Spatial and Temporal Variation in Domestic Biofuel Consumption rates in southern Africa

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I declare that this Dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted previously as a dissertation or thesis for any degree at any other University.

R.P Tshikalanke **19 February 2007**

Abstract

Biomass burning is an important source of trace gases such as CO_2, CO and NO, which influence regional and global atmospheric chemistry. Biomass is burnt in bush fires as well as in households as an energy source. Even though there have been numerous studies on domestic biofuel use in Africa over the last two decades there is still a lack of consumption data on the continent. Biofuel is used in rural and urban areas in Africa, but this project focuses on rural consumption. This project aims to quantify biofuel use at representative rural sites around southern Africa and to investigate the spatial and temporal variation. Three sites, one in the south, central and northern parts were selected in each of seven countries (Botswana, Namibia, South Africa, Mozambique, Zambia, Zimbabwe and Malawi). Consumption rates for all fuel types were determined by weighing the fuel used throughout the day. The survey was conducted during the months of May 2003 to February 2004. The forms of biofuel used over southern Africa were found to be wood, charcoal and to a lesser extent maize residue. To obtain a consumption estimate for the whole of rural southern Africa consumption values for Swaziland and Lesotho from previously studies were included. The total annual rural fuelwood consumption in southern Africa is estimated to be 54.7 ± 3.5 Tg with an average daily consumption of 2.55 kg person^{-1} day^{-1}. South Africa has the highest consumption of wood and Swaziland the least. While fuelwood was used in all countries charcoal was only consumed in the rural areas of South Africa, Zambia and Mozambique. Rural southern Africa is estimated to consume 8.1 ± 0.8 Tg of charcoal per year. Malawi was the only country to consume maize residue at an average rate of 0.51 ± 0.16 kg person^{-1} day-^{1}, leading to a consumption of 1.8 ± 0.1 Tg yr^{-1} over the whole region. The total rural biofuel consumption over southern Africa was estimated to be 64.6 ± 3.6 Tg yr^{-1}. Namibia and South Africa had increased consumption rates between August and October, and Zambia shows slightly higher consumptions between May and July. The other countries show little monthly variation with no specific seasonal trends. There was a slight positive relationship (r^2 = 0.168; p = 0.065) between consumption rate and altitude, but the data is very scattered due to monthly variation. Slopes are only shown to be significant between January and March. Altitude is therefore not shown to be a significant controlling factor of biofuel consumption in this study.

To my grandmother Mukhakhisi Tshavhungwe Tshikovha

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LIST OF ABBREVIATIONS

CRG – Climatology Research Group
CSIR – Council of Scientific and Industrial Research

ESKOM – Electrricity Supply Commission

THRIP – Technology and Human Resources

UN – United Nations

CO_2 – Carbon dioxide

No_x – Nitrogen Oxide

O_3 – Ozone

Tg – Tera gram

kg – kilogram

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Chapter 1
Introduction

Biomass is a renewable resource, which has sustained the human race ever since the discovery of fire. It continues to supply domestic energy requirements for a majority of the world population (Cline-Cole *et al*., 1990). The interest in the amounts of biomass burnt derives from the ongoing investigations into the atmospheric budgets of carbon dioxide (CO_2) and other radiatively or photochemically active trace gases in the atmosphere (Crutzen *et al.,* 1990). Evidence suggests that biomass burning in its various forms represents an important disturbance of the atmospheric chemistry comparable in magnitude to the effects of fossil fuel burning (Lindesay, 1992). Biomass burning has a significant impact on global atmospheric chemistry since it produces large quantities of gross CO_2 (net CO_2 is much less due to biomass regrowth), nitrogen oxides (NO_x), and hydrocarbons (Crutzen *et al.,* 1990). These atmospheric trace gases are precursors of troposphere ozone (O_3) and are known to influence the chemistry of the OH radicals (Logan, 1985). For these reasons, the contribution of biomass burning to the atmospheric trace gas budget has been the subject of several investigations, and many atmospheric scientists are now considering emissions from biofuel as a major source of atmospheric pollution (Andreae *et al.,* 1991; Brocard *et al.,* 1998; Crutzen *et al.,* 1990; Ludwig *et al.,* 2003; Marufu *et al.,* 1997, 1999 and 2000; Otter *et al.,* 2001; Scholes *et al*., 1996; and Yevich and Logan, 2003).

It has been found that the burning of fuelwood, charcoal and non-woody biofuels is a daily practice for about half of the world population (Meyers and Leach, 1989), and that burning of biofuels occurs in both rural and urban situations (Tyson *et. al*., 2002). Biofuels include woodfuels (charcoal as well as fuelwood) and agricultural wastes such as crop residues and dung (Meyers and Leach, 1989). It is becoming clear that domestic biomass burning is a global phenomenon (Andreae *et al.,* 1993). In many rural regions in Africa, more than 90% of energy requirements are met by biofuels (Brocard *et al.,* 1998; Marufu *et al.,* 1999). In remote rural areas, even high-income families typically depend almost entirely on biofuels, with perhaps a little kerosene for lighting and for cooking.

Besides contributing to regional and global atmospheric pollution, domestic burning also leads to indoor pollution. Rural people who depend on biofuel are directly exposed to harmful smokes and are threatened by the carcinogenic risk associated with the pollutants (Mukherji *et al.*, 2002). High CO emissions are reported to cause many deaths among rural people who depend entirely on biofuels (Enger *et al*., 1995).

Given the widespread use of biofuel in developing countries, the trace gas source strength of domestic biomass burning in these countries is quite significant at a global scale (Andreae *et al.,* 1991). Marufu *et al* (1997) estimated that biofuel burning in southern Africa contributes 138 Tg yr^{-1} to the regional trace budget. To improve the accuracy of these estimates more information is needed on the quantities of biofuel consumed (Marufu *et al.,* 1999). More information is also required on the social aspects of biofuel use, as well as physical factors (such as ambient temperatures) since this also may have an impact on the amount of biofuel consumed.

1.1 Global overview of biomass burning estimates

Global biomass consumption rates, from bush fires as well as domestic use, have been estimated in several studies (table 1.1), and these estimates vary substantially from study to study mainly due to the improved techniques used to estimate biomass consumption rates. The burning of forests and savannas are the single largest emissions in Africa, followed by biofuel burning (Andreae *et al.,* 1996).

The consumption of biofuels (including wood, charcoal and agricultural residues) for domestic use is estimated to be between 20.5% and 43.1% of the global biomass consumption (table 1.1), which is a significant percentage of the total bugdet. Table 1.1 indicates that the consumption of agricultural wastes is higher than fuelwood use on a global basis. However if these numbers are broken down into regional values it is shown than sub-Saharan Africa and Latin America depend mainly on wood, while Asia uses all fuel types (Andreae, 1991).

Table 1.1 Comparison of annual amount of biomass burnt in different ecosystems and different biofuels (from Andreae, 1991).

Source	Seiler and Crutzen (1980) (Tg y^{r-1})	Hao *et al* (1990) (Tg y^{r-1})	Andreae (1991) (Tg y^{r-1})
Tropical forest	2420	1260	1260
Savanna	1190	3690	3690
Temperate and Boreal forest	280		280
Fuelwood	1050	620	1430
Charcoal			21
Agricultural wastes	1900	660	2020
World total	**6840**	**6230**	**8700**

1.2 Domestic biofuel use across the globe

The total world biofuel is estimated at 3199 Tg yr^{-1} for a total population of 5716 million (table 1.2). Asia has the highest biofuel consumption (59.3% of the total), followed by Africa and America.

Table 1.2 Inventory of global domestic biofuel consumption (Ludwig. *et al.,* 2003).

Region	Population (1995) (in millions)	Biofuel consumption (Tg^{-1} yr^{-1})
Africa	728	633
Asia	3386	1896
Latin America	482	236
Oceania	29	6
N. America	293	243
Europe	506	86
Former USSR	292	99
World total	**5716**	**3199**

1.2.1 The developed world

The developed world contributes less than 15% to the global domestic biofuel consumption budget. Consumption rates are low as they mostly use modern forms of energy (electricity) (Delmas *et al.,* 1991). Fuelwood in the whole of Europe is estimated at 86 Tg yr^{-1}, of which France, Sweden, Finland and Italy are the main contributors because they consume about 12% to 18% of Europe's total energy budget (Yevich and Logan, 2003). Prinn (1991) undertook a survey for Germany, France and the United Kingdom and found that in France wood was reported as the primary space heating fuel in some three million houses of people who used wood regularly as an alternative source of fuel. In Germany the consumption of biofuels is generally not recorded in their statistics. In the United Kingdom most fuelwood is directly used as a household fuel in open fires, cooker boilers and other wood burning stoves. Charcoal consumption is at its highest level in the United Kingdom, estimated around 5 Gg per year.

1.2.2 The developing world

The vast majority of people in the developing world, particularly in Africa, rely on biomass in the form of wood, charcoal and crop or animal residues for their basic household fuel (Munslow *et al.,* 1988). Those responsible for biomass burning are the individual farmers, ranchers and housewives in most of the rural areas. Developing countries mostly do not keep a record of amount of biofuel burned and as such it has been difficult to determine their consumption patterns; however the number of biofuel studies in developing countries has increased over the last few decades (Munslow *et al.,* 1988; Andreae *et al.,* 1991; Hall and Mayo,1994; Brocard *et al.,* 1998; Crutzen *et al.,* 1990; Lindesay, 1992; Ludwig *et al.,* 2003; Marufu *et al.,* 1997, 1999 and 2000; Yevich and Logan, 2003).

Fuelwood is the predominant type of fuel used in the developing countries (table 1.3). Asia uses the largest amount of all fuel types whereas Africa has the second highest usage of wood, but it uses very small quantities of dung and plant residue compared to other developing countries. Dung has the lowest consumption rates but in India they use almost equal amount of dung and plant residue.

Table 1.3 Total biofuel consumption (Tg) in the developing countries (Yevich and Logan, 2003).

