CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The aim of this chapter is to review the literature on household energy demands and consumption patterns in urban areas so that urban household energy consumption patterns can be analysed. The characteristics of urban household energy consumption in developing countries are used to develop a suitable conceptual framework. This conceptual framework enables an exploration of household fuel consumption patterns in urban areas. The first section of this chapter introduces a brief overview of various household's energy sources and their impacts in developing countries. The second section reviews sustainable development debates on household energy consumption at a global, regional and local level. The third section traces debates on household energy trends in developing countries with specific reference to multiple fuel use, fuel switching (fuel stacking) and the energy ladder model. The last section of this chapter extends the energy ladder concept to develop an energy mix and offers a critique of the energy ladder and multiple fuels models.

2.2 The energy sources and their impacts in the Developing World

The household energy sector is divided into three sub-sectors: electricity, hydrocarbon fuels (coal, gas or paraffin) and biomass fuels (wood, dung and crop waste). In many urban communities, people use a combination of these sources to meet their energy needs. Poor urban households use biomass fuels or a combination of biomass fuels and hydrocarbon fuels in order to save electricity costs (May, 2000). For the purposes of this study, these six energy sources and their related impacts are discussed below.

2.2.1 Electricity consumption in South Africa

Electricity is a secondary fuel dependent on the transformation of other sources of energy and requires a high-tech environment (Trollip, 1997). The infrastructure involved in the generation and distribution of electricity is enormous and costly. About 90 percent of

South African electricity is produced from coal. Eskom, which is state owned, produces 95 percent of electricity for distribution in all sectors of the economy including households in South Africa and three local authorities (Johannesburg, Pretoria and Kokstad) also operate power stations (Trollip, 1997). Most of the coal used is low grade with a high ash content and a low calorific value. The Eskom-owned national grid links all major power generating systems in the country to electricity distribution and large customers. It also has links to all neighbouring countries that include Lesotho, Bostwana, Namibia, Mozambique, Swaziland and Zimbabwe (EIA, 2000).

Even though Eskom and Municipalities have a licensed capacity of 43,142 MW, the net maximum power produced in 2000 was 34,471 MW, a 33 percent decrease from the 1998 value (NER, 2003). The generating capacity, which is primary coal-fired, also includes one nuclear power station at Koeberg (1,840 MW), two gas turbine facilities, two conventional hydroelectric plants and two hydroelectric pumped-storage stations (EIA, 2000). Eskom is the world's fourth largest electricity utility (Trollip, 1997). While Eskom does not have an exclusive right to generate electricity, it has a practical monopoly on bulk electricity sales to its customers. The electricity supply industry is structured in three layers, namely generation, transmission and distribution. Most of Eskom power stations are situated in Mpumalanga Highveld. The declining availability of consolidated coalfields, increased air pollution and water scarcity are becoming serious constraints to the further development of very large coal-fired stations (Trollip, 1997).

An overview of South Africa's electricity sources is presented in Table 2.1. The electricity supply industry in South Africa deals with electricity supply and distribution. Electricity (primarily from coal based power stations) dominates urban household energy consumption in South Africa. According to Howells *et al*. (2003) although Eskom is also heavily involved in distribution, local authorities also contribute significantly to the distribution and retailing of electricity to customers for domestic use. Local authorities primarily supply electricity to urban and peri-urban customers (Eskom, 2001).

Table 2.1: South Africa's electricity production profile (NER 2001 21)

Source	Eskom	Mini Capital	Private	Total	% of Total
Coal	175, 222.8	609.6	7,440.0	183,272.6	93.7%
Nuclear	10,718.6		0	10,718.6	5.5%
Pumped storage	-769.2	-67.5	0	-836.8	-0.4%
Hydro	2,194.0	9.6	14.2	2,218.8	1.1%
Biogas	0	0	306.8	306.8	0.2%
Gas	-0.7	5.7		4.9	0.03%
Total	187,365.5	557.5	7,761.2	195,684.3	100%

The industrial sector (excluding mining) accounts for the largest portion of electricity use in South Africa with 40 percent of overall consumption, followed by mining industry, which accounts for 27 percent of total consumption. Domestic (residential) use is the third biggest consumption sector, accounting for 17 percent of the overall consumption (Figure 2.1).

