped curve and the U shaped curve pattern of fuel expenditure is also evident when household size changes for firewood and kerosene respectively among unelectrified households. This is shown by the negative and positive coefficients of household size squared for firewood and kerosene respectively. For both kerosene and firewood, an increase in own price leads to a reduction in the share of the commodity concerned, while an increase in the price of the other fuel has the opposite effect. However, for this group of households, only household size, the number of rooms and price of kerosene are statistically significant.

The results of model estimations at all stages of household decision making show that the sets of variables that significantly explain differences in energy consumption patterns are different between electrified and unelectrified households. Energy expenditure patterns of electrified households on one hand are affected by a wide set of variables, including incomes, prices of fuels and other household characteristics like household size, the number of rooms used by households, and the educational level of the household head. Unelectrified households on the other hand are less affected by household characteristics such as household size, the number of rooms, education, apart from income and prices.

The fourth research question of this study requires an estimation of the ultimate quantity of firewood demanded in Harare. Using the expenditure data for firewood, it was estimated that all households in Harare consume about 120,600 tones annually. This is based on the expenditure patterns at the time of the survey. This figure adds the total consumption figures of electrified and unelectrified households. Using appropriate conversion figures from the literature, this demand is equivalent to about 1,800 ha of miombo woodland. These figures refer only to wood that is purchased, and does not include wood that households collect on their own. Electrified households contribute 68% to the estimated total firewood demand while unelectrified households contribute 32%.

The results of policy simulations show the effect of changing several variables on total firewood demand, and the contributions of the electrified and unelectrified groups of households to such demand. The values of key demand variables, total energy expenditure, appliances, educational level of household head and prices of different fuels, were increased and decreased by 10%, and the total demand for firewood by all households in Harare calculated. The highest reduction in total firewood demand is achieved by decreasing the price of kerosene, similar to a policy subsidizing the fuel. Similarly, the highest increase in fuelwood demand is experienced when the price of kerosene was increased by 10%. The shares of each fuel is total energy expenditure was noted in each case. The effect of changing the proportions of electrified and unelectrified households in the total population on total fuelwood demand was also investigated. The result show that total electrification of all households in Harare reduces total firewood demand only to a certain extent, beyond which other demand factors come into play. Therefore combinations of a policy that enhances electrification of households and policies that target other demand variables are most effective in influencing firewood demand.

7.5 Policy implications

The overall objective of policies for managing fuelwood demand in urban areas should have both an environmental focus and a welfare focus and should be feasible within the state budget. The environmental aspect comes from the contribution of fuelwood demand to deforestation. The welfare focus is related to the different levels of energy consumption among urban households with differing socio-economic characteristics. The two policy objectives are linked by the fact that it is those households whose energy consumption levels are low who make the highest demand for fuelwood, thereby contributing more to deforestation. The results form this study show that it is mainly low-income, electrified households and all unelectrified households who make higher demands for fuelwood, and the most defining feature of these households is income. There is therefore a very strong linkage between poverty and the environment.

The overall approach in managing fuelwood demand in urban areas should target overall energy consumption rather than fuelwood only, as household decisions on the consumption and expenditure on other sources of energy affect their expenditures and consumption of fuelwood. This is the most effective demand-side management approach that ensures significant results. This calls for the incorporation of fuelwood consumption and its environmental cost in energy planning processes.

The differences in the energy expenditure patterns of electrified and unelectrified households have shown that most policies will have different outcomes on the two groups of households. For example, initiatives that increase incomes of all households when all other factors are the same will reduce demand for fuelwood among electrified households while increasing it among unelectrified households. In most cases, combinations of approaches will be most effective.

While total electrification reduces total fuelwood demand substantially, it does not totally eliminate it; in fact, more than 50% of total fuelwood demand in Harare is accounted for by electrified households. It is therefore apparent that if conditions that increase household fuelwood demand among electrified households persist, overall demand will increase. It is therefore recommended that policies look beyond just electrification, and address factors that reduce the share of fuelwood in the energy mix of all households, such as reducing prices of alternatives, imposing a tax on firewood thereby increasing its price, raising the educational levels of urban dwellers etc. A total electrification program makes it easier to focus attention on electrified households only.

Policies that ensure the ease of access to appliances by electrified households have been suggested in this study, as well as promoting the availability and use of other sources of energy such as gas, in addition to those already available to households. Among electrified households, these additional fuel options will help reduce the role of fuelwood. Among unelectrified households, these other fuels will reduce the share of firewood in the energy consumption mix.

Finally, promoting a positive economic environment to ensure rises in real incomes of urban households is the most important tool that reduces the use of fuelwood in the long term. This enables households to access and increase their shares of modern fuels in their energy mixes, as well as creating employment that reduces the tendency by unemployed urban dwellers to engage in the environmentally damaging fuelwood business i.e. many unemployed urban residents engage in informal business activities such as collecting and selling firewood as a source of income. As some past studies in Zimbabwe have pointed out, the current negative economic trends will only help to increase the share of fuelwood in household energy mixes.

7.6 Contributions and weaknesses of the study and areas of further research

7.6.1 Contributions

The urban fuelwood demand problem typifies an environment – economy linkage. Specifically, it fits within the poverty-environment nexus. This study makes a contribution to the debate on this key environmental issue in Africa, where deforestation is one of the leading environmental problems, and where most causes of deforestation are anthropogenic. The specific contribution of this study is to analyze the factors at play at the level of the primary agents of deforestation i.e. urban consumers and their energy consumption dynamics and the factors at play.