Country	**Residue**	**Dung**	**Fuelwood**
Africa	47	11	354
Asia	465	123	784
India	87	93	220
China	294	20	264
Latin America	85	2	186
Brazil	47	-	102
Total	**1025**	**249**	**1324**

India:

Biofuels are extensively used for cooking and house heating in rural as well as urban households in India (Joshi, 1991). The biofuels used in India include wood, crop waste and dung cake (Leach, 1988). Recent studies suggest that forests in India are likely to come under increased pressure for meeting domestic biofuel demand. Domestic biofuel burning accounts for 42% of the total biomass burnt in India (Prastad *et al.,* 2001).

China:

China has the single largest impact on global biomass energy use (Yevich and Logan, 2003). Fuelwood is the main source of rural energy and provides 264 Tg (45.6%) of the total biomass consumption in China (578 Tg) (Yevich and Logan, 2003). Residue is consumed at the rate of 294 Tg yr^{-1}. Increasingly however, coal and electricity are replacing fuelwood and residue use as domestic fuels.

Latin America:

Biofuel use is a predominant source of fuel in rural areas of Latin America and these fuels provide a larger fraction of the total household energy use than in other developing countries (Meyers and Leach, 1989). Fuelwood provides most of the household energy and is used largely for cooking. Charcoal use is negligible in the rural regions of Central America and is limited to the urban households and commercial sectors (Yevich and Logan, 2003).

Africa:

Africa is suggested to have the lowest per capita consumption of electricity generated fuel in the developing world (Yevich and Logan, 2003). The majority of the African population depends on biomass-derived energy in the form of fuelwood, charcoal and agricultural residue to meet their cooking and lighting needs (Musa, 2002; Evict, 2003). Modern energy resources are concentrated in a few countries such as Nigeria, Libya and South Africa (Kahane and Lwakabamba, 1990). Most African countries are rural and their economic output is very low, and as such these countries cannot afford to buy oil-based fuel (Barnes *et al.,* 2001). In the sub-Saharan African economy the household sector accounts for 50-95% of total energy consumption in contrast with the world's industrialized economies in which the household share is usually around 25-30%. The highest proportion is found in poorest countries such as Tanzania and Ethiopia, in which households rely almost exclusively on biomass sources, including fuelwood, charcoal, crop residue and animal dung (Kendall *et al.*, 1996).

Tiffen (1995) reported that people in Africa are engaged in charcoal burning and fuelwood sales to generate income to replace lost earnings from crops. Demand for rural fuelwood and for urban charcoal is on an upward trend because of the increase in population and the formation of new households.

1.3 Biofuel use in Africa

1.3.1 Fuelwood consumption rates

The total fuelwood consumption in Africa is estimated to be 294.6 Tg yr^{-1} (table 1.4). The rural population of Africa relies on wood and charcoal as the main fuels for domestic consumption (Aron *et al.,* 1991; Kahane and Lwakabamba, 1990; Kituyi, 2001; Kgathi *et al*., 1997; Marufu, 1997; 1999; 2000; Ludwig, 2003). Yevich and Logan (2003) subdivided the African continent into regions, grouping together neighboring countries that share similar woody vegetation and population density. The highest fuelwood consumption rates occur in the eastern and southern drylands of Africa (between 1.8 and 3.24 kg cap^{-1} day^{-1}) due to plentiful forest resources. Countries such as Nigeria, Ethiopia, Tanzania, Kenya and Zaire use 138 Tg yr^{-1} of fuelwood or about 50% of the total for Africa (table 1.4). Sahel region has the lowest consumption (16.26 Tg yr^{-1}) of fuelwood compared to all other regions, with consumption rates of below 1.0 kg cap^{-1} day^{-1}. The Mediterranean countries of North Africa are oil rich states, such as Libya and as such fuelwood consumption is negligible (Hosier, 1987).

Table 1.4 Total fuelwood consumption rates in Africa (Yevich and Logan, 2003).

Country	Totals, Tg DM yr^{-1}	Per Capita, kg cap^{-1} day^{-1}
Algeria	7.34	0.92
Egypt	0.88	0.05
Libya	0.00	0.00
Mauritania	0.66	1.02
Morocco	6.70	0.78
Tunisia	1.11	0.42
W.Sahara	0.00	0.00
Total	**16.26**	
Chad	0.55	0.30
Mali	4.46	1.49
Niger	2.82	1.17
Senegal	1.15	0.48
Sudan	18.16	2.28
Total	**27.14**	
Benin	1.92	1.30
Burkina faso	4.94	1.70
Gambia	0.63	2.33
Ghana	7.94	1.71
Guinea	5.48	3.22
Guinea-B	0.39	1.22
Ivory Coast	5.69	1.57

Liberia	1.79	2.24
Nigeria	52.39	1.50
Sierra Leone	2.03	1.50
Togo	1.55	1.58
Total	**84.75**	
Angola	6.33	1.98
Cameroon	5.90	1.79
Cen. Af. Ref	1.89	1.99
Congo	1.14	1.61
Eq. Guinea	0.29	2.54
Gabon	0.58	1.61
Zaire	17.41	1.54
Total	**33.54**	
Kenya	14.03	1.89
Malawi	7.91	3.01
Tanzania	25.46	3.21
Uganda	12.45	2.18
Zambia	7.95	3.24
Total	**67.80**	
Botswana	0.80	2.04
Burundi	2.15	1.25
Ethiopia	29.11	1.84
Lesotho	0.03	0.05
Mozambique	8.37	1.66
Namibia	0.28	0.50
Rwanda	3.85	1.73
Somalia	2.28	0.98
South Africa	9.08	0.79
Swaziland	0.30	1.28
Zimbabwe	4.70	1.55
Total	**60.95**	
Cape Verde	0.09	0.77
Comoros	0.28	1.66
Madagascar	3.43	0.94
Mauritius	0.23	0.63
Sao Tome	0.10	2.56

Seychelles	0.00	0.25
Total	**4.13**	
Africa Total	**294.57**	

1.3.2 Charcoal production and consumption in Africa

Charcoal production is a process in which heat is applied to organic matter inside a relatively airtight container commonly referred to as a kiln. Charcoal is wood charred in the absence of oxygen. Due to its lack of moisture and high carbon content, charcoal contains large amounts of energy per unit mass. Charcoal is more compact to burn on a fire compared to wood; however, charcoal was found to be 40% less efficient than fuelwood (Chidumayo, 2003). Charcoal can be produced from wood, millet stems and corn cobs (Karekezi and Ranja, 1997).

Africa has the largest per capita charcoal production among the developing continents (Hemistock and Hall, 1997). Charcoal production for domestic and industrial use has become an important alternative to wood as fuel. Transportation of wood from the forest to consumers in urban areas is very difficult and therefore wood is often replaced by charcoal, which is easy to transport to urban areas (Andreae, 1991).

Studies undertaken by Marufu *et al*. (1999) and Kituyi *et al* (2001) indicated that charcoal is used in greater quantities in urban areas than in rural areas. Kituyi *et al* (2001) investigated charcoal usage in urban and in rural areas and found that out of 4 African countries (Tanzania, Mali, Kenya and Zimbabwe), Kenya was the only country that used charcoal in rural area. The other countries use charcoal in urban areas. It is argued that the higher consumption of charcoal in urban areas is mainly due to the convenience associated with its usage and cost while the abundant fuelwood and higher cost of charcoal is a reason for the trend observed in rural areas. Charcoal is mainly an urban phenomenon in Africa.

The greatest per capita production of charcoal is in the east African highlands (table 1.5). These countries (Kenya, Tanzania and others) have a substantial woody supply (although this is rapidly declining due to wood utilization and land use change) that can be converted to charcoal and then transported in regions of demand. By contrast, little charcoal is used in southern drylands.

Table 1.5 Quantity of wood for charcoal production in Africa (Yevich and Logan, 2003))

Country	**Total wood needed (Tg^{a})**	**Choice kg charcoal $urbancap^{-1}$ yr^{-1b}**
		Eastern Highlands
Burundi	0.2	165
Kenya	6.4	283
Mozambique	2.6	217
Rwanda	0.4	197
Tanzania	4.5	177
Uganda	1.9	192
Zambia	5.1	256
Total	**21.1**	
		Southern Drylands
Namibia	<0.1	8
Zimbabwe	<0.1	1
Others	<0.1	0
Total	**<0.1**	
Sudan[c]	15.0	667
		Rest of Africa
Angola	1.3	73
Benin	0.1	27
Burkina Faso	0.1	12
Cameroon	0.6	24
Cape Verde	<0.1	3
Cen. Af. Rep.	0.4	49
Chad	0.4	53
Comoros	<0.1	1
Congo	0.3	40
Djibouti	0.1	28
Egypt	0.1	1
Eq. Guinea	0.1	1
Ethiopia	1.3	43
Gabon	<0.1	3
Gambia	<0.1	22
Ghana	3.0	110

Guinea	0.5	57
Guinea-B	0.1	61
Ivory Coast	1.1	41
Liberia	0.7	189
Libya	0.1	4
Madagascar	1.2	84
Malawi	0.6	103
Mali	0.4	34
Mauritania	0.1	143
Mauritius	<0.1	9
Morocco	0.8	13
Niger	<0.1	4
Nigeria	1.2	12
Reunion	<0.1	7
Sao Tome	<0.1	41
Senegal	1.8	1262
Sierra Leone	1.0	169
Somalia	1.2	113
Togo	0.3	110
Tunisia	0.2	7
Western Sahara	<0.1	6
Zaire	4.0	49
Total	**23.1**	
Total Africa	**59.2**	

[a] Assumed a 15% efficiency in converting wood to charcoal.
[b] Charcoal is mainly an urban phenomenon in Africa.
[c] Assumed a 20% efficiency in converting wood to charcoal.

Urban users in Zimbabwe and Swaziland prefer firewood and coal. In Lesotho, Botswana and Namibia, the urban population uses firewood, kerosene, and coal (Yevich and Logan, 2003). Sudan is unusual in that charcoal is significant as an energy source for both the urban and rural populations. The rural population uses almost 80% of the charcoal consumed in the Central Region and this explains the very high charcoal use expressed in per urban-capita units in table 1.5 (Yevich and Logan, 2003).