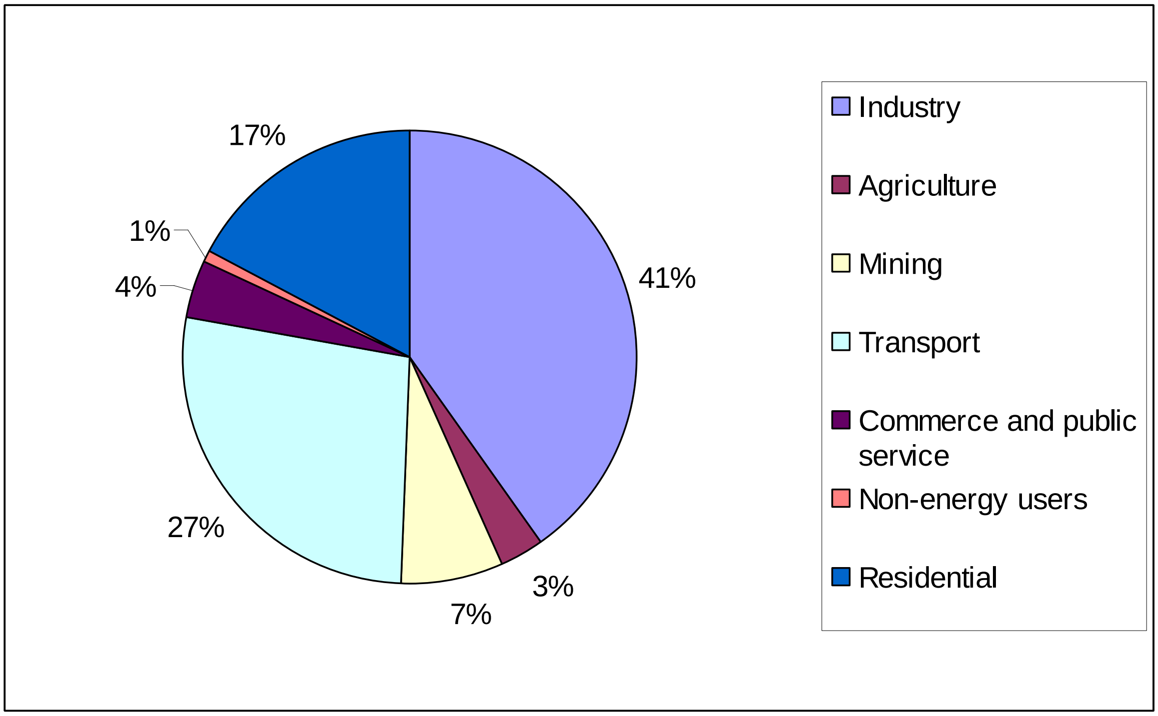

Figure 2.1: Energy consumption by sector in 1999 (ISES, 2001: 34)

While many households are able to benefit from access to electricity services, May (2000) states that low-income urban households still find the cost of the supply more than their budgets are able to sustain. This brings some difficulty for low-income households in keeping up with the pace of energy transition. Some households in most poor households switch between electricity and biomass fuels because of the cost and other related reasons. Monthly billing is particularly problematic for low-income households, and some have even found the pre-paid meters difficult to manage (Eskom, 2001). The difficulty of finding affordable efficient energy source is becoming more serious in urban areas. The next section examines issues related to coal consumption and demand in South Africa.

2.2.2 Coal consumption in South Africa

South Africa is a major coal producer and exporting country. Two major local users for coal are generation of electricity and liquid fuels production. Coal provides 70 percent of primary energy supply in South Africa (Cooper, 2000). Estimates of South Africa's coal reserves are not exactly recorded. A large coal mining industry has developed over the years and South Africa should have sufficient coal for the next 100 years at least. Three fields (Waterberg, Witbank and Highveld) hold 70 percent of the total recoverable reserves. The peak demand for coal will be reached around 2070 and there will thereafter be a growing pressure on coal and a need to introduce alternative energy sources (EIA, 2000).

The coal mining industry is privately owned and controlled. However, state owned entities, or entities strongly influenced by government regulation consume the majority of the coal. Most output goes to the Eskom parastatal (56 percent) which negotiates long-term contracts with private suppliers. Large amounts of coal are exported (about 23 percent), making an important contribution to South Africa's foreign exchange. In 2001, 93 percent of electricity in South Africa was generated from coal; with nuclear energy and hydropower accounting for the remaining seven percent (Figure, 2.1).

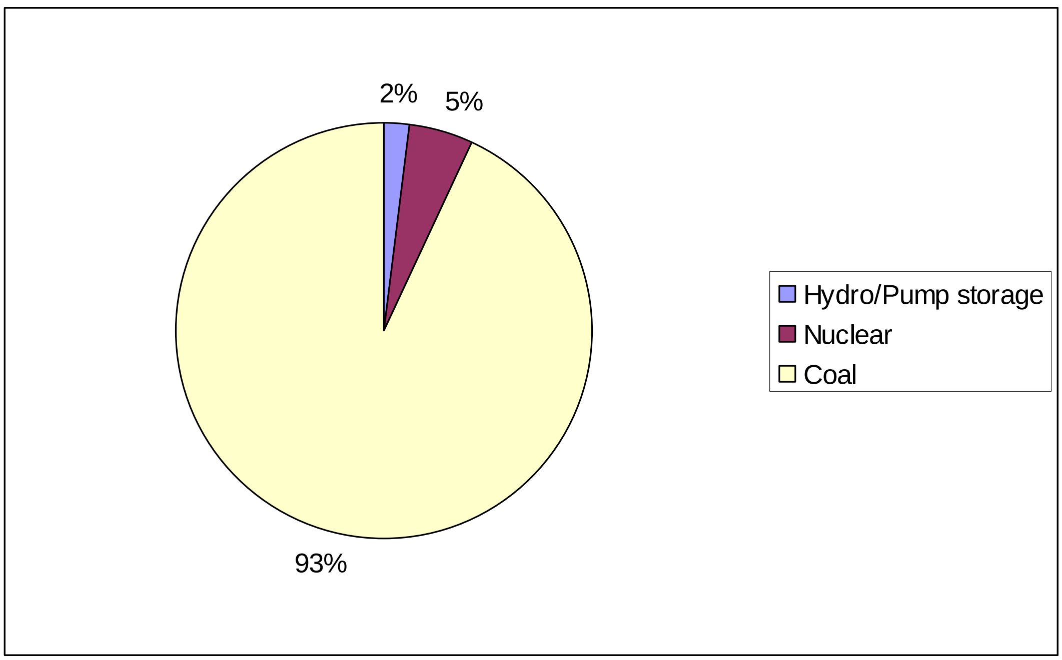

Figure 2.2: Energy sources used in electricity generation in South Africa (NER, 2003, 4)

South Africa relies on coal for about 75 percent of its primary energy and comparatively the majority of lower income urban households in South Africa use coal (Dept of Mineral and Energy (DME), 2003). Coal provides about three quarters of total energy consumed in all sectors in South Africa. According to the DME (2003), coal is used as an energy supplier, particularly at the household level mainly among the urban poor.