This study also makes a significant contribution to the development of methodologies for the analysis of urban fuelwood demand. The use of systems of demands takes into account household decisions on all sources of energy available to them in a way that is theoretically consistent. The approach developed in this study can be applied in studying urban fuelwood demand or energy demand in general. Methods applied in the analyses of fuelwood demand in Africa are very limited, and the method used in this study will add to the few approaches that are available. Discussion of fuelwood demand at methodological level has been very limited.

For the Zimbabwean case, this study also helps to provide a view of the current status of fuelwood in the urban areas as it uses empirical data. Empirical data on fuelwood demand in Zimbabwean urban areas is limited to only a few studies. At the official level, this data is not available at all. Therefore the data collected in this study, though limited to the sample size used, will form a basis for discussion and policy analysis.

7.6.2 Limitations

The sample of unelectrified households in this study was small, and may have contributed to the low level of statistical significance associated with most variables in the estimated models.

The applicability of the results to other countries is also limited by the focus of the data set to Harare. Cities in different countries have different sets of alternative energy sources with different shares of different fuels in the mix. Their responses to changing circumstances will therefore differ. For example this study does not include charcoal because households in Harare do not use it. However, charcoal is widely used in urban households of many African countries. However, the approach in the analysis can be easily applied in any country.

The data used in our analyses was collected at just one point in time, which does not correctly represent seasonal changes in household energy expenditure patterns. Specifically, the data was collected in the month of September, when temperatures are warmer, thus underestimating the demand for most energy sources. This is especially true for firewood whose use increases in the cold season. We tried to minimize this error by asking households their average expenditures per month for a period longer than one month. Since September is only a few months after winter, households were still able to recall their expenditures during the cold months. Also, expenditures recorded in the current period usually refer to previous periods.

Despite these limitations, the results of our study give a reliable indication of the demand for fuelwood and energy in general in Harare. The policy implications of the results also give a reliable guidance to policy makers and researchers.

7.6.3 Areas of further research

We recommend that the data set be extended to cover several cities in Zimbabwe, and other countries so that the results may be generally applicable. This will enable us to generalize the results of this study to apply to all urban areas of Zimbabwe, and of

African countries with higher levels of certainty. Incorporation of other cities in the study should include cities with differing sizes, socio-economic characteristics and different energy options so as to have a realistic representation of urban areas. This work however requires considerable financial resources.

We also suggest that future research on the subject integrate the conditions under which households get electrified as variables in the analyses, without having to separate households into electrified and unelectrified groups and analyzing them separately. This study separates electrified and unelectrified households and analyzes their demand patterns separately. It would however be more interesting to investigate the conditions, or the stage at which currently unelectrified households will get connected to electricity, or electrified households will get reconnected, and incorporate that into the analyses.

This study has focussed on studying the demand for fuelwood by households, and further research should look into the supply side of the fuelwood chain. This should cover the marketing of fuelwood, the means of acquisition and the sources of firewood. The sources and means of acquisition should include issues such as the tenure prevailing in the fuelwood source areas, and the effect of different tenure regimes on fuelwood prices and ease of access. The fuelwood supply side and marketing chain provide other policy options that can be used to influence fuelwood demand in urban areas.

In addition to the marketing of fuelwood, we also suggest that research be undertaken on the sustainable management of woodlands. This includes exploring such issues as post-harvest management, sustainable harvesting methods and harvesting rotations. It is also important to consider ways in which communities in areas where fuelwood is sourced can contribute to the management of woodland resources, and participate in decisions about harvesting and selling of firewood. This will help explore other options for sustainable supply of fuelwood to urban areas thereby providing additional options for the conservation of woodland resources in general.

APPENDIX

HOUSEHOLD SURVEY QUESTIONNAIRE

URBAN FUELWOOD SURVEY

This survey is part of the urban fuelwood study being carried out with the assistance of WWF to determine the use by households of different sources of energy, with particular focus on firewood in urban areas. Your household has been selected in a purely random process to participate in this survey. The information will be used to estimate the total demand for energy, and particularly firewood in Harare, and how different factors influence such demand. You are kindly requested to participate in this interview, which aims to gather information to fulfill these requirements by providing information to the questions in this questionnaire. This interview will take between 20 and 45 minutes of your time. All information in this survey is confidential, and will not be disclosed. No names are required in this survey, thus your name will not be used as a reference, neither will it be disclosed to anyone. We greatly appreciate your participation in this study. *Interview only the household head or the spouse.*

Date of interview: [ ] Start of interview… [ ]

Enumerator… [ ]

Section A: Background / Socio-economic data

1.Location (suburb):.. [ ] [ ]

2. Location income category: [ ]

3. House number: .... [ ]

4. Road name:.. [ ]

5. Residence of the household:….. [ ]
   1. *Main house*
   2. *2. Cottage*

6. If cottage, type of cottage:…. [ ]
   1. *Brick walls*
   2. *Wooden cabin*
   3. *Plastic / shack*

7. Respondent: Age (years)… [ ]

8. Sex of respondent…

1. Male

2. *Female*

9. Sex of household head…...

10. Size of household (*Adults are individuals aged 15years and above)*

1. *Adults* ……….
2. *Children………*
3. *Total …………*.