Charcoal is not a predominant fuel type in South Africa (The Digest of South African Energy Statistics, 2002). Charcoal in South Africa is sold mainly in urban areas in the filling stations where majority of the people who have cars buy them. The rural people who use charcoal buy it from trucks on the streets or from people who buy them from towns.

Zambia on the other hand produces and uses large amounts of charcoal. Charcoal is the most important household fuel, which meets the energy needs of about 83% of urban households (Karekezi and Ranja, 1997). With an urbanization level of 42%, charcoal is the major source of energy for more than a third of the population. Charcoal is produced in Zambia from miombo woodland by the traditional earth kiln method (Karekezi and Ranja, 1997).

1.3.3 Factors influencing biofuel consumption

Climate, altitude, demand, and household size are some of the main factors affecting the biofuel consumption rates (Marufu *et al.,* 1997; Means, 1995). Climate affects consumption rates indirectly through fuel availability and directly through the amount of energy needed for heating. High rainfall areas have plentiful woody vegetation which can be used as fuelwood whereas desert areas are characterized by sparse vegetation thus consumption rates are low (Yevich and Logan, 2003). Climate also influences the seasonal variation in fuel consumption. In winter households are likely to use more fuel than they do in summer due to the increased need for space heating. Altitude is linked with climate in that high altitude regions often have more severe winters. High lying regions which experience large seasonal temperature variations, and where temperature reach below 0^{o}C in winter are likely to have wider seasonal variations in fuel demand than those with low temperature fluctuations (Marufu *et al.*, 1997).

The use of maize residue depends on technical and economic constraints, as well as social and environmental constraints (Diaze *et al.,* 1981). This is because people in rural areas are poor and therefore do not have tractors to cultivate many hectors of maize, thus there is little maize residue for burning. Furthermore, the seasonality of maize production and maize residue production as well as the level of fertility of the land will influence the availability of maize residue as a fuel.

An investigation of the socio-economic characteristics has shown that cultural factors are important in determining the level of biofuel use (Cline Cole *et al*., 1990). Rural people are mostly poor and have poor access to energy services. Rural people have poorly insulated housing and inefficient heating systems. They also have low incomes because they are mostly unemployed. They often spend longer periods at home than those in paid work and therefore have higher heating requirements (Yevich and Logan, 2003). Rural people are also marginalized that they do not even have enough to cook everyday. In times of severe food scarcity rural people often rely on fruits obtained from their surrounding forests. These decrease their daily fuel consumption significantly because they often do not have enough to cook (Yevich and Logan, 2003).

1. 4 Contribution of biomass burning to the atmospheric aerosol loading

Recent estimates indicate that emissions from biomass burning may be the second largest human source of aerosols after the production of sulphates from sulphur dioxide (Van Wilgen *et al.,* 1997). The emission of these aerosols into the buoyant smoke plumes from fires can result in their diffusion through some depth of the troposphere and over considerable distances (Davidson, 1992). Davidson also estimated that biomass burning maybe the largest global source of atmospheric black carbon. The emission of total particulate matter in the tropics is estimated as 104 Tg yr^{-1}, most of which was recorded as organic matter. Of the particulate organic carbon released (70 Tg yr^{-1}), about one quarter (20 Tg yr^{-1}) is in the form of black carbon. Based on these estimates, particulate organic carbon from biomass burning accounts for over one-third of the organic carbon aerosol released globally (Andreae, 1991). Black carbon is important because it absorbs solar radiation, resulting in cooling at the surface and heating aloft. This effect may be enlarged by an increase in cloud reflectance due to an increase in condensation nuclei concentration as a result of the aerosols emissions (Davidson, 1992).

One of the most visible impacts in the atmosphere of biomass burning is the brownish haze that pervades rural areas of the tropics and the sub-tropics that are subjected to heavy biomass burning and long term atmospheric transport transform this haze into a regional scale aerosol layer (Ramanathan *et al.,* 2001). The composition of inorganic chemicals, atmospheric stability and transport conditions over southern Africa leads to the development of a haze layer that is a ubiquitous sub-continental scale feature below 500 hPa level (Swap and Tyson, 1999; Picketh, 2000; Tyson and Preston-Whyte, 2000). Estimation indicated that biomass burning (including domestic burning) smoke contributes about three quarters of the aerosol burden in the regional haze, while other sources like fossil fuel burning contribute the remainder (Kirchstetter *et al.,* 2003).

1.5 Rationale for this project

There is a lack of reliable biofuel consumption data for most developing countries. Much of the fuel is obtained by individual gathering and not marketed, therefore adequate statistics on fuel use are not kept. This is a situation that has hampered efforts to quantify the contribution of emissions from domestic biomass burning to the global atmospheric trace budgets (Kituyi *et al.,* 2001b). More information on the biofuel consumption is necessary to better understand the sources and sinks of the atmospheric trace gases and to construct a credible assessment of biofuel consumption in Southern Africa.

In attempting to quantify consumption rates in southern Africa Marufu (1999) measured biofuel consumption rates in Zimbabwe and scaled these values up to create country level estimates. These estimates for Zimbabwe were then used to calculate annualized biofuel consumption rates in the rest of southern Africa. This approach provided initial estimates for the region. There have been a few other studies in the region (Kituyi *et al.,* 2001b; Marufu, 1997, 1999; Kahane and Lwakabamba, 1990), which investigated different types of fuels namely charcoal, maize residue and fuelwood but these other studies have not been used for scaling the data up to the southern African level. Kituyi *et al.* (2001b) studied the consumption rates in Kenya in different institutions, namely boarding schools, Universities and colleges, and found that there is no significant variation on consumption rates in the institutions. Marufu *et al*. (1997, 1999) studied biofuel consumption in rural and urban Zimbabwe. His studies found different forms of biofuel used in rural areas namely wood, agricultural residues and cow dung, with wood being the dominant fuel type used. When available, agricultural residues were the second most popular form of fuel. His studies also found that cow dung was only used in situations of severe fuel shortage. Kahane and Lwakabamba, (1990) studies were focused on Zambia studying factors that contributes to the availability of charcoal in Zambia and found that a large amount of charcoal in Zambia was from the miombo woodland. All these studies were focusing on the individual countries, whereas this study covers seven countries in the southern African region.

1.6 Objectives of the study

The main objectives of this study are to:

- Investigate the spatial and temporal variation in rural biofuel consumption rates in southern Africa;
- Quantify rural consumption rates of various fuel types across southern Africa;
- Determine the effects of altitude on rural consumption rates and type of fuel used;
- Estimate the annual rural biofuel consumption rate for southern Africa.

Chapter 2
Methodology

2.1 Study sites

Biofuel consumption was investigated in seven southern African countries, namely South Africa, Mozambique, Malawi, Zambia, Zimbabwe, Botswana and Namibia. Each country was subdivided into three sections, namely a southern, central and northern section. In each section of the country one site was chosen for biofuel data collection thereby giving three sites in each country. This gave a total of 21 sites throughout southern Africa (figure 2.1)

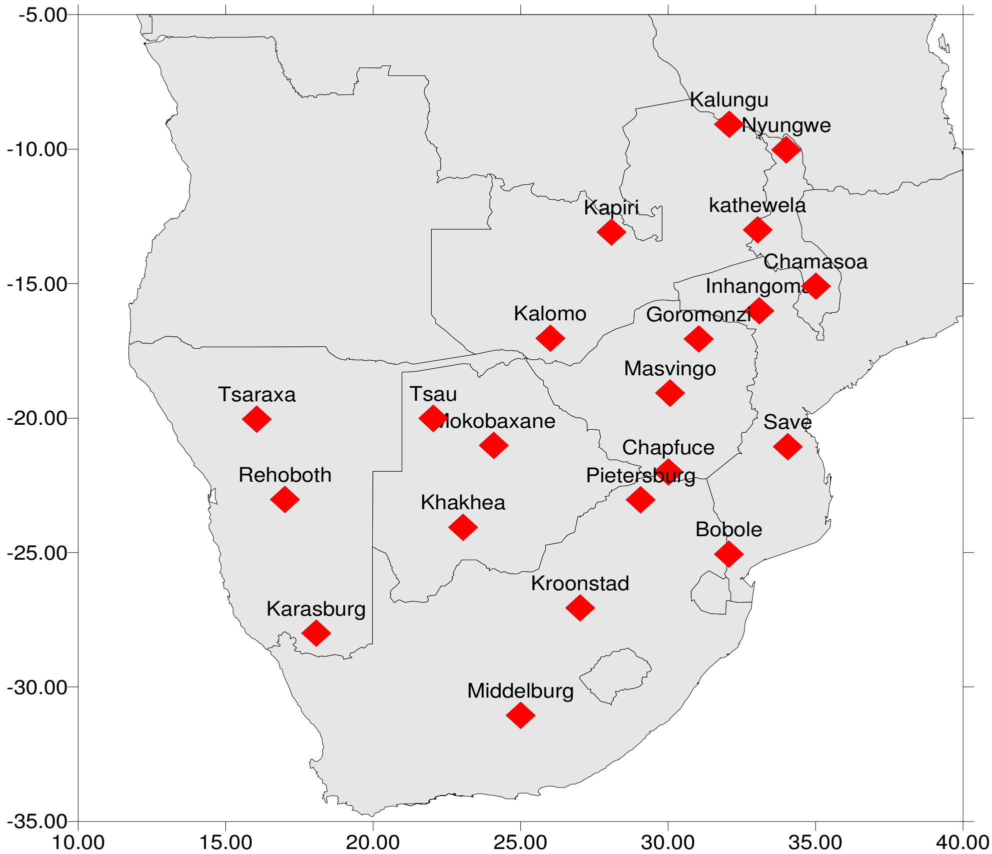

Figure 2.1: Map showing the location of all sampling sites in southern Africa. All dotes are below the site names.

The individual sites were chosen subjected to the conditions that (a) the area was rural in nature and (b) if the household used electricity it should at least substitute with biofuels. These two criteria were chosen because the research was aimed at specifically studying domestic biofuel consumption in rural areas. Each household unit had a kitchen area from which they ate on a daily basis.