Coal is mainly purchased by merchants from the mines and it is then distributed to poor urban households around South Africa. A small number of people collect coal for domestic use from the mine dumps to supplement the use of electricity. Many poor urban households consume coal and other inefficient fuels simply because they cannot afford electricity and other clean fuels (DME, 2003).

Most of the coal is high in ash (about 45 percent) but has low sulphur content (about one percent) (EIA, 2000). In lower-income households coal is usually burned in an *imbawula* (or brazier) and in cast iron stoves. This raises health concerns resulting from both particulate and carbon monoxide emissions. For example, the *imbawula* is used without a chimney and the stove is usually lit outside and moved indoors once the smoke level declines. Emissions from coal burning remains unacceptable in most townships and is a health hazard (DME, 2003). According to Horen *et al.* (1996) epidemiological studies done on the urban coal-using townships sampled in South Africa shows that the single most significant risk factor for the development of respiratory tract illnesses was coal. This study indicated that not only the use of coal in homes but also the extent of coal use in the wider residential areas enhances the risk of developing respiratory tract illnesses. One of the important findings of the research was that up to 50 percent of homes in urban areas, which are electrified continued to use coal for space heating in winter. In these homes, the air pollution exposures and related health risks were still significantly higher (Horen *et al.*, 1996).

2.2.3 Biomass fuel use in developing countries

Biomass fuel plays a key role in poor urban households for cooking and space heating. According to the World Bank (2003), many urban people use biomass fuels for cooking in South Africa. Biomass fuel is largely free and relatively available to most communities. Biomass fuel supply is not managed by government in South Africa but is an unregulated activity (World Bank, 2003). Communities collect biomass fuel from a variety of sources or buy biomass fuel from an unregulated local market. In urban areas however, increasing income often implies a decline in biomass fuel consumption, with an accompanying increase in the use of modern fuels (Chambwera, 2004). Wood continues to be burned in simple stoves and the *imbawula*.

The combustion of biomass fuels contributes to poor indoor and outdoor air quality. For example, burning biomass, charcoal releases smoke and other pollutants, which particularly affect those closest to the stove (i.e. women and children) (Meikle and Bannister, 2003). Biomass combustion emits products of incomplete combustion such as methane and benzene, which threaten human health and contribute towards global warming (Karekezi and Kithyoma, 2002).

2.2.4 Paraffin use in South Africa

Paraffin is widely used in poor urban households as the main source of energy. There are about five refineries supplying about 800 million litres per year of paraffin to the household sector in South Africa. The DME (2003) states that there is a fairly well established paraffin distribution network, which has been successful in promoting the use of paraffin in low-income urban households. Despite its popularity, kerosene or paraffin has a number of drawbacks, such as burns and fires, resulting from wick stoves and stove pressure malfunction. Kerosene causes many casualties resulting from exposure to fumes from burning kerosene and poisoning of children who accidentally ingest paraffin kept in cold drink bottles (DME, 2003).

2.2.5 Liquid Petroleum Gas

Liquid Petroleum Gas (LPG) is commercially available through the petroleum and gas industry (Howells *et al.*, 2003). Most of the multinational oil companies sell LPG through their subsidiaries such as Shell Easigas, BP Gas, TotalElfFina and Handigas (Afrox). According to Howells *et al.* (2003) the distribution of LPG however, is mainly concentrated in urban areas. Despite its convenience, there is a great feeling of insecurity in relation to safety issues and the cylinder being stolen act as a barrier to the use of gas fuels. A fear about explosions is a concern raised by many people in relation to hazards and indoor air pollution effects (Howells *et al.*, 2003). Of course, choice is further constrained by cost as well and not only fuel costs, but also the start-up costs of connections, equipment and stoves. Some recent studies that have compared total costs of different cooking fuels in India find that in some cases the option of purchased traditional fuels can be more expensive than LPG (Farsi, 2004).

2.2.6 Solar power in urban areas

Solar energy is among the many household technologies proposed to address climate change (Middleton, 1995). Small solar electric systems can cost-effectively supply energy to poor urban parts of developing countries while substituting for energy sources that emit carbon dioxide (CO2). Photovoltaic (PV) solar home systems (SHS) are often the least expensive electrification option in most poor urban households (Middleton, 1995). Typically consisting of a 10 to 50 watts peak (Wp) PV module, a rechargeable lead acid battery and sometimes a charge controller, the systems generate modest amount of electricity for lights, radio, television and other small appliances. However, early experience with the technology included operational failures caused by poor maintenance and unsustainable donation programs (Middleton, 1995).

Having discussed different sources of energy, the following section reviews the literature on policy reforms in South Africa and consequences thereof.

2.8 Sustainable Development agenda on household energy use

This section builds more explicitly on the relationships between the international agenda and national concerns in trying to address the fuel question in the context of creating sustainable household. The world leaders discussed energy at the 2002 World Summit on Sustainable Development (WSSD), which brought new and quite intense repeated references to household energy and sustainable development (Najam, 2003). The 2002 WSSD document on energy goes beyond Agenda 21 by focusing more on the social dimensions of household energy and sustainable development (DEAT, 2003). In essence Agenda 21 is the global action plan for sustainable development agreed on at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992

(Davidson and Mwakasonda, 2004). It recognised that about two billion people world wide, particularly in developing countries lack access to affordable household energy. The 2002 WSSD concentrated on the role household energy plays as a prerequisite for basic human needs, including those defined in the UN's Millennium Development Goals (MDGs). These MDGs were developed to address the problems of poverty, hunger, diseases, illiteracy, environmental degradation and discrimination against women (WHO, 2004). The aim of the MDGs is to promote a comprehensive approach and to allow many problems to be tackled simultaneously across the wide range of spectrum concerning energy. Modern household energy services are inextricably linked to many of the MDG goals as a solution to these problems. The most significant of the WSSD 2002 references is made in Article 8 of the Plan of Implementation, which falls within the section on poverty eradication (Najam, 2003). The WSSD 2002 covered new ground, which calls for "access to reliable and affordable household energy services for sustainable development sufficient to facilitate the achievement of the millennium development goals" (Najam, 2003, 3).