Section B. Firewood consumption

1. Do you use firewood?………………...

1. Yes *2. No*

If No, go to 14.(c). page 7

2. For how long has your household been using firewood: state month and year you started using firewood.

Year Month

3. If you have been using firewood for two years or less, why did you switch to it? (Reason 1 is the most important reason, reason 3 is the least important)

Reason 1:......

Reason 2:.....

Reason 3:....

1. Other fuels became expensive
2. Other fuels became difficult to find, or unavailable
3. Firewood became easily available on the market
4. Moved to property without other fuel facilities
5. Other reason (specify)………………………………………..

4. How do you get / acquire the firewood you use?…

1. Buy *2. Fetch own* *3. Both buy and fetch own*

5. Could you indicate where you usually buy or fetch, the frequency of buying or fetching (number of times/days per month), and the average price that you pay per unit?

	Source (dominant)	**Frequency / month**	**Price per unit ($)**	**Unit size (kg) approx.**	**Price per kg ($)**
Buying					
Own Fetching					

Possible sources

1. *Local market*
2. *Nearby farms*
3. *Local residential areas*
4. *Own property (stand/plot)*
5. *Neighboring woodland, woodlot or plantation*
6. *Communal area woodland or forest*
7. *Other*…………………………………….

How long do you normally walk to the nearest source of firewood and back?

Distance (approx km) Time taken (approx minutes).

7. If fetching, how do you normally transport the wood, and how many loads do you collect each time you fetch?
Transport form… *Number of loads…*

Transport forms

1. Head loads *2. Wheel barrow* *3. Push cart*
4. Bicycle *5. Car (size)………* *6. Other (specify)…………………*

8. What is the approximate amount of firewood that you consume per week? (kg)…

9. In what proportions do you use indigenous and exotic species of wood? Indicate approximate proportions? *Tick appropriate ratio.*

Tick	**Indigenous %**	**Exotic %**
	100%	0%
	90%	10%
	80%	20%
	70%	30%
	60%	40%
	50%	50%
	40%	60%
	30%	70%
	20%	80%
	10%	90%
	0%	100%

10. Which species do you prefer?..
1. Indigenous species *2. Exotic species*

11. What are the 2 most important reasons for preferring such species?

Possible reasons

Reason 1:... *1. Cheaper* *2. Easily available*
Reason 2:... *3. Good burning qualities* *4. Other reason (specify)……*

12. Under what conditions do you use firewood?…
1. *Only when other sources of energy are not available*
2. *Even when all other sources of energy are available*

13. What are the 2 most important reasons for your using firewood?

Reason 1:..... [ ]

Reason 2:..... [ ]

1. Electricity is not available
2. Electricity is not reliable (power cuts)
3. It is cheaper than other fuels
4. It is easily available
5. The appliances used are cheaper for firewood
6. It is convenient
7. Other reason (specify)……………………………….

14. (a) What is your estimated monthly expenditure on firewood?… [ ]

Would you still use firewood if it would cost you the following per month?

Value	**Yes/No**
$0	
$5	
$10	
$20	
$30	
$40	
$50	
$100	
$150	
$200	
$250	
$300	
$350	
$	

Value	**Yes/No**
$400	
$500	
$600	
$700	
$800	
$900	
$1000	
$1250	
$1500	
$1750	
$2000	
$2500	
$3000	
$	

Starting f*rom the consumer's current expenditure and going up, lead them through a series of cost steps, a small step up at a time as given below, until you get to the maximum expenditure at which they would stop using firewood. At each step value, ask them if they would still consume firewood at that cost. Stop at NO. Tick for yes, and put an X for No.*

14. (b)
Units of buying firewood ______ Price per unit ______ Price per kg ______

If the price of the unit of firewood were to up to …….. per unit, how many units would you buy per week or per month? If the price were to go down to …… per unit, how many units would you buy / consume per week or month?

Price per unit	Price / kg	Units/ week	Units bought per month	Kg per month
$0				
$5				
$10				
$15				
$20				
$30				
$40				
$50				
$60				
$70				
$80				
$90				
$100				
$150				
$200				
$250				
$300				

Enumerator: Lead the respondent through the price schedule above. Starting with the current price per unit and number of units bought per week or per month, going up first, then down, a step at a time. For each price per unit, ask how much they will buy or consume, until the price is so high that they stop consuming. The same is for prices lower than current prices, until the price is zero. Tick current consumption.

14. (c) If you are not using firewood, would you start using firewood if its monthly cost were:

Value	Yes/No
$3000	
$2500	
$2000	
$1750	
$1500	
$1250	
$1000	
$900	
$800	

Value	Yes/No
$700	
$600	
$500	
$400	
$350	
$300	
$250	
$200	
$150	

Value	*Yes/No*
$100	
$50	
$40	
$30	
$20	
$10	
$5	
$0	

Again as in the previous question, lead the respondent through the values, this time starting with the highest figure. Ask them if they would start using firewood at each cost value, and stop at YES.

15. (a) Does the use of firewood have any environmental problems in your opinion?.. ☐

1. Yes ***2. No***

15. (b) If yes, what are the 2 most important environmental problems related to using firewood?