2.2 Data collection

By early 1985 the common method for biofuel data collection was the use of telephone to contact households for interviews. The interviewers collected information using the standardized questionnaires. If households collected their own types of biofuel, different questions were asked about the amount and proportion of biofuel obtained from various sources (Rudis, 1986). The telephone method had the disadvantage that not all people in rural Africa have a phone and as such the method could not really obtain data from rural Africa where much of the domestic biofuel burning was occurring. The method undertaken by Marufu *et al.,* (1997, 1999) and Kituyi *et al.,* (2001) for Zimbabwe and Kenya has improved from collecting the data using telephone method, to the one which involves going to the sites and collecting data as well as conducting questionnaires. This approach was adopted in this study.

Initial site visits where conducted in which a member in each household was given a spring balance with a capacity of 50 kg and a logbook. They recorded the type (wood, charcoal and maize residue) and quantity of biofuel used at each cooking session (breakfast, lunch and dinner) as well as the number of people for which it was used. The household occupants were interviewed to acquire additional information on factors that may affect fuel type and consumption rates. The altitude data was collected at every site through the use of a Global Positioning System (GPS). This altitude data was then used to determine the relationship between altitude and consumption rates. Daily household biomass consumption data were collected from each site in southern Africa between May 2003 and February 2004 (table 2.1). The project is on-going so that annual values can be obtained but only the data for these months was used to this study due to the nature and time-constraints of this project.

Table 2.1 Table showing the months during which data were collected in the 7 countries (dark grey = data collected; light grey = no data collected).

Month	Botswana	Namibia	South Africa	Mozambique	Zambia	Malawi	Zimbabwe
March							
April							
May							
June							
July							
August							
September							
October							
November							
December							
January							
February							

2.3 Data analysis

To determine the consumption rates, each household recorded the amount of wood, charcoal and/or maize residues they use in a day and the number of people who used the fuel. This data was used to calculate biofuel consumption rate per person day^{-1} at each household by using the following formula:

Daily consumption rate (kg person^{-1} day^{-1}) = kg of fuel used in a day / number of people in the household.

The daily consumption rate (kg person^{-1} day^{-1}) was calculated from three cooking session (breakfast, lunch and dinner) and these values were then used to obtain monthly (kg person^{-1} month^{-1}) for each site. Three sites were then averaged to get an average monthly value. These average values, multiplied by the rural population data, were used to calculate the annual rural biofuel consumption per country. During this study data was collected for 7 months of the year[1] for all countries (table 2.1). For the missing summer months and average summer estimate, calculated from the November, December and January (mid-summer months) data, was used. Similarly, for winter and average winter estimate was calculated from the June, July and August (mid-winter months) data. These average values were only used in the annual calculations. The population data used was acquired from the World Population Data from the United Nations (2003). Rural population numbers were used instead of the total population numbers because consumption rates were only measured in rural areas (i.e. urban consumption was excluded) and therefore all the consumption data referred to in the rest of the document is for the rural population of these countries. Annual estimates are based on the assumption that all rural areas over southern Africa use biofuel as a form of domestic energy generation and that all sites in a country are representative of the entire country. The other assumption was made when calculating the consumption rates using the United Nation population projection for 2030, where it was assumed that consumption rates would remain as they are in this study and only population density changed.

To determine the relationship between consumption and altitude monthly consumption rates were plotted against altitude and linear lines were fitted to the data. This was done for each month as well as an average fit for all the data. To test whether the slopes were significant (i.e. slope > 0) t-tests were conducted as the samples size was small. The Pearsons correlation coefficient was calculated to determine the correlation between consumption rate and altitude.

[1] Data was collected for the rest of the year so that actual annual values can be calculated, however this was done after the completion of this report.

Chapter 3
Results

3.1 Biofuel consumption rate variation and seasonal trends

Biofuel consumption rate variation within countries is high and the seasonal variation pattern found in one part of the country is not the same as that in other parts of the country (Figure 3.1 and 3.2). Mozambique and Malawi (figure 3.1) show low biofuel consumption rates in all sites throughout the year, with Malawi having the smallest variation between sites. In Zambia the central regions have the highest consumption rates but there is a definite increase in consumption in all regions in January. Central and northern Botswana show similar consumption rates and seasonal pattern, however southern Botswana has higher consumption rates with a sharp decline in October and an increase in December. Namibia and South Africa have the highest in country variation. In Namibia the central region has low consumption rates with very little monthly variation. The Northern and southern sites have a sharp increase in consumption to values greater than 220 kg person^{-1} month^{-1} in October and November, respectively, and then decline to values lower than 80 kg person^{-1} month^{-1}. In South Africa the northern and central sites have fairly low consumption rates, while the southern site shows very high consumption rates (figure 3.2). Unfortunately the household in the southern site did not collect data in November and January and the December consumption at this site is very high. It should be noted that only one household in each region of the seven countries was investigated so this in country variation may be reduced (or increased for that matter) if the samples size is increased.

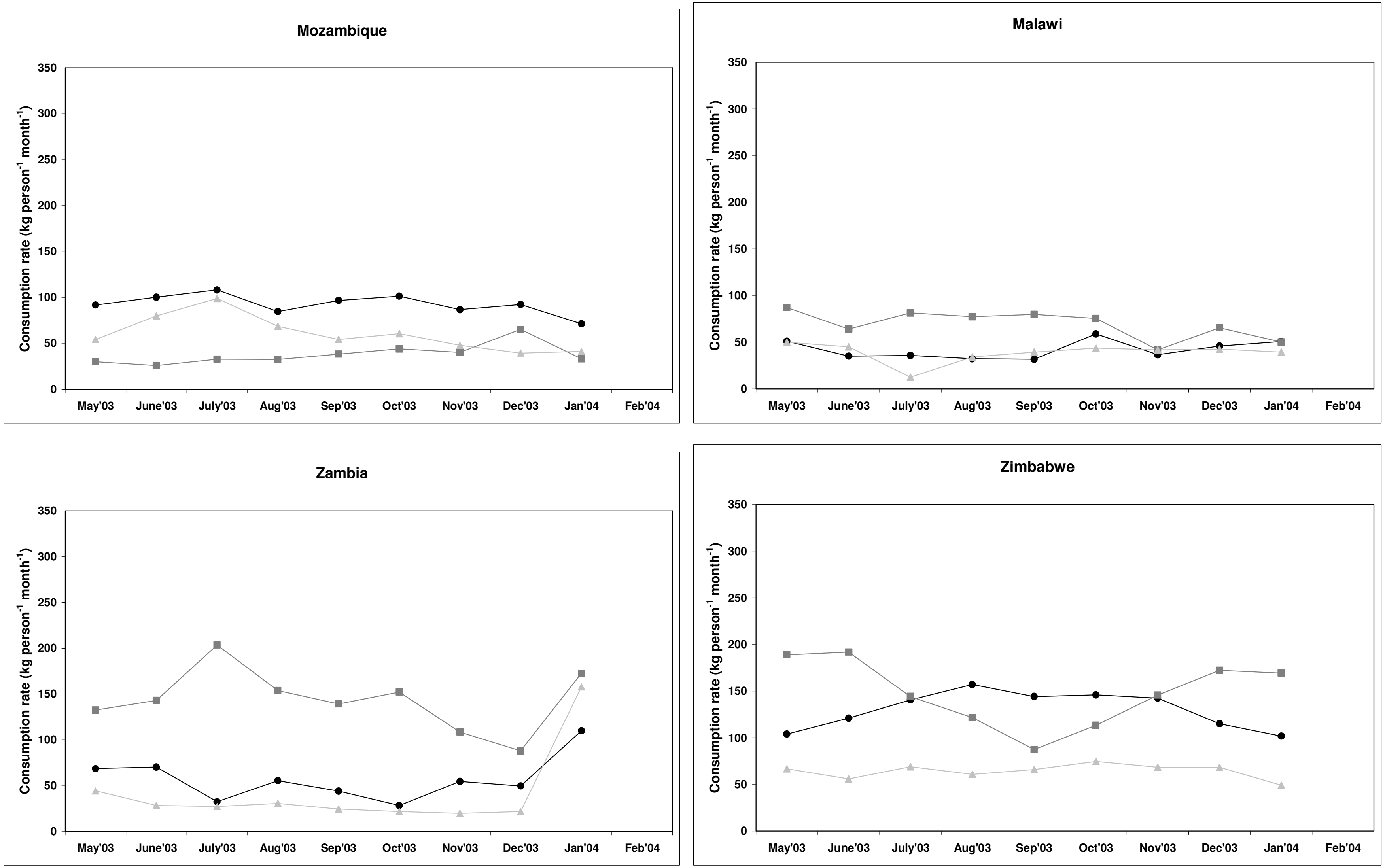

Figure 3.1: Biofuel consumption rates (kg person^{-1} month^{-1}) in the southern (black circles), central (dark-grey squares) and northern (light grey triangles) parts of Mozambique, Malawi, Zambia and Zimbabwe (n=1).