For the Southern African region to achieve the MGDs agreed to at the WSSD held in Johannesburg in 2002, there needs to be a substantial increase in modern household energy service provision, especially affordable, reliable and adequate electricity (Davidson and Mwakasonda, 2004). Modern household energy will help in improving the current high infant mortality, low life expectancy, and high illiteracy and fertility rates of the Southern African region (World Bank, 2003). The region will require substantial electricity provision, particularly for the poor who are deprived of these services (Davidson and Mwakasonda, 2004).

At a national and local level, household emissions remain unacceptable in many poor urban areas and have an impact on health and on the environment. People in poor urban areas should be assisted in understanding the need for efficient utilisation of energy to achieve sustainable development principles (DIMSUD, 2002). These principles are sustainability, equity, efficiency, integration and good governance. In addition, the National Environmental Management Act (NEMA) of 1998 also provides a core strategy for improving the provision and the use of household energy to contribute to sustainable development (DEAT, 1998). This Act aims at improving environmental management while facilitating sustainable development to ensure that significant impacts on the environment are avoided and mitigated (DEAT, 1998). The Act widens access to clean, reliable and affordable modern household energy supplies in order to reduce the negative health and environmental impacts related to household energy use (Jefferson, 2002). The 1998 White Paper on Local Government concerning household energy sees environmental sustainability as an integral component of integrated development planning (Jefferson, 2002). In order to assess the effectiveness and appropriateness of energy consumption in developing countries, the next section explores one of the key themes from which this study is based.

2.9 Household energy trends in developing countries

This section draws on the energy scholars and policy makers around the world who have devoted considerable effort to understanding household energy use in developing countries. In this section, the focus of attention will be on the energy ladder and fuel switching in developing countries. Household partial fuel switching is a temporary strategy, whereby a household switches to a new fuel, but continues to use the old fuel as well, whereas with complete fuel switching; the old fuel is not used at all (Kgathi *et al.*, 1997). Complete household fuel switching is also known as an energy transition. The energy ladder is a scale, which rates the quality of household fuels (Chambwera, 2004). It is important to understand these processes when investigating energy consumption patterns (Soussan *et al.*, 1992). Understanding the process of energy transition in households will require research into why available electricity services are not used in poor urban areas

The work on household energy draws on the concept of an energy ladder with solid fuels on the lowest rung, and kerosene, LPG and electricity on successively higher rungs (Jack, 2004). According to Meikle and Bannister (2004) the energy ladder (Figure 2) represents fuel types that might be used by households as their prosperity increases. The energy ladder fuel order corresponds with increased technological efficiency, decreased CO_2,

SO_2 emissions and particles, and increased capital cost (Meikle and Bannister, 2004). Davis (1998) argues that South Africa generally supports the notion that households climb the energy ladder, as they grow wealthier. Households that make use of electricity are more likely to use clean cooking fuels (Davis, 1998). Urban dwellers are more likely to use cleaner technology as their income grows (Hosier and Dowd, 1987; Campbell *et al.*, 2003).

Household energy types and consumption levels are determined by:

- Income
- Infrastructure
- Fuel availability
- Fuel prices
- Distribution network proximity
- Cultural preferences
- Demographic distribution
- Physical environment (urban or rural) (Davis, 1998).