Problem 1 ☐ ☐ **Problem 2**

Possible problems

1. *None*
2. *Air pollution*
3. *Health hazard*
4. *Contribution to global warming*
5. *Soil erosion*
6. *Loss of biodiversity*
7. *Destruction of wildlife habitat*
8. *Loss of natural beauty and attraction*
9. *Loss of other resources on which we depend for survival*

16. What are your 2 most important sources of environmental awareness?

Source 1.. ☐ Source 2.. ☐

Possible sources

1. *Radio programmes*
2. *TV programmes*
3. *Newspapers and magazines*
4. *School*
5. *General knowledge*
6. *Peers and friends*
7. *Work place*
8. *Other (specify)*

17. Would you be willing to use other sources of energy in the place of firewood in the light of these probl☐…

1. Yes *2. No*

18. **If no**, why are you not willing to use other sources of energy?… ☐

Possible reasons:

1. *We cannot afford other sources*
2. *Firewood is convenient*
3. *We are used to firewood use*
4. *Other tasks need use of firewood only*
5. *Other sources are not available*
6. *Firewood is readily available*
7. *Our change will not be significant to stop the problems*
8. *Other…………………………………………….*

19. How long has it been since you saw / visited a well-wooded natural woodland or forest?

☐ months or ☐ years

20. Where have you recently noticed tree cutting / deforestation?… ☐

1. *In and around Harare*
2. *In and around another town (name of town:……………………….)*
3. *In a communal area*
4. *In commercial farming areas*
5. *Have not noticed any deforestation*
6. *Other (specify)…………….*

21. Of your six immediate neighbours, (2 across the road, 2 behind your house and two on the sides), how many of them do you know to be using firewood for any us☐

Section C: Energy Consumption /Usage

1. List the three major fuels that you use, starting with the most dominant one. What is the two most important reason that influences your choice of each of these sources of energy? *Start listing the major fuels and then ask the influences.*

Category	Fuel type	Influence 1
Most dominant		
Second dominant		
Third dominant		

Energy sources: ***Influences:***

1. Electricity 5. Gas 1. Low cost 2. Shortage of alternatives
2. Firewood 6. Solar 3. Clean 4. Fast and efficient
3. Paraffin 7. Coal 5. Convenient 6. Low cost appliances
4. Charcoal 8. Other (specify) 7. Other (specify)

2. Which sources of energy do you normally use for each of the following common tasks? Start with the most dominant fuel for that task. Energy source 1 is the most important fuel.

Common task / use	Energy source 1	Energy source 2	Energy source 3
1. Cooking			
2. Lighting			
3. Heating space			
4. Heating bath water			
5. Other use (Specify)			

Energy sources: 1. Electricity 5. Gas
2. Firewood 6. Solar
3. Paraffin 7. Coal
4. Charcoal 8. Candlr
…9. Other (specify)………………………………..

3. How much money do you spend on each of the fuels per month?

Energy source	**Monthly expenditure**
1.Electricity (average bill)	
2.Firewood	
3.Paraffin	
4.Charcoal	
5.Gas	
6.Solar	
7.Coal	
8.Other (Specify)	
Total	

4. What % of your total income goes to energy expenditure?… [ ]

5. How do you cope in periods when the energy source you use most is not available (e.g when there is a power cut, or shortage of paraffin).

Energy source	**Coping strategy**	**Fuel switched to**
1.Electricity		
2.Firewood		
3.Paraffin		
4.Charcoal		
5.Gas		
6.Solar		
7.Coal		
8.Other (Specify)		

Coping strategies

1. *Switch temporarily to another fuel (specify fuel)*
2. *Switch permanently to another fuel (specify fuel)*
3. *Stop activities that use the fuel in shortage*
4. *Stop less important activities using*
5. *Reduce the number of meals*
6. *Other strategy (specify)*

6. List the sources of energy in the order of your preference for them, starting with the most preferred one.

Preference rank	Fuel	Reason for preference
1.Most preferred		
2		
3		
4		
5		
6		
7		
8. Least preferred		

Fuel types

1.Electricity
2.Firewood
3.Paraffin
4.Charcoal
5.Gas
6.Solar
7.Coal
8.Other (specify)

Possible preference reasons

1. Low cost
2. Clean
3. Fast and efficient
4. Easily available
5. Other (Specify)

7. Switching between alternative sources of energy:

(a) What is the main/dominant source of energy for this household?

Current monthly expenditure on this fuel:

If prices of other sources of energy remain constant, at what monthly cost of this fuel would you stop using it as the main source of energy?:

Percentage (%) change in price of (a):

(b) What is the next best alternative (second dominant) source of energ after (a)?

Current monthly expenditure on this fuel

Supposing that (b) is readily available, at what monthly cost would you start using it as the main source of energy in the place of (a), given that the cost of (a) does not cl

Percentage (%) change in price of (b):

8. How easy is it to get each of these fuels?

Fuel type	**Ease of availability**
1.Electricity	
2.Firewood	
3.Paraffin	
4.Charcoal	
5.Gas	
6.Solar	
7.Coal	
8.Other (specify)	

Ease of availability

1. Easily available
2. Available
3. Difficult to find
4. Unreliable
5. Not available at all

9.Could you mention the 2 most important sources of each of these fuels, source 1 being the most important, and source 2 being the least important

Fuel type	**Source 1**	**Source 2**
1.Electricity		
2.Firewood		
3.Paraffin		
4.Charcoal		
5.Gas		
6.Solar		
7.Coal		
8.Other (specify)		

Source categories

1. ZESA
2. Local service station
3. Tuck shop
4. Local shops
5. Roadside market
6. Nearby bush/ forest
7. Surrounding farms
8. Other (specify)

10.How many days per week do you use these sources of energy

Energy source	**Frequency of use**
1.Electricity	
2.Firewood	
3.Paraffin	
4.Charcoal	
5.Gas	
6.Solar	
7.Coal	
8.Other (specify)	

Section D: Household Socio-economic stasus

In this section, we ask you questions that will help us establish how firewood and energy consumption differ with households in different social categories

1. How many families live at this property?...... [ ]

For how long have you lived in this house?… [ ]

2. How many rooms is your family using? …. [ ]

3. Are you owning or renting?….. [ ]

1. Owning
2. Renting

If renting go to 7

4. If owning, do you let out any rooms?…. [ ]

1. Yes
2. No

If No, go to 8.