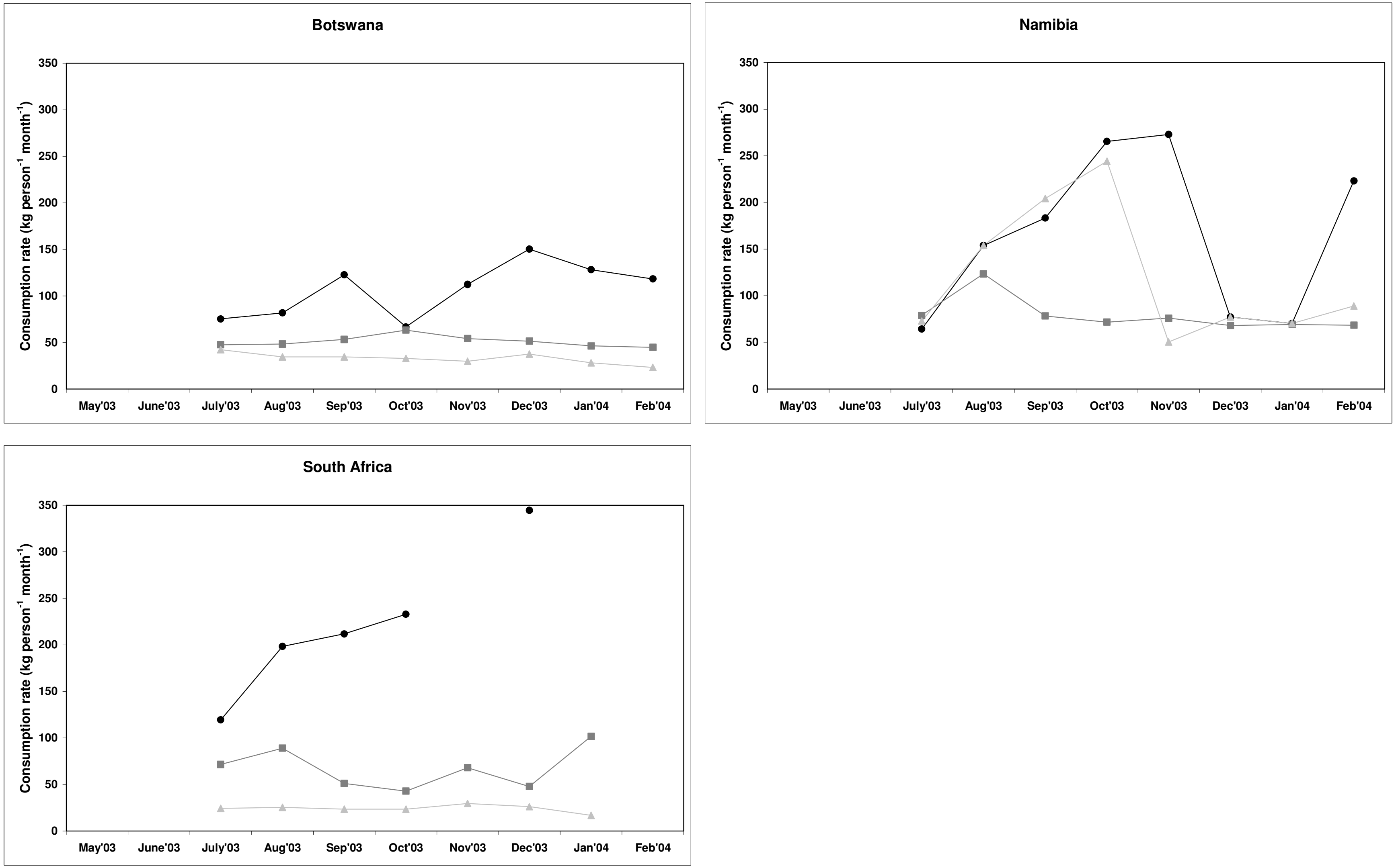

Figure 3.2: Biofuel consumption rates (kg person^{-1} month^{-1}) in the southern (black), central (dark-grey) and northern (light-grey) parts of Botswana, Namibia and South Africa (n=1). Unfortunately household recipients in SA did not collect their data during November and January, hence the missing data points.

Seasonal trends are a bit clearer once the data is averaged for each country (figure 3.3). Generally there does not seem to be an increase in consumption rate during winter, except Namibia and South Africa where consumption rates are higher between August and October. Zambia does show slightly higher consumptions between May and July, declining to December with a sudden sharp increase in January. Zimbabwe has relatively high consumption rates throughout the year which are fairly constant through the year except for a decline in September.

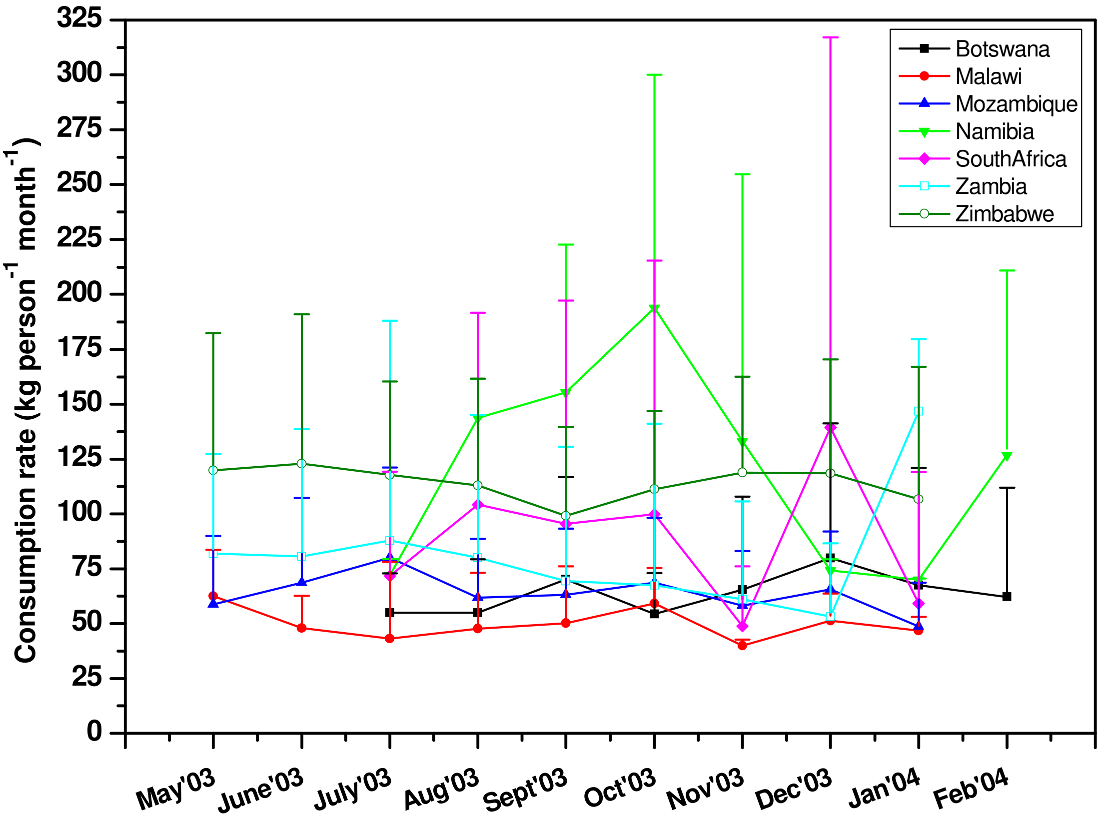

Figure 3.3 Average monthly consumption rate (+ SE) for all seven southern African countries.

3.2 Variation in biofuel type

Most of southern African countries were shown to use fuelwood as their main, if not only, source of fuel (table 3.1). In all countries fuelwood was consumed at a higher rate (regional average of 2.55 kg person^{-1} day^{-1}) than charcoal and maize residue. Namibia and Zimbabwe have high average daily fuelwood consumption rates (4.53 and 3.91 kg person^{-1} day^{-1}, respectively) relative to the other five countries.

Table 3.1 Average consumption rates, for the entire study period, of different fuel types in southern Africa (n = 3).

Country	Average consumption rate (kg person^{-1} day^{-1}) ± SD (*n*)		
	Fuelwood	**Charcoal**	**Maize residue**
Botswana	2.11 ± 1.26		
Mozambique	1.75 ± 0.62	0.75 ± 0.66	
Namibia	4.53 ± 2.24		
South Africa	2.13 ± 1.86	2.22 ± 3.08#	
Zambia	2.13 ± 1.13	0.95 ± 0.87	
Zimbabwe	3.91 ± 1.51		
Malawi	1.31 ± 0.43		0.51 ± 0.16

**Blanks indicates that the fuel type was not found to be used in that country*
#This includes a very high consumption rate (11.48) at the southern site during December. If this value is excluded from the average calculation the average consumption rate becomes 0.31 ±0.53 kg person^{-1} day^{-1}.

Mozambique, South Africa and Zambia use charcoal as well as wood, while Malawi uses wood and maize residue. Maize residue was mainly used during dry months whereas charcoal and wood were used interchangeably throughout the year particularly in South Africa and Mozambique. No seasonal pattern was shown in the use of wood and charcoal. In South Africa and Mozambique charcoal is used throughout the year with its consumption usually being related to a declined usage of wood (figure 3.4). In South Africa charcoal was generally low (0.31 kg $person^{-1}$ day^{-1}) except for a huge consumption during December in the southern site and this contributed to the very high average consumption rate relative to Mozambique and Zambia. In Zambia charcoal was mainly used in May, when wood consumption was low, and very little during July and August. It is also important to note that charcoal was mainly used in the southern site (and on the odd month the northern site as well) in Mozambique. On the other hand charcoal was consumed at all three sites in Zambia during the indicated months. Maize residue was used during most months of the year except August, October and January when wood consumption was at its highest in Malawi. Maize was mainly used in the southern and central sites in Malawi.