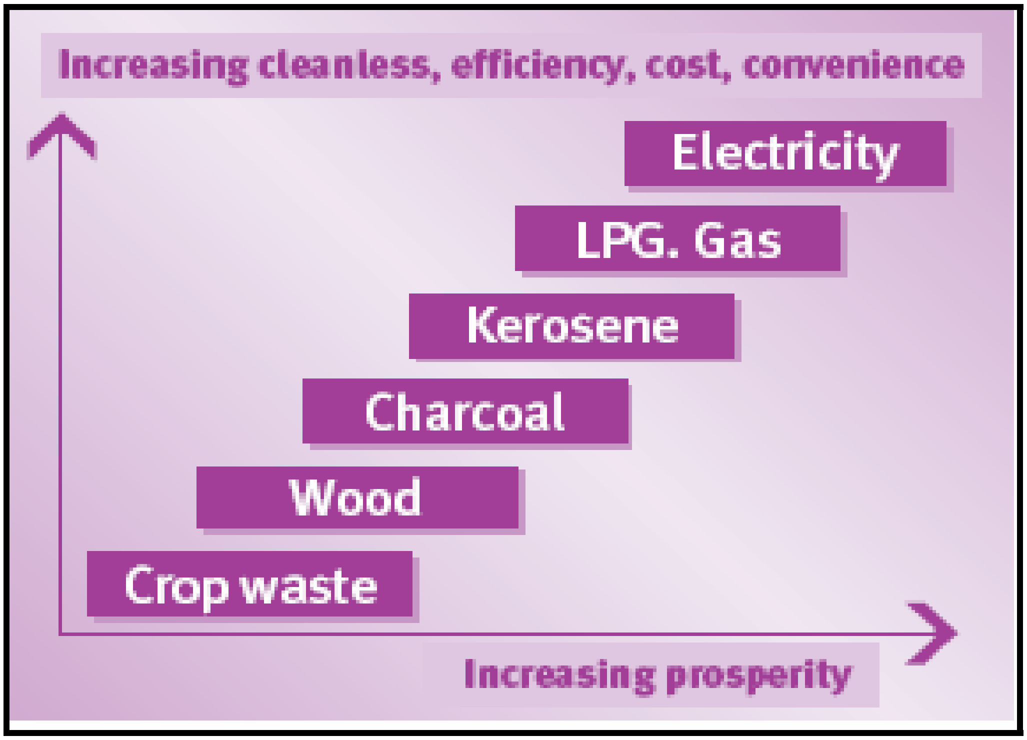

Figure 2.3: The energy ladder, (WHO, 2002 13)

The energy ladder studies by Leach (1992) and Smith *et al.* (1994) were based on the factors that determine the choice of fuel used and both studies concluded that the choice of fuel is determined by a particular household's personal choices and income. These studies argue that fuel switching in developing countries has been that households gradually ascend an 'energy ladder'. There is a tendency for a linear progression from relatively inefficient fuel and energy end-use equipment to a more efficient fuel, electricity and equipment, with increasing income levels and urbanization (Farsi *et al.*, 2004). However, research into the energy consumption of households in developing countries shows that the energy ladder theory is simplistic. The results show that there are many factors other than income that determine fuel choice e.g. culture, social desirability and security of supply (Davis, 1998 and Bernett, 2000).

Leach (1987) asserts that there is an energy transition process whereby households climb the ladder of fuel preferences. Recent studies conducted in South Africa have shown that as a result of the mass electrification programme the pattern of energy use has changed (Davis, 1998). Most urban households tend to switch to more extensive electricity use after being connected the electricity grid (Davis, 1998). In a study in South Asia, Leach (1987) found that income, relative prices, the cost of appliances and the availability of modern fuels in urban areas were the most important variables affecting this transition process. In discussing the concept of an energy transition from low to high quality fuels, Soussan (1987) found that multiple fuel use and fuel switching were common in poor urban households and were the result of a specific budgeting strategy. The nature of fuel transition is also disturbed where households are faced with insecure energy supplies (Soussan *et al.,* 1990). Under these circumstances, fuel security is the way that household energy is managed, and may prevent permanent energy transition (O'Keefe and Munslow, 1989).

Again, the state of the energy report for Cape Town 2003 states that households in Cape Town consume about 15 percent of total energy and 38 percent of total electricity (CCT and SEA, 2003). The rapid electrification since 1994 has meant that only eight percent of dwellings are currently not electrified. These are informal dwellings and backyard shacks. CCT and SEA (2003) states that low income households, whether electrified or not, are very much dependent on paraffin to meet their energy needs. Other fuels, such as wood and dung are popular amongst all households for specific activities such as braaing and brewing beer. Coal is used very little because it is expensive due to transport cost associated with it. LPG gas is very little used amongst poor households due to poor access and perceptions that it is unsafe. However, middle to high-income households use electricity almost exclusively (CCT and SEA, 2003). This is a clear indication that households only manage to climb the ladder of fuel preferences once they can afford modern fuels. It can be argued that low-income households depend on multiple fuel use as fuel switching is difficult to achieve. Again, the nature of transition in these households is not well understood.

A growing body of literature on household energy use reveals that the energy transition does not occur as a series of simple, discrete steps but multiple fuel use is more common (Masera *et al*., 2000). In South Africa this transition has not been clearly defined, as diversity of energies has not declined in poor urban households (Madubansi and

Shackleton, 2005). With increasing affluence, households adopt new technologies and fuels that serve as partial rather than perfect substitutes for more traditional fuels (Masera, *et al*., 2000; Leiwen and O'Neill, 2003). In poor urban China, for example, biomass and electricity are the most common fuel types that are paired in households (Leiwen and O'Neill, 2003). In urban areas of Guatemala, the simultaneous use of firewood and LPG for cooking is quite common (ESMAP, 2003). The situation in Brazil is different in the sense that the firewood fraction of fuel budgets falls as income rises. Woodfuel use continues even at relatively high-income levels. Only at the highest income levels do fossil fuels and electricity usually account for nearly all energy use (de Almeida and de Oliveira, 1995).

Multiple fuel use has also been termed 'fuel stacking' (Masera *et al*., 2000). Although poor households often use several fuels simultaneously, they generally shift towards the adoption of cleaner, more efficient energy sources as income rise. Multiple fuel use arises for several reasons. First, households often have significant capital invested in 'traditional' technologies (e.g., wood-burning stoves) and may not have the spare capital to purchase new energy-consuming appliances immediately upon gaining access to new energy sources (Saghir, 2004). Second, modern energy sources are usually expensive and thus are applied carefully for unique services such as radios and television for entertainment (Thom, 2000). Thus, when new fuels arrive, traditional fuels and technologies tend to exit more slowly. Thus, modern transistor radios exist alongside primitive cooking stoves. Finally, multiple fuels can provide a sense of energy security. Complete dependence on commercially traded fuels leaves households vulnerable to variable prices and often unreliable service. Households in Hyderabad, India, for example, experience an average of two or three power outages each day (ESMAP, 1999).