5. If yes, how many rooms are being rented out?… [ ]

6. How much rent do you charge per room per month?:… [ ]

If owning skip 7

7. If renting, how much rent do you pay per room per month ($)…. [ ]

8. How many members of this household are involved in each of the following occupations?

1. Formal employment………..………… [ ]
2. Informal employment / small business… [ ]
3. Total employed………………………… [ ]

9. (a) Is the household head employed?….. ☐ *1. Yes* *2. No*

9. (b) What is the occupation of the household head? Could you indicate the occupation and position held and the employer. If the head is in informal employment, please indicate type of activities.

Employer… ☐ Position… ☐ Informal Actitivies… ☐

Employer classification categories	***Position***	***Informal Activities***
1. *Government*	1. *General hand*	*1. Vending (Fruit, food etc)*
2. *Private company*	2. *Officer*	*2. Metal work, carpentry*
3. *Non governmental organizations*	3. *Manager*	*3. Sales, marketing*
4. *Parastatal*	4. *Director*	*4. Construction*
5. Other………………………	5. *Secretary/cleric*	*5. Tree felling*
	6. *Other…………*	*6. Repairs and maintenance*
		7. *Shoe mending*
		8. *Transport*
		9. *Market gardening*
		10. *Other*

10. What educational level has been attained by the head of this household?

Level… ☐ *Years of schooling…* ☐

Questions 11 and 12 should be answered with the consent of the respondent. Ask them first if they are willing to provide the information. If the answer is NO, ask question 12 (b).

11. Into which income category does your household fall?

1. Less than $1000/month
2. $$1001 - $2500 per month
3. $2501 - $5000 per month
4. $5001 - $10,000 per month
5. $10001 - $15,000 per month
6. $15001 - $20,000 per moth
7. $20,001 - $30,000 per moth
8. $30,001 - $40,000 per month
9. $40,001 - $50,000 per month
10. $50,000 - $75,000 per month
11. $75,001 - $100,000 per month

11. 12. More than $100,000 per month (specify ……………………….………)

12. (a) What is your average total monthly expenditure as a household, including transport, rent, food etc?….. ☐

13. 12 (b) What percentage or proportion of your total income do you spend each month? What proportion do you save?
Expenditure %…… Savings %……

13. How many standard meals do you eat per day?…

14. Is the house connected to electricity?… 1. *Yes* *2. No*

15. Which of the following **energy using appliances** do you own and use, and what are their approximate ages and current market values (what price would you be willing to accept or pay for each appliance in its current condition)?

Appliance	**Own: 1.Yes 2. No**	**Use 1. Yes 2. No**	**Age years/months**	**Current value ($)**
1. Electric stove (with oven)				
2. Hot plate (1 or 2 plate)				
3. Microwave oven				
4. Gas stove (1 or 2 plate)				
5. Gas stove (with oven)				
6. Paraffin wick stove				
7. Electric heater				
8. Firewood/charcoal heater				
9. Electric kettle				
10. Geyser				
11. Boiler				
12. Gas lamp				
13. Paraffin lamp				
14. 1 plate metal grate				
15. 2 plate metal grate				
16. 3 plate metal grate				
17. 4 plate metal grate				
18. Food mixer				
19. Food processor				
20. Refrigerator / freezer				
21. Electric pressing iron				
22. Other				
Total value				

16. Do you have access to

Radio… ☐ Television… ☐ Local news papers… ☐

1. *Yes*
2. *No*

17. How many days in a week do you

1. Listen to news on the radio… ☐
2. Watch news on TV…………. ☐
3. Read the newspaper……….. ☐

Thank you for your participation. The information you have provided will greatly assist in this study.

END OF INTERVIEW… ☐ TIME TAKEN… ☐

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Samenvatting en conclusies

Ontbossing is een van de meest urgente milieuproblemen in Afrika. Het heeft zowel lokaal als wereldwijd gevolgen voor het milieu en implicaties voor de volksgezondheid en het levensonderhoud van de mens. In de meeste Afrikaanse landen ten zuiden van de Sahara overstijgt het tempo waarin ontbossing plaatsvindt het wereldwijde jaarlijkse gemiddelde. De belangrijkste drijfveer achter ontbossing in Afrika is menselijke activiteit en één van de belangrijkste activiteiten is het kappen van hout ten behoeve van energie. Ontbossing vanwege brandhoutconsumptie varieert van plaats tot plaats, maar de belangrijkste impact ervan is wel toe te schrijven aan levering van hout aan stedelijke gebieden. Bij de houtwinning als brandstof voor stedelijke gebieden worden vaak hele, levende bomen gekapt. Dit is een belangrijk verschil met de houtwinning voor de behoeften van plattelandsbewoners, waarbij vaak dood hout wordt verzameld. De stedelijke gebieden van Afrikaanse landen vormen zeer grote energieverbruikers in vergelijking met de plattelandsgebieden. De hoge bevolkingsdichtheid van stedelijke gebieden maken deze gebieden tot centra van geconcentreerde energieconsumptie. Vanwege de hogere integratie in de markteconomie wordt vaak op basis van marktafspraken in hun energiebehoeften voorzien.