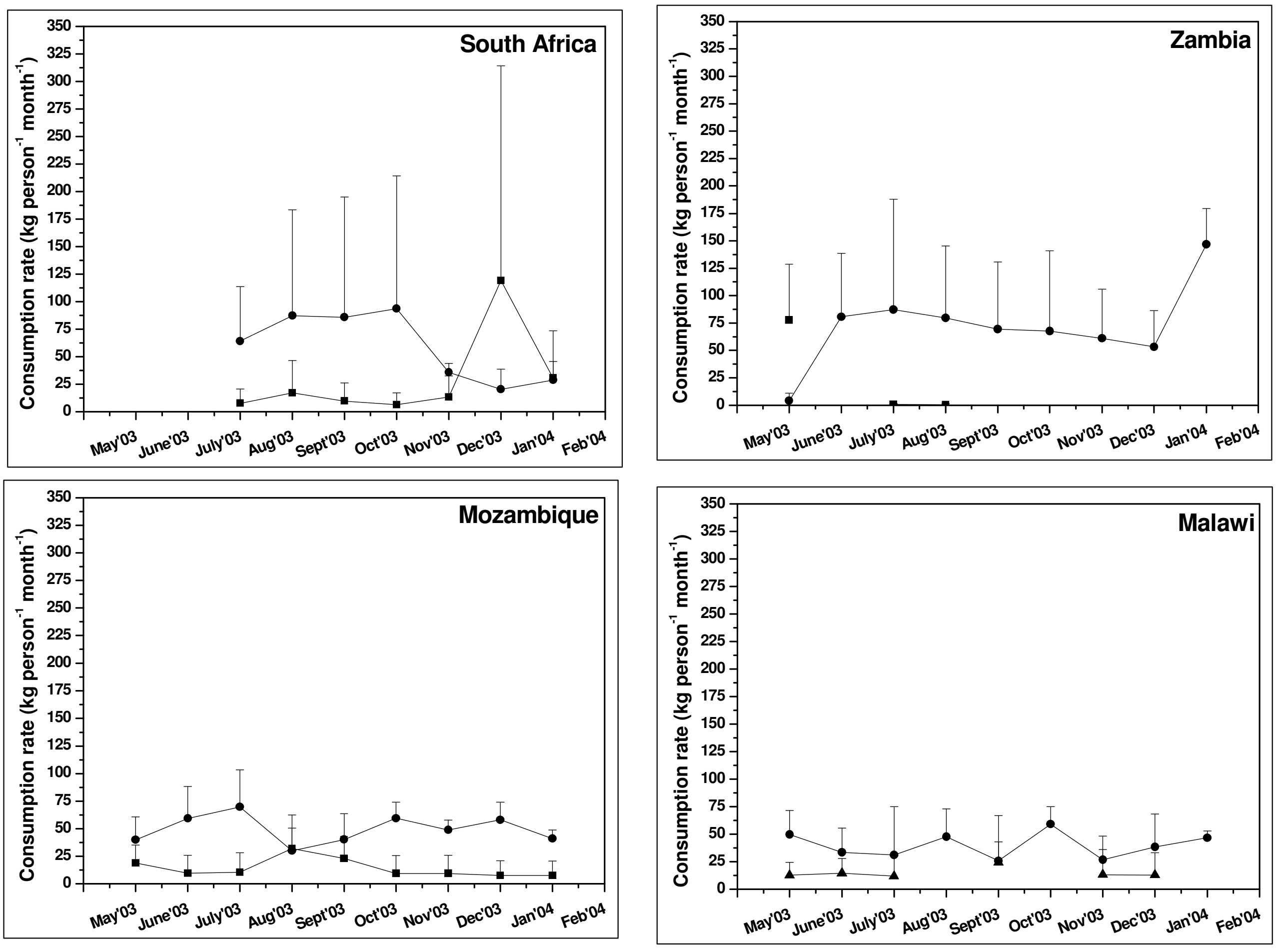

Figure 3.4 Wood (circles), charcoal (squares) and maize residue (triangles) were the three different fuel types used in SA, Zambia, Mozambique and Malawi. Wood and charcoal are used almost interchangeably, particularly in SA and Mozambique, whereas maize residue is used more seasonally. The bars represent +SD.

3.4 Relationship between consumption and altitude

There is a slight positive relationship ($r^2 = 0.168$) between consumption rate and altitude, but the data is very scattered (due mainly to seasonal variation) (figure 3.5) and thus the slope is only shown to be significantly different from zero at the 90% level ($p = 0.065$). The graph generally showed that consumption rates are higher at high altitudes. The consumption rate increases by almost 4 kg person^{-1} month^{-1} with every 100m increase in altitude. The consumption rate increases more sharply with altitude during the summer months, particularly between December and March, than the winter months as can be seen by the slopes of the linear fits (table 3.2). The positive relationship is only shown to be significant in January, February and March. During the winter months of July and August there is even a slight negative relationship between consumption and altitude but these are not significant. In other words more biofuel is consumed at higher altitudes during summer than at lower altitudes sites, and during winter fuel is consumed at a similar rate at all sites.

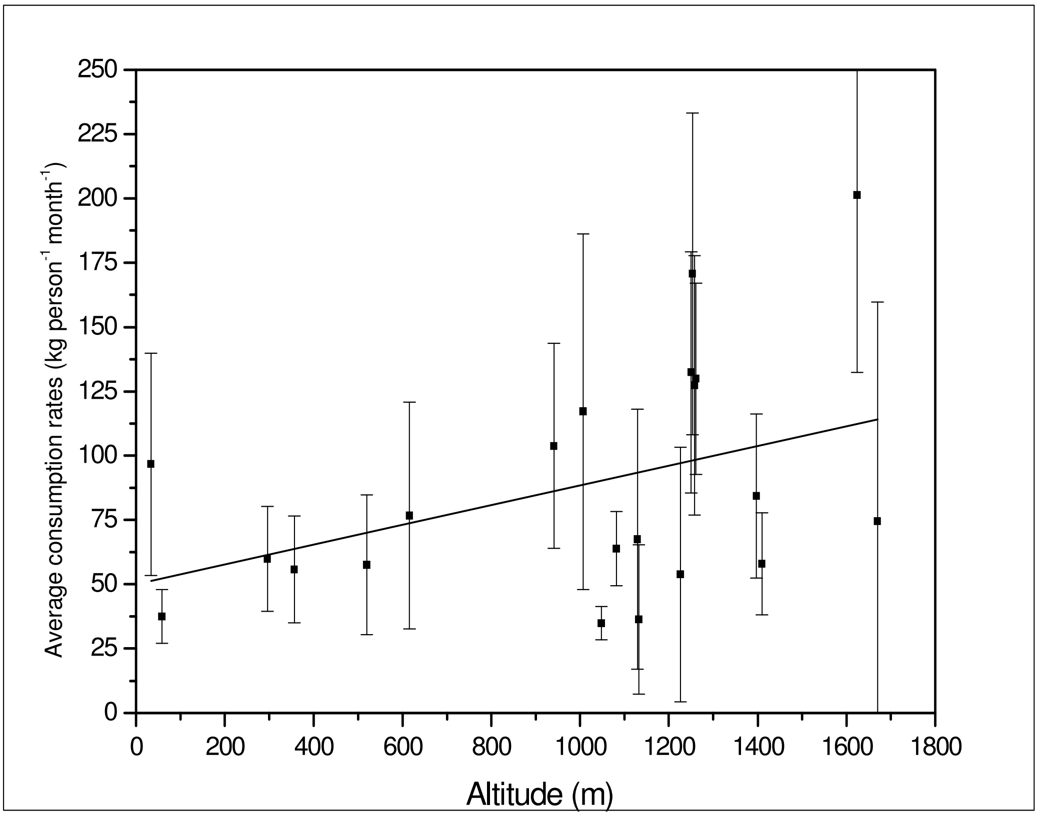

Figure 3.5 Relationship between the average monthly consumption rates and altitude at all sites across southern Africa. The standard deviation bars are fairly large due to seasonal variation at each site. The solid black line is the linear relationship between consumption rate and altitude ($y = 0.038x + 50.091$; error on the slope = 0.0195; $p = 0.06481$; $n = 21$).

Table 3.2 Details of the linear correlation between consumption rate and altitude for each month of the year, with the slope indicating the change in consumption rate (in kg person^{-1} month^{-1}) for every 1m change in altitude (n = 21 for each month).

Month	Slope (error)	y-intercept	p	r^2
Jan	0.059 (0.028)	35.6	0.045**	0.195
Feb	0.048 (0.024)	22.2	0.067*	0.165
Mar	0.028 (0.022)	26.6	0.075*	0.228
April	0.042 (0.024)	31.7	0.102	0.135
May	0.034 (0.024)	28.4	0.170	0.097
June	0.046 (0.034)	33.5	0.184	0.091
July	0.015 (0.031)	24.2	0.634	-0.040
August	0.017 (0.029)	23.4	0.577	-0.035
Sept	0.048 (0.027)	32.7	0.091*	0.098
Oct	0.039 (0.027)	27.6	0.183	0.091
Nov	0.027 (0.025)	25.8	0.289	0.059
Dec	0.057 (0.038)	34.3	0.152	0.105

** Significant at the 95% level
* Significant at the 90% level

3.5 Annual biofuel consumption estimates

Total annual rural biofuel usage for southern Africa was shown to be 64.6 Tg yr^{-1} with a rural population of 61 515 000 (table 3.3). The annual consumption rate of Lesotho and Swaziland was derived from Marufu (2000) and was added to obtain a total consumption rate for southern Africa. Of all the biofuel used, wood had the highest consumption rate of 54.7 Tg yr^{-1} and maize residues the least with 1.8 Tg yr^{-1}. South Africa is the major consumer of fuelwood compared to the other countries, consuming an amount of 22.8 Tg yr^{-1}, while Zambia is the main charcoal user (3.4 Tg yr^{-1}). South Africa contributes the most (39%) to the rural biofuel consumption in the region. South Africa is followed by Zimbabwe (18%), Mozambique (14.7%), Zambia (13.3%), Malawi (10.3%), Namibia (3.6%), Botswana (0.9%), with Lesotho (0.3%) and Swaziland (0.03%) contributing the least.

Table 3.3 Annual rural biofuel consumption estimates for southern Africa (average ± SE). Population numbers are taken from United Nations (2003).

Country	Total population (x 1000)	Rural population (x 1000)	Rural biofuel consumption (Tg yr^{-1})			
			Fuelwood	**Charcoal**	**Maize**	**Total**
South Africa	45 028	19 389	22. 8 ± 15.6	2.4 ± 2.4	0	25.2 ± 15.8
Mozambique	18 863	12 140	7.2 ± 1.5	2.3 ± 1.6	0	9.5 ± 2.2
Malawi	12 105	10 133	4.8 ± 1.3	0	1.8 ± 1.0	6.6 ± 1.6
Zimbabwe	12 892	8 390	11.6 ± 2.8	0	0	11.6 ± 2.8
Zambia	10 812	6 951	5.2 ± 2.2	3.4 ± 1.7	0	8.6 ± 2.8
Namibia	1 988	1 344	2.3 ± 0.7	0	0	2.3 ± 0.7
Botswana	1 785	865	0.6 ± 0.2	0	0	0.6 ± 0.2
Lesotho[a]	1 802	1 479	0.2 ± 0.06[b]	0	0.02 ± 0.01[b]	0.2 ± 0.06
Swaziland[a]	1 077	824	0.02 ± 0.006[b]	0	0	0.02 ± 0.006
Total	**106 352**	**61 515**	**54.7 ± 3.5**[c]	**8.1 ± 0.8**[c]	**1.82 ± 0.1**[c]	**64.6 ± 3.6**[c]

[a] The values for these countries were calculated from the consumption rates of Marufu *et al* (2000) and the rural population data given in this table.
[b] SE values were estimated by using the average coefficient of variation for the other countries.
[c] These summed SE values were calculated using the weighted accumulation of uncertainties method.