The energy ladder and multiple fuels metaphor differ in the conception of precisely how energy sources are adopted. Both recognise that hierarchies in household energy services are quite common. According to Victor (2002) cooking and heating are the first functions fulfilled, followed by lighting and later entertainment. For the poorest people in developing countries, cooking (and space heating in particularly cold times) can account for upwards of 90 percent of the total volume of energy consumed. Lighting accounts for the majority of the remaining share (Howells *et al*., 2003). Appliances such as electric irons, refrigerators and water heaters arrive in household energy budgets only after core heating, cooking and lighting services are satisfied (Victor, 2002). Thus, the first kilowatts of electricity acquired by households are commonly used for lighting, entertainment and communication services, while many households continue to cook and heat the home with traditional fuels long after modern energy enters the household (EIA, 2002; WEC/FAO, 1999). Taste preferences and familiarity of cooking with traditional fuels and technologies contribute to the tendency of cooking to be the last energy service supplied by modern fuels. In India, for example, many wealthy households retain a biomass fuel stove for baking traditional breads (Malhotra *et al*., 2000). While in certain regions of Mexico even high-income households cook tortillas over an open wood fire rather than using an LPG stove because they prefer the taste and texture provided by wood cooking (Masera *et al*., 2000; Saatkamp *et al.*, 2000).

Hosier and Dowd (1987) conducted a similar study in urban Zimbabwe using a multinomial logit model to test the energy ladder hypothesis for household fuel choice. The multinomial logit model refers to a model, which shows that although economic factors do affect fuel choices, a large number of other factors such as culture, social desirability and security of supply are also important in determining household fuel choice (Hosier and Dowd, 1987). Furthermore, fuel switching is often not complete and is a gradual process with many households often using multiple fuels. There are a number of reasons for multiple fuel use and sometimes they are not dependent on economic factors alone. In some households, people choose to use more than one energy source because people want to increase the security of supply. In other cases, the choice might be dependent on cultural, social or taste preferences (Hosier and Dowd, 1987). The community can also influence the fuel choice. Living amongst people using coal can prompt others to use it despite economic advantage (Hosier and Dowd, 1987).

An investigation of household energy choices for a sample of households residing in the city of Bangalore uses a bionomial logit model (Reddy, 1995). A binomial logit is defined as a model, which determines the choice between each pair of energy sources. This model according to Reddy (1995) helps to explain the shift in the energy pattern of consumption of different fuels used for cooking and water heating. The findings confirm that urban households ascend an energy ladder and the choice is determined by income. However, other factors worth noting that play a significant role in fuel switching amongst households is family size and occupation of head of the household (Reddy, 1995).

A similar study in India also employed a multinomial logit framework to represent household fuel choice (World Bank, 2003). However in the World Bank model a household's decisions concerning the choice of both cooking and lighting fuels are dealt with together. The World Bank took a closer look at a choice set that consists of all the key alternatives to different energy sources combinations used by a household. The objective of this model was to study the effectiveness of the existing price subsidies in facilitating a shift to cleaner and more efficient fuels like kerosene and LPG. The results showed that subsidies are unsustainable in meeting social policy objectives and disproportionately favours the rich (World Bank, 2003).

The study done in India shows that degree of urbanisation has been shown to influence energy consumption such that households living in larger cities consume more electricity than the inhabitants of cities with less than one million inhabitants (Horsier and Kipondya, 1993). According to (Madubansi and Shackleton, 2005) this is also true in South African context where larger cities and townships have well developed infrastructure and sufficient supplies of electricity. As a consequence, better employment opportunities that exist in large cities also enable households to allocate more of their income to modern fuels. However, the limited employment opportunities limit electricity consumption in poor urban townships in South Africa (Madubansi and Shackleton, 2005). The changes in the consumption patterns in low-income urban households disprove the energy ladder model as they continue to consume energy sources at lower end of the ladder (Davis, 1998). In order to assess the effectiveness and relevance of the energy ladder as a suitable framework for analysis in developing countries, the next section takes a critical look at the concept of an energy ladder.

2.10 A critique of the energy ladder model

The household energy use in urban areas of developing countries is poorly understood mainly due to the complexity of the switching process. Masera and Navia (1997) contend that the complexity is caused by the fact that economic aspects are inter-linked with social and cultural issues. As the result of such complexity, the energy ladder model has been rendered insufficient to represent actual energy consumption dynamics (Foster *et al.*, 2000). Whereas economic factors such as income and prices suggest that consumption of modern fuels increases with increasing income, 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 level attained are examples of factors that contribute to the complexity (Foster *et al.*, 2000).

The energy ladder hypothesis provides the basis upon which further understanding of the subject may be built. However, the model, in its current simplified form, such as equating progression up the ladder with development (Masera *et al.*, 2000), provides a limited representation of the fuel switching process. The process should be considered as a process resulting from the simultaneous interactions of factors pushing households away from bio-fuels and pulling them back towards bio-fuel use (Masera *et al.,* 2000). Factors such as the convenience of the use of modern fuels, the price associated with the use of these fuels, and the social status may push consumers up the ladder while economic factors such as income and prices of fuel push consumers down the energy 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 (Jack, 2004). Even when augmented with the influences of economic and social factors, the energy ladder 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 about energy consumption is more complex, involving partial adoption and relinquishment of several fuels at the same time and is influenced by a complex set of factors (Chambwera, 2004).

One of the strongest assumptions of the model is that movement of households up the ladder is as a result of improving economic circumstances, and the ability to purchase appliances associated with modern fuels. The reverse is that, households move down the ladder. There are different switching curves for moving up and for moving down the ladder (Chambwera, 2004). Movement up the ladder is associated with huge financial outlays in acquiring appliances and getting connections to carriers of modern fuels (Reddy, 1995). Movement down the ladder on the other hand simply involves using appliances already possessed and does not therefore represent large expenditures, compared to household income, for a household that had climbed 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 (Chambwera, 2004).