Alle huidige trends in Afrika wijzen erop dat naarmate de bevolkingsgroei in de steden de energieconsumptie omhoog drijft, deze consumptie hoofdzakelijk uit houtbrandstoffen zal bestaan. Aangezien houtbrandstoffen op de middenlange en lange termijn waarschijnlijk een zeer belangrijke energiebron en een belangrijk milieu- en ontwikkelingsprobleem in Afrika zullen blijven, dient het beheer van brandstofbronnen te worden beschouwd als een belangrijk onderdeel in het proces van energieplanning. De milieuproblemen als gevolg van stedelijke houtbrandstofconsumptie kunnen daarom het best worden aangepakt aan de vraagzijde. Beheersing aan de vraagzijde vormt een aanvulling op beheerstrategieën aan de aanbodzijde. Voor beheersing van de vraagzijde is inzicht en kennis van de dynamiek van de energieconsumptie in de stedelijke gebieden noodzakelijk, een onderwerp waarnaar nog weinig onderzoek is verricht.

In deze studie maken we een economische analyse van de vraag naar stedelijk brandhout door het volledige systeem van de stedelijke energievraag in ogenschouw te nemen. Hieronder volgen de specifieke doelstellingen van deze studie:

5. Het ontwikkelen van een schema van stedelijke huishoudelijke energieconsumptie waarin de huishoudelijke vraag naar brandhout wordt geanalyseerd.
6. Het gebruiken van empirische gegevens om de energiemix van huishoudens in Harare te begroten op basis van gegevens over huishoudelijk energieverbruik; op basis hiervan wordt de vraag naar brandhout geschat.
7. Het onderzoeken van de factoren die van significante invloed zijn op de vraag naar brandhout in stedelijke gebieden.
8. Aangeven wat de beleidsimplicaties zijn van de energievraagpatronen op het huishoudelijke energiewelzijn en de vraag naar brandhout.

Aan de hand van deze doelstellingen beantwoorden we de volgende vragen:

6. Wat is het aandeel van het energieverbruik in de totale huishoudelijke bestedingen?
7. Wat zijn de respectieve verhoudingen tussen de belangrijke bronnen van energieverbruik in Harare?
8. Welke factoren beïnvloeden de waargenomen verbruikspatronen in de bovenstaande vragen (1) en (2)?
9. Wat is de uiteindelijke invloed op de vraag naar brandhout?
10. Wat zijn de beleidsimplicaties van de waargenomen patronen?

De algemene benadering van dit onderzoek was het ontwikkelen van het conceptuele model, de theorie en het empirische model voordat deze op de feitelijke gegevens werden toegepast.

In hoofdstuk 2 vindt u achtergrondinformatie over brandhout- en energieconsumptie in Afrika en Zimbabwe. De specifieke kenmerken van stedelijke brandhout- en energieconsumptie worden gegeven, evenals de verwachte trends op het gebied van de brandhoutvraag in stedelijk Zimbabwe in het licht van de huidige demografische en economische trends in het land.

In hoofdstuk 3 ontwikkelen wij het conceptuele model voor de analyses. Het concept van de huishoudelijke energiemix in stedelijke gebieden is ontwikkeld op basis van eerdere modellen, zoals de energieladder en de zogenoemde inter-fuel substitution, het vervangen van de ene brandstof door de andere. Het energiemixmodel houdt rekening met het feit dat huishoudens in een bepaalde periode diverse soorten brandstoffen gebruiken. De huishoudens doen dit om diverse redenen, zoals het gebruiken van verschillende brandstoffen voor gespecialiseerde taken en functies, omdat ze de risico's willen spreiden, kosten verminderen en omdat ze inspelen op periodes waarin andere brandstoffen niet beschikbaar zijn. De mate waarin huishoudens een combinatie van brandstoffen gebruiken, is afhankelijk van de individuele kenmerken van de huishoudens en de prijzen en beschikbaarheid van alternatieve brandstoffen. De beslissingen die huishoudens maken, zijn gericht op de bestedingen voor verschillende brandstoffen in een bepaalde periode, wat een energiemix oplevert in termen van verbruik. Aan de hand van de modellen kunnen we beslissingen op het gebied van stedelijke energieconsumptie aan het milieu koppelen.