Chapter 4
Discussion

4.1 Combustion practices over southern Africa

Studies have shown that rural people of southern Africa, more especially women, spend most of their time gathering fuelwood, charcoal, maize residue and in some cases animal dung to make fire for domestic purposes (Kgathi *et al.,* 1997). These biofuel sources are used interchangeably depending on the fuel type that is available for collection. The combustion practices were normally conducted in indoor huts (sometimes shacks) (figure, 4.1), which were normally away from the main huts. The fire was made on the ground and the fireplace is surrounded with corrugated iron (or sometimes a stone or brick wall) to avoid wind, which increases the fire intensity and leads to increased fuel use. Biofuel combustion was mostly undertaken three times a day (in the morning, at noon and in the evening) for cooking purposes as was found to be the case in Marufu (1997). Morning combustion was usually short because light meals were normally cooked in the morning, while the other two meals took longer, thereby consuming more fuel.

To conserve fuelwood the wood was taken off the fire after cooking activities and then used again the following day. This was mostly done when there was a fuelwood scarcity. During fuelwood scarcity, meals that take long time to be cooked are avoided and biofuel is used solely for cooking purposes and not for space heating. All these changes in biofuel combustion behavior influence biofuel consumption rates. Biofuel scarcity forces households into being more careful in the way they use fuel, resulting in lower biofuel consumption levels.

Figure 4.1. The kitchen area in Namibia (Karasburg) showing the biofuel, the fireplace as well as the corrugated iron sheet protecting the fire from wind.

4.2 Consumption rate variation within countries

A high variability in terms of fuel consumption rates was found both within and between countries in southern Africa. The northern, central and southern sites have different consumption values throughout the year and there is no consistent seasonal trend for any of the sites. High biofuel consumption variability between countries in southern Africa has been seen before (Otter *et al.*, 2001, Marufu *at al.,* 1999 and Scholes *et al.,* 1996). Furthermore studies in other African countries, such as Kenya, have also been seen to have high in country variation (Kituyi *et al.,* 2001).

Some of the reasons for the high in country variation in consumption rate in this study were found, through observations and questionnaires, to be poverty, fuel availability and alternative energy sources. In Mozambique, for example, consumption rates were very low in the central site and this was mainly because people did not make a fire for breakfast as they did not have food to cook and this lowered the consumption rates. Where fuel was freely available and accessible, consumption rates tended to be high, whereas the opposite was true for fuel-stressed areas. This was witnessed in Namibia were fuel consumption was high in areas where fuel was freely available and accessible and low in fuel stressed areas. In South Africa and Namibia (figure 3.2) the variation between sites could be due to the availability of electricity. Whenever electricity is available, people tended to use less fuel. Consumption rates were lower in the central and northern site in South Africa and the central site in Namibia and these are the sites that have electricity.

4.3 Seasonal variations between countries

Seasonal trends were clearer when data was averaged, but biofuel consumption did not appear to increase during winter except in Namibia and South Africa where the increase in consumption rate was observed between August and October. Zimbabwe showed a general increase of biofuel consumption rate throughout the year except for a slight decline in September, which may have been caused by the fuel scarcity at this time. No clear seasonal trend in the use of wood and charcoal was observed in this study, but charcoal was used more interchangeably with wood. In the households that used wood and charcoal, charcoal use was often higher when wood consumption was low and visa versa. Unlike Marufu (1999) where maize residue was found to be used seasonally, maize residue was used almost all year round except for August, October and January. The main maize growing season is between November and April and so most of the maize is used between May – July which is after the growing season. It seems that household keep some maize residue handy for when woodfuel sources are low because during August and October wood use was high so no maize was used, but in September the opposite was true. The main reason why a seasonal trend in consumption rate is not very clear might well be the short duration of the data collection. Yevich and Logan (2003) state that surveys done in the short period of time frequently cannot account for seasonal fluctuations. This suggests that this study would need to be repeated over several years in order to determine if and what the seasonal pattern is.

4.4 Biofuel types usage

4.4.1 Fuelwood

Fuelwood was used in all countries, which makes wood the predominant fuel type of southern Africa. Questionnaires conducted indicated that fuelwood is gathered free of charge from the surrounding environment. Inhabitants of areas with abundant fuel supplies tend to consume more fuel than those of fuel stressed areas. The ease of wood collection, its low cost and heating ability makes wood consumption higher than that of charcoal and maize residue. The most common alternative to fuelwood was found to be charcoal, while very few people used maize residue. This is contrary to the study done by Marufu (1997) who found that fuelwood was often substituted by agricultural wastes and cow dung. In this study no cow dung was found to be used as a source of fuel for domestic purposes and charcoal substituted fuelwood in three countries (South Africa, Mozambique and Zambia). Kgathi (1997) also found that cow dung was used to substitute fuelwood in Botswana, whereas this study indicates that wood was the only fuel used in Botswana. Kgathi's (1997) study was only done in Khakhea where he had several sites, whereas this study only had one site in Kakhea and therefore there was a lower probability for this study to find the use of cow dung in the area.

Studies undertaken by Marufu *et al.* (1997) have shown that fuelwood in Zimbabwe was consumed at the rate of 2.71 kg person^{-1} day^{-1} and Kituyi *et al,* (2001) estimated the weighted average fuelwood consumption of 2.7 kg person^{-1} day^{-1}. Both Marufu *et al.* (1997) and Kituyi *et al.* (2001) average daily consumption was slightly lower than the consumption rate of 3.91 ± 1.51 kg person^{-1} day^{-1} for Zimbabwe measured in this study. This slight difference may be caused by the fact that study sites undertaken by Marufu *et al*. (1997) were situated next to urban areas whereas study sites of this research are in rural areas. This simply shows that urban areas consume slightly less fuelwood than rural areas.

4.4.2 Charcoal

Charcoal is the second largest fuel consumed in domestic households in southern Africa (Otter *et al*., 2001). This is contrary to such countries like Brazil, Philippines, and Malaysia where charcoal was mostly used in industries and not for domestic purposes (Woods and Hall, 1994). In this study, charcoal is used for domestic purposes in South Africa, Mozambique and Zambia.

In South Africa and Mozambique charcoal is used throughout the year. In South Africa small quantities were used between July and October (6 - 17 kg person^{-1} month^{-1}) and during this time fuelwood consumption was relatively high (between 64 and 94 kg person^{-1} month^{-1}). Wood was probably used for cooking and charcoal for space heating during these months. During the hotter months of November and January both wood and charcoal consumption are decreased. December is unusual because of its extremely high charcoal consumption. This is the holiday period when people return to their homes and it is likely that there is an insufficient wood supply to sustain the cooking load for the increased number of people during this time. Even though charcoal is produced in South Africa (often produced from alien invasives such as the wattle (Greenwood, Pers. Comm)) and is easily accessible, as it is sold in chain stores and garages across the country, it should be noted that it was mainly the central site in South Africa that used charcoal. Charcoal is also easily accessible in Mozambique and was found to be used in all sites throughout the year. Charcoal consumption was generally < 20 kg person^{-1} month^{-1} with a slight increase in August to 32 kg person^{-1} month^{-1}. This was completely opposite to the pattern of fuelwood consumption, indicating that in Mozambique they used wood and charcoal interchangeably.

In Zambia charcoal was mainly used in May, when fuelwood consumption was very low (4 kg person^{-1} month^{-1}), with an almost insignificant amount (< 1 kg person^{-1}

month^{-1}) being used during July and August. Zambia is a large charcoal producing country and it was expected that there would be an increase in charcoal usage, however it was found that in Zambia charcoal is largely an urban phenomenon as rural household occupants can often not afford charcoal. Rural people therefore they rely heavily on fuelwood which is a free commodity.

4.4.3 Maize residue

Maize, wheat, rice, barley, millet and sorghum are used as agricultural residues and they are burnt in the field and in households specifically in fuel-deficit regions (Yevich and Logan, 2003). Only few studies about the use of maize residues were found in sub-Saharan Africa. This study only found the use of maize as an agricultural residue. Malawi was found to be the only user and only small amounts of maize residue were consumed relative to wood and charcoal. Marufu *at al*. (1997 and 1999) and Kituyi *et al,* (2001) reported the use of maize residue in Zimbabwe and Kenya, respectively, but no national consumption rates estimates were found in their studies.

Maize residue is often used early on in the fire making process to help start the fire but then is replaced by other fuels while the fire is burning. Maize residue is the less preferred fuel because (a) it produces a lot of smoke, which is harmful to the household residents, (b) it does not burn for a long time and (c), it can only be used in the dry season when harvesting occurs. Further more the production of maize in southern Africa is heavily reliant on rainfall, and so if there is low rainfall maize production is low and thus the amount of maize residue is also reduced. Maize residue is also used as a fodder and thus it is often used for this purpose before it is used as a fuel. All these reasons make it very difficult for rural people to rely heavily on maize residue as their source of fuel and that is the reason why there is low consumption of maize residue.