The model assumes households to behave in a manner consistent with the neoclassical theory of consumer behaviour (Horsier and Dowd, 1987). The deficiency of the model is in its assumption that households move to more sophisticated energy carriers as income increase, without being explicit on the 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 the findings by Horsier and Kipondya (1993) in Tanzanian cities, which showed all surveyed households to be using more that one fuel for cooking. This is supported by Masera *et al.* (2000) whose Mexican data confirms 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.

Using the energy ladder model, issues around the fuel choices of households have been conceptualised (Chambwera, 2004). The energy ladder model puts more emphasis on income in explaining fuel choice and fuel switching. According to Chambwera (2004) the main drivers affecting the movement up the energy ladder, according to the studies reviewed above, are income and fuel prices. The 'ladder' image presents a stereotypical movement, which is only upward. It does not take into account the downward movement on the energy ladder, which may also occur in poor urban areas where income is unstable (Hosier and Dowd, 1993).

Recent research by Jack (2004) suggests that the relationship between income and indoor air quality may be more complex than the energy ladder metaphor indicates. According to a study from Nepal done by Bardhan *et al.* (2003) the conclusion was that urban households might not necessarily climb the ladder if suppliers of clean energy fuels are lacking. This finding is consistent with the work done in India by Rosenzweig and Foster (2003) and in Kenya by Patel *et al.* (1995) on forest use, which shows that demand for firewood generally increases as urban households become wealthier.

Many countries around the world argue that LGP succeeds electricity as a cleanest energy forms usually found at the successive end of the energy ladder (Jack, 2004). However, it could be argued that these two energy sources can be swapped in South Africa because electricity is generated from coal fired power stations compared to the LPG (Trollip, 1997). More than 90 percent of South Africa's electricity is generated from the combustion of coal, which contains approximately 1 percent sulphur and up to 45 percent ash (EIA, 2000). Coal combustion can lead to particulate matter in the air and contribute to acid rain. Despite the harmful environmental effects, electricity provides clean air quality at the household level away from the electricity generation stations. LPG, if compared to electricity, has clean health and environmental benefits at the point of production (Howells *et al.*, 2003).

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 level, status and ownership of the dwelling place etc (Madubansi and Shackleton, 2005). The contribution of these variables to fuel choice are lacking in the specification of the energy ladder model. The literature generally concludes that a number of non-income variables as discussed below are central to explaining observed patterns of energy use (Davis, 1998).

2.11 Non-income variables affecting energy consumption

2.11.1 Climate variation and energy demand

Populations living in colder climates tend to consume more energy that those in warmer regions (Eberhard and Van Horen, 1995). This is especially true at lower income levels, where energy is often used to supply heating services; only at high income levels do households purchase fans and air conditioners that fulfil the demand for cooling (ESMAP, 1999). In rural China, for example, energy use is, on average, greater in the cooler regions of the north than in the warmer regions of the south (Leiwen and O'Neill, 2003).

2.11.2 Resource endowment as a predictor of energy consumption

The relative shares of different fuels in a country's overall energy mix are determined to a large part by the nation's endowment of natural resources and agricultural activity, especially at low income levels where non-active, imported fuels are beyond the economic reach of most (Dunkerley and Gottlieb, 1987; Kaul and Liu, 1992). Where forest is a sizeable section of a country's total land area, such as in Laos and Cambodia, fuelwood is likely to account for a large fraction of total energy supply (Victor and Victor, 2002). Families living in close proximity to forests see a larger fraction of their energy mix comprised of woodfuel than do those located further from forested areas. A study conducted in urban India by Bowonder *et al.* (1985) found this pattern to hold true even for high-income households. Other countries lack large fuelwood supplies but boast an abundance of other primary energy sources. In South Africa, coal dominates domestic energy supply in the coal-rich part of the nation (e.g. Johannesburg).

2.11.3 Distance to markets and energy use

Rural towns and villages are particularly prone to a lack of modern energy services because of the high cost of connecting to energy infrastructures (e.g., electricity grid) and service networks (e.g., kerosene and LPG supply chains). Even when remote regions are supplied with modern fuels, services to sustain energy infrastructure are often in short supply, making the availability of energy unreliable (ESMAP, 2002; Chaurey *et al*., 2004). Even high-income households in remote areas are frequently forced to rely largely on biomass because the low density of demand for modern energy services makes the supply networks prohibitively costly (WEC/FAO, 1999). The trend of continued reliance on biomass fuels can be seen in India, where the top expenditure decile in rural areas uses almost seven times as much of biomass energy as the top expenditure decile in urban areas (Pachuari, 2004).

Though the energy ladder model has been used to understand the energy use dynamics of urban households in developing countries, the model provides a limited view of reality in actual households. It is specifically limited in its ability to estimate the actual quantities of different fuels consumed by households.

2.12 Conceptual framework

2.12.1 Fuel switching and the energy ladder

On a theoretical level, an exploration of complex and diverse understanding of the energy ladder, which is crafted by income and lifestyle clearly affects the energy transition in the developing world. In order to assess these realities, the final part of this chapter uses a theoretical framework as an analytical tool to accommodate the diverse energy demand in urban household of developing countries. The concept of a fuel switch or an energy transition is central to any understanding of the peri-urban and urban sector. As urbanisation proceeds, there is a tendency for household energy use to increase, diversify and switch from wood and charcoal to modern fuels. The key issue in this sector is the relative price and availability of different fuels and technologies. Where sustainable fuelwood supplies can be provided, they should be encouraged. However, there is little confidence in the potential of wood and charcoal as major long-term fuels. Energy transitions are not unidirectional; fuel shortages can encourage hoarding (i.e., stocking) or switching “downwards”, from commercial fuel back to a tradition fuel (Chambwera, 2004). Bensel and Remeda (1993) state that, generally speaking, the extents to which modern fuels have replaced woodfuels in a particular urban area have been determined by the size of the city and the level of economic development of the country involved.