In hoofdstuk 4 wordt de theorie die ten grondslag ligt aan de empirische analyses besproken. De consumententheorie vormt de basis van de empirische modellen die worden gebruikt om de vraag naar brandhout in stedelijke gebieden te schatten. Allereerst wordt brandhout beschouwd als één van de vele mogelijke energiebronnen. Vervolgens wordt brandhout gezien als een marktgoed te midden van andere energiebronnen die eveneens door huishoudens worden aangeschaft. Op basis van het energiemixmodel worden huishoudens beschouwd als economisch handelende wezens die economische beslissingen nemen over de hoeveelheden die van iedere energiebron worden aangeschaft om het nut ervan te optimaliseren. Wij gaan ervan uit dat huishoudens inzake energiebestedingen een budgetteringproces volgen dat uit diverse stappen bestaat. Bij de eerste stap beslissen ze welk gedeelte van de totale bestedingen wordt besteed aan verschillende groepen goederen. Energie is één van deze groepen. Bij de tweede stap beslissen de huishoudens welk gedeelte van hun energiebestedingen per bron wordt toegewezen om maximaal gebruik van de bronnen te maken. We hebben vraagsystemen aangevoerd om de theorie en het conceptuele model te implementeren. Met deze systemen kunnen we een schatting maken van de vraag naar alle brandstoffen in de consumptieset. Hiertoe hebben we het zogenoemde 'Almost Ideal Demand System' (AIDS) model overgenomen. We nemen huishoudkenmerken op in de lineaire specificatie bij benadering van het AIDS-model, zodat het relevanter wordt voor vraagvariaties die worden veroorzaakt door verschillen in huishoudens.

Hoofdstuk 5 biedt een specificatie van het empirische model en gegevensverzameling. Voor het specificeren van het model worden drie fases gevolgd. Allereerst specificeren we waarschijnlijkheidsmodellen om de waarschijnlijkheid in te schatten dat een huishouden in de steekproef al dan niet over elektriciteit beschikt. Dit levert de Inverse Mills Ratio (IMR) op, die in volgende schattingen wordt gebruikt om vertekening van steekproefselectie te corrigeren, die ontstaat omdat er in de steekproef een splitsing is gemaakt tussen geëlektrificeerde en niet-geëlektrificeerde categorieën. Vervolgens specificeren we het budgetteringsmodel uit de eerste stap, waarin het aandeel van energiebestedingen in de totale huishoudbestedingen wordt geschat. Ten slotte specificeren we een modellensysteem waarin de aandelen van de diverse brandstoffen in de totale energiebestedingen worden geschat. In dit hoofdstuk bespreken we eveneens de huishoudkenmerken en andere variabelen die in de modelschattingen worden opgenomen. Tevens stellen we een *a priori* hypothese op over hun effect dat ze op de huishoudelijke energieconsumptie op de twee besluitvormingsniveaus hebben. De primaire gegevensverzameling is gebaseerd op een onderzoeksvragenlijst die aan een steekproef van 500 huishoudens in Harare is verstrekt. Er wordt gebruikgemaakt van gelaagde willekeurige steekproeftrekking bij het bepalen van de te ondervragen huishoudens.

In hoofdstuk 6 worden de empirische resultaten van modelschattingen gepresenteerd. Analyses van de gegevens tonen aan dat energie 13% van de totale budgetten van alle huishoudens in de steekproef vormt, respectievelijk 13% en 11% voor huishoudens met en zonder elektriciteit. Het aandeel aan energiebesteding is hoger in huishoudens met grotere investeringen in huishoudelijk apparaten en in grotere huishoudens. Afnemend verbruik bij schaalvergroting geldt ook voor energieconsumptie. De modelresultaten geven aan dat naarmate een huishouden groter wordt, de aanvullende bestedingen voor energie kleiner worden. Dat wil zeggen dat de coëfficiënt van het kwadraat van de huishoudgrootte negatief is. Het aandeel van energiebestedingen is groter in huishoudens die gebruikmaken van meer kamers dan in huishoudens die gebruikmaken van minder kamers. Het aandeel van het energiebudget is tevens positief gerelateerd aan het aantal huishoudens dat op hetzelfde perceel woont. Aangezien het aandeel van energiebestedingen afneemt naarmate de totale bestedingen toenemen, spenderen huishoudens met lage inkomens een groter aandeel van hun inkomen aan energie dan huishoudens met hoge inkomens. De gegevens tonen tevens aan dat elektriciteit, kachelhout en petroleum de belangrijkste energiebronnen in Harare zijn. De respectieve aandelen van de drie brandstoffen in de totale energiebestedingen van huishoudens met elektriciteit zijn 81%, 9% en 10%, terwijl ze voor huishoudens zonder elektriciteit 0%, 55% en 45% bedragen.

In huishoudens met elektriciteit nemen de aandelen van kachelhout en petroleum af zodra de totale energiebestedingen stijgen, terwijl het aandeel van elektriciteit toeneemt. Hetzelfde patroon geldt voor de waarde van energie bij gebruik van huishoudelijk apparaten of inventaris. Zowel het aandeel van elektriciteit als kachelhout nemen toe wanneer de grootte van het huishouden toeneemt, terwijl het aandeel petroleum afneemt. De bestedingen aan kachelhout volgen het patroon van een omgekeerde U-vormige curve in relatie tot de grootte van het huishouden. Het bestedingsaandeel voor petroleum volgt echter het patroon van een U-vormige curve, waarbij het kwadraat van de huishoudgrootte positief is. Het aandeel van elektriciteit wordt groter naarmate het aantal huishoudens dat op hetzelfde perceel woont toeneemt. Hetzelfde geldt voor het aandeel van kachelhout, terwijl het aandeel van petroleum afneemt. Het aandeel van elektriciteit wordt kleiner wanneer het aantal kamers toeneemt, in tegenstelling tot verwachtingen die men vooraf had. Aan de andere kant worden de aandelen van kachelhout en petroleum groter wanneer het aantal kamers toeneemt. Het aandeel van elektriciteit in de totale energiebestedingen neemt toe naarmate het opleidingsniveau van het hoofd van het huishouden stijgt, terwijl de aandelen van kachelhout en petroleum dalen. Het aandeel van elektriciteit daalt wanneer de prijs van elektriciteit en de prijs van petroleum stijgen, terwijl het aandeel groter wordt wanneer de prijs van kachelhout stijgt. Het budget voor kachelhout daalt echter alleen wanneer de prijs ervan stijgt, maar het stijgt wanneer de prijzen van zowel elektriciteit als petroleum stijgen. Het aandeel van petroleum daalt wanneer de prijs ervan en de prijs kachelhout stijgen, maar het stijgt wanneer de prijs van elektriciteit stijgt. In huishoudens zonder elektriciteit hangen stijgingen van de totale energiebestedingen samen met een toename van het aandeel van kachelhout en een afname van het aandeel van petroleum. Vergelijkbare patronen bestaan voor de waarde van huishoudelijke apparaten, de grootte van het huishouden en het opleidingsniveau van het hoofd van het huishouden. De omgekeerde U-vormige curve en het patroon in de vorm van een U-vormige curve van de brandstofbestedingen zijn eveneens evident bij veranderingen in de grootte van het huishouden voor respectievelijk kachelhout en petroleum in huishoudens zonder elektriciteit. Bij zowel petroleum als kachelhout leidt een stijging van de prijs tot een afname van het aandeel van het desbetreffende product, terwijl een stijging van de prijs van de andere brandstof het tegenovergestelde effect heeft.

Op basis van de bestedingsgegevens voor kachelhout kon worden gecalculeerd dat alle huishoudens in Harare jaarlijks ongeveer 120.600 ton consumeren. Dit staat gelijk aan ongeveer 1.800 ha miombobos. Huishoudens met elektriciteit dragen 68% bij aan de geschatte totale vraag naar kachelhout, terwijl huishoudens zonder elektriciteit 32% voor hun rekening nemen.

De resultaten van beleidssimulaties tonen het effect aan van de verandering van diverse variabelen binnen de totale vraag naar kachelhout, en de bijdragen van de groepen huishoudens met en zonder elektriciteit naar deze vraag. De grootste daling in de totale vraag naar kachelhout wordt bereikt door de prijs van petroleum te verlagen; dit is vergelijkbaar met een beleid van brandstofsubsidie. Zo ontstaat ook de grootste toename in de vraag naar kachelhout wanneer de prijs van petroleum wordt verhoogd. Simulatieresultaten geven tevens aan dat totale elektrificatie van alle huishoudens in

Harare slechts tot op zekere hoogte leidt tot daling in de vraag naar kachelhout, waarna andere vraagfactoren een rol gaan spelen. Vandaar dat de combinatie van een beleid dat stimuleert dat huishoudens overgaan op elektriciteit en een beleid dat is gericht op andere vraagvariabelen de vraag naar kachelhout het effectiefst beïnvloeden.

In hoofdstuk 7 vindt u de samenvatting en conclusies van het onderzoek. Wij concluderen dat men zich bij het beheer van de vraag naar brandhout in stedelijke gebieden moet richten op de totale energieconsumptie, en niet alleen op die van brandhout. Beslissingen van huishoudens over consumptie van en bestedingen aan andere energiebronnen zijn namelijk van invloed op de bestedingen aan en consumptie van brandhout. De verschillen in de energiebestedingspatronen van huishoudens met en zonder elektriciteit hebben aangetoond dat de meeste beleidsplannen verschillende resultaten zullen hebben op deze twee groepen huishoudens. Hoewel totale elektrificatie een aanzienlijke daling van de vraag naar brandhout tot gevolg heeft, valt deze vraag niet volledig weg. Wij wijzen er daarom op dat beleid verder dient te kijken dan elektrificatie alleen en zich ook moet richten op andere factoren die het aandeel van brandhout in de energiemix van alle huishoudens verkleinen. Andere aanbevelingen in dit onderzoek zijn gebaseerd op de specifieke variabelen in de modellen. Concluderend kan worden gesteld dat stedelijke brandhoutconsumptie en de bijbehorende milieukosten in algehele energieplanningsprocessen moeten worden opgenomen, in het belang van het welzijn van mens en milieu.

Curriculum Vitae

Muyeye Chambwera was born and raised in the Jichidza communal land of Zaka District in in Masvingo, Zimbabwe, on 30 March 1971. He did primary education at Chivingwi Primary School in Jichidza, and secondary and higher secondary education at St Anthony's High School in Masvingo. In 1991, he started to study Agricultural Economics at the University of Zimbabwe in Harare, and graduated with a Bachelor of Science degree in Agriculture in 1993. In 1994, he worked as a Research Associate in the Department of Agricultural Economics and extension at the University of Zimbabwe. From 1995 to 1996, he studied for a Masters degree in Natural Resources Management at the University of western Australia in Perth. After completing his Masters degree, Muyeye worked for Environment and Development Activities (ENDA-Zimbabwe) in Harare as Natural Resources Management Officer. In 1998, he joined theWorld Wide Fund for Nature's Southern Africa regional Programme Office (WWF –SARPO) in Harare, where he worked as a Senior Research Fellow. It was during his stay at WWF that he initiated a research project on urban fuelwood demand, following a huge upsurge in fuelwood marketing activities in Harare. In 2000, he formally enrolled as a PhD student at Wageningen University in a Sandwich construction, and registered his research topic with Mansholt Graduate School. He is currently working as a Senior Research Fellow (Policy and Economics) with WWF-SARPO in Harare.