4.5 Altitude and biofuel consumption rate

Marufu (1997) argued that high altitude areas are cooler and as such high consumption rates are more likely to occur. This study showed that consumption rates are only slightly higher in higher altitudes but it is not significant because of the high variability in the data. The consumption rate increases more sharply with altitude during the summer months, particularly in December and January, than the winter months. The slope in December was shown to be 0.057, indicating an increase in consumption of 5.7 kg person^{-1} month^{-1} for every 100m increase in altitude. The slopes of the linear relationships between altitude and consumption varied between 0.027 and 0.059 in summer, while the values were between 0.015 and 0.046 during winter (table 3.2). This pattern is the opposite of what was initially expected, and the reason for higher consumptions at higher altitudes during summer is unclear. It would seem that during winter all areas are cold, not just those at altitude, so biofuel is used by everybody and thus consumption rates are more consistent in winter. The results suggest that altitude, and thus temperature (due to the assumed relationship between altitude and temperature), is not the main or only driving factor of consumption rate. It should however, be noted that more data, particularly in terms of weather data, are required in order for some of the assumptions and conclusions can be confirmed.

4.6 Annual consumption estimates for southern Africa

Annual consumption rates for wood are very similar to those found in Otter *et al.*, (2001) which is 55.96 Tg yr^{-1} compared to 54.7 Tg yr^{-1} respectively (table 4.1). Yevich and Logan (2003), on the other hand, gave an estimate of 47.2 Tg fuelwood yr^{-1} which is lower than both Otter et al. (2001) and this study. The information from Otter *et al* (2001) and Yevich and Logan (2003) are based on the whole population not just rural population therefore it is not directly comparable to this data set. This suggests that consumption values measured in this study are much higher than those used in either of the two studies.

The trend in fuelwood consumption in this study is slightly different to that of Yevich and Logan (2003). The major difference is seen in South Africa where this study estimated the usage of 22.8 Tg yr^{-1} of fuelwood, whereas Yevich and Logan (2003) estimated 9.08 Tg yr^{-1}. This major difference can be attributed to the fact that this study reports much higher daily consumption rates compared to Yevich and Logan (2003). In South Africa, fuelwood seems to be much more dominant in rural areas as is the case in other countries in southern Africa. This huge different in fuelwood consumption in South Africa also applied to Otter at al., (2001) studies. This was also the case in Zimbabwe as well, both Otter *et al*. (2001) and this study found high consumption as compared to the findings in Yevich and Logan (2003).

Charcoal consumption in this study was found to be much higher than the estimates in Otter et al. (2001) (table 4.1). This may be because data was collected at different sites and the data shows there is a high in country variation. Data was also collected in different years and so fuel costs or availability may have changed. Perhaps more people in Zambia, Mozambique and South Africa have started to climb the energy ladder and can afford to use more charcoal than previously. In South Africa rural people can still afford to buy charcoal because rural people mostly buy it in black market rate and so it is often used as a substitute fuel to fuelwood. In Zambia, charcoal is sold in rural areas and along the roads where transport is not a problem. In Zambia charcoal prices do not differ whether it is in town or away from town. Kahane and Lwakabamba, (1990) found that in Zambia large quantities of charcoal is generated from the Miombo woodland in the forest and charcoal is thus much more abundant than in South Africa and Mozambique.

India uses more wood as fuelwood than the whole of southern Africa. An estimated amount of 250 Tg yr^{-1} of biomass is used in a form of fuelwood, dung and charcoal while the other 342 Tg yr^{-1} is attributed from natural fires (Prastad *et al*., 2001), while this study has estimated an amount of 64.6 Tg yr^{-1} for both fuelwood, charcoal and to a lesser extent maize residue.

Table 4.1 Annual consumption estimates for fuelwood and charcoal (Tg yr^{-1}) (± SE). The blank space indicates that no charcoal was used in these countries.

Country	Otter *et al.* (2001)		Yevich and Logan (2003)	This study[a]	
	Wood	Charcoal	Wood	Wood	Charcoal
South Africa	18.40	1.19	9.08	22.8 ± 15.6	2.4 ± 2.4
Mozambique	10.82	0.10	8.37	7.2 ± 1.5	2.3 ± 1.6
Malawi	6.35	0.32	7.91	4.8 ± 1.3	0
Zimbabwe	9.76	0	4.70	11.6 ± 2.8	0
Zambia	7.78	1.11	7.75	5.2 ± 2.2	3.4 ± 1.7
Namibia	1.34	0	0.26	2.3 ± 0.7	0
Botswana	0.48	0	8.80	0.6 ± 0.2	0
Lesotho	0.62	0.62	0.03	0.2 ± 0.06	0
Swaziland	0.41	0	0.30	0.02 ± 0.006	0
Total	**55.96**	**5.44**	**47.2**	**54.7 ± 3.5**	**8.1 ± 0.8**

[a] Values and details as from table 3.3.

As people move up the energy ladder and become more urbanized the rural population, together with the biofuel consumption, will decline. United Nations (2003) has predicted that there will be a decrease in the rural population in many countries in the region by the year 2030, except in Zambia and Malawi where the rural population will still be increasing (table 4.2). Overall, with the general decrease in population, the rural biofuel consumption is estimated to decrease in 2030 in southern Africa (table 4.3). The consumption of fuelwood is estimated to decrease from 54.7 to 44.2 Tg yr^{-1} over this 30 year period; while charcoal will decrease from 8.1 yr^{-1} to 7.3 yr^{-1}. Maize residue showed an increasing trend, with an increase of 0.7 Tg yr^{-1} between 2003 and 2030. This increase is mainly because of the expected increase in population in Malawi – the only country shown to use maize residue.

Table 4.2 UN 2003 and 2030 rural areas population projection.

Country	2003 rural population (thousand)	2030 rural population (thousand)
Mozambique	12 140	10 643
Zambia	6 951	7 586
Malawi	10 133	13 495
Zimbabwe	8 390	6 154
Botswana	865	536
Namibia	1 344	1 186
South Africa	19 3889	12 630
Lesotho	1 479	1 092
Swaziland	824	647

Table 4.3 Estimates of annual rural biofuel consumption (Tg yr^{-1}) (± SE) in southern Africa for 2003 and 2030.

Country	2003 consumption rate			2030 consumption rate		
	Fuelwood	Charcoal	Maize	Fuelwood	Charcoal	Maize
Mozambique	7.2 ± 1.5	2.3 ± 1.6	0	6.3	2.0	0
Zambia	5.2 ± 2.2	3.4 ± 1.7	0	5.7	3.7	0
Malawi	4.8 ± 1.3	0	1.8 ± 1.0	6.4	0	2.5
Zimbabwe	11.6 ± 2.8	0	0	8.5	0	0
Botswana	0.6 ± 0.2	0	0	0.4	0	0
Namibia	2.3 ± 0.7	0	0	2.0	0	0
South Africa	22.8 ± 15.6	2.4 ± 2.4	0	14.8	1.6	0
Lesotho	0.2 ± 0.06	0	0.02 ± 0.01	0.1	0	0.00
Swaziland	0.02 ± 0.006	0	0.00	0.00	0	0.00
Total	**54.7 ± 3.5**	**8.1 ± 0.8**	**1.82 ± 0.1**	**44.2**	**7.3**	**2.5**

4.7 Motivation for future research

This study has improved on previous biofuel studies by expanding the biofuel consumption database by including measurements from 7 countries in southern Africa. The outcomes of this study could be used by policy makers and could also contribute to the global domestic biofuel energy budget. Although this study has expanded the existing biofuel database there are still many questions in terms of biofuel consumption in Africa. This research has highlighted a few areas that need further work in the future and some of these are listed below.

- This research has looked at the biofuel consumption variations in rural areas and has used rural population to estimate the consumption rates in rural areas. Future research should a large study on the variations between rural areas and urban areas so that the entire population for southern African countries can be covered in the research.

- The study indicates that season and temperature are not the only factors influencing biofuel consumption. Discussions with the local people seem to indicate that social and economic dimension may play a prominent role in influencing biomass consumption patterns. The social aspect should include cultural impacts as this may influence fuelwood choice; while the economic aspect should compare the price of charcoal and fuelwood and also investigate the income of the occupants in order to determine the affordability.

- The data collection period in this research was short because of the time and financial constraints of the research. Government and private sectors are encouraged to invest more money in energy studies because energy data is one of the most difficult and expensive data to collect more especially on the larger scale.

- Future research should also extend this study to the rest of Africa rather than only southern African region

Chapter 5
Conclusions

Questionnaire surveys have shown that there are three forms of biofuel used in southern Africa, namely; fuelwood, charcoal and maize residue. The total rural biofuel consumption in southern Africa was found to be 64.6 Tg yr^{-1} in 2005 and was consumed by a total of 61 515 000 rural people. South Africa contributes the most (39%) to the rural biofuel consumption in the region and is followed by Zimbabwe (18%), Mozambique (14.7%), Zambia (13.3%), Malawi (10.3%), Namibia (3.6%), Botswana (0.9%), with Lesotho (0.3%) and Swaziland (0.03%) contributing the least.

Fuelwood, which is found around rural settlements and is mostly a free commodity, was found to be the predominant source of biomass energy. It was consumed at an average rate of 2.55 kg $person^{-1}$ day^{-1} and the total consumption in southern Africa was determined to be 54.7 ± 3.5 Tg yr^{-1} with the highest consumption (22.8 ± 15.6 Tg yr^{-1}) being in South Africa.

Charcoal was found to have low daily consumption in southern Africa compared to fuelwood. Questionnaires have revealed that charcoal is not a free commodity and because it is processed and distributed to some cities and towns it is not necessarily always available. The cost and availability influence the amount of charcoal consumed. Further more not all countries produce, or have access to charcoal. Charcoal was only found to be used in Zambia, South Africa and Mozambique and the average daily consumption in these three countries was 1.3 kg $person^{-1}$ day^{-1}. The total consumption of charcoal over southern Africa was shown to be 8.1 ± 0.8 Tg yr^{-1}.

In the studied sites maize residue was only used in Malawi at an average daily rate of 0.51 ± 0.16 kg $person^{-1}$ day^{-1}. Previous studies indicate that maize was also used in Lesotho. The total annual consumption of maize in southern Africa is 1.82 ± 0.1 Tg yr^{-1}. It was found that maize residue is less favored by the inhabitants since it produces smokes when burnt and also because it is only available seasonally.