Household fuel switching may be a seasonal or short-term response to changes in supply, or a long-term measure. Bensel and Remeda (1993) also state that it is quite common for households with access to electricity to rely on coal or wood for cooking because of inadequate supplies, power cut or high electricity prices. The concept of an energy ladder, where people change to high-quality fuels and technologies based on growing income elasticity, is complicated in urban townships areas as energy-technology security is a key issue, not income elasticity to purchase commercial fuels (Chambwera, 2004).

In poor urban areas, wood is likely to be a market commodity and people are generally aware of the cost (in monetary terms) of their fuel (Chambwera, 2004). It is in such cases that fuel-efficient stoves are more likely to have an impact and fuel switching is likely to be higher priority, as well as more feasible. Keterere (1990) indicates that there are two essential criteria for fuel-switching to occur. Firstly, people must have sufficient income to be able to afford the asking price (both for the fuel and for the necessary equipment); secondly, the fuel supply must be maintained. Two issues are apparent, income and infrastructure. As individuals become wealthier, (assuming the infrastructure can maintain alternative fuel supply), fuel switching will occur.

There are a number of factors that work against a fuel switch. Paraffin is often seen as unsafe and a fire hazard; it is also seen as a “dirty” fuel which leaves prepared food with bad taste (Bensel and Remeda, 1993). If a household has had the experience of kerosene at an earlier stage, it can often prompt the same household to switch to another, higher on the energy ladder. However, the mitigating factor with kerosene is the ability to purchase it in small quantities, which is the major factor in explaining why people do use kerosene (Bensel and Remeda, 1993). Furthermore, it is suitable for two specific end-uses, namely lighting and boiling water for drinking.

In some parts of residential urban areas, the energy transition from wood to coal through kerosene, LPG and electricity has been seen in many different countries. This transition may be a slow or a rapid process. This transition will be patchy as different sectors of the residential urban zone use modern fuels, traditional fuels and a mix of fuels, depending on income and availability (Chambwera, 2004).

2.12.2 Multiple fuel use in urban areas

The gaps prevalent in the energy ladder hypothesis provide a basis for building on alternative models that describe household energy consumption. In this study, a conceptual framework is developed on which empirical household energy demand will be based. Such a framework should lend itself to understanding household energy consumption patterns.

The literature confirms the fact that households use multiple fuels (Foster *et al.*, 2000; Masera *et al.*, 2000; Kebede *et al.*, 2002; Campbell *et al.*, 2003). The estimation of the demand for one fuel (electricity 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 and household size. In the case of income, the wealthier the household, the more likely the household will use more of modern fuels than traditional fuels. Masera *et al.* (2000) propose an alternative "multiple fuels or fuel mix" 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 (Masera *et al.,* 2000). The specific combination and the relative consumption of each fuel are governed by the characteristics of fuels and end-use devices, fuel availability and local cultural and social contexts (Chambwera, 2004).

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 for each fuel for its purchase (Chambwera, 2004). Economic theory postulates that consumers allocate their disposable income amongst different goods to maximize utility (Chambwera, 2004). 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 of the consumption patterns by households using different sources of energy, economic theory can be employed to analyse the behaviour of the consumer i.e. 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 economic theory concerning the allocation of income to several goods to maximize utility, a conceptual framework presents itself in terms of urban household energy consumption (Chambwera, 2004). To meet their energy requirements limited income households decide how much of their total income or expenditure to allocate to their energy. According to Kebede *et al*. (2004) in any particular period, households are assumed to choose a set of energy types that they use for household tasks to meet their total energy requirements. For example, a household chooses to use electricity for 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. These decisions differ from one household to the other, and they 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 (Chambwera, 2004; Forster, *et al.*, 2000; Masera *et al*., 2000).

When the circumstances concerning a particular fuel change, 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 (Chambwera, 2004). 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 (Chambwera, 2004).

The key features are the types of energy and their levels of consumption in any fuel mix. For any household with defined characteristics such as income and household size, it is possible to analyse 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.

2.13 Summary

The literature review section shows different types of energy used in most developing countries. Many countries in the developing world are characterised by a variety of traditional and modern energy sources. In the urban areas of South Africa, with a particular reference to townships, the household energy sector is subdivided into electricity, hydrocarbon fuels and biomass fuels. The household emissions from these fuels, particularly hydrocarbon and biomass fuels, remain unacceptable in many urban areas.

The recent literature shows that most household energy debates draw from the concept of an energy ladder, where solid fuels occupy the lowest rung and modern fuels like electricity, LPG sits on the higher rungs. The energy ladder is based on the premise that the choice of fuels is determined by a particular household based on income and choices people make. Some researchers criticise the energy ladder hypothesis, saying that multiple fuel use is most common in poor urban households. Both multiple fuel use and the energy ladder model recognise that hierarchies in household energy services are quite common. In some urban areas, households might not climb the energy ladder even if supplies of clean energy fuels are lacking.

It is important to note that household energy use in the urban areas of developing countries is poorly understood because of the complexity of the fuel switching process. This section has presented a critical discussion of the energy ladder model and has concluded that the energy ladder has been rendered insufficient to represent actual energy consumption dynamics in many poor urban areas. The last section provides conceptual frameworks on two aspects: the energy ladder and multiple fuel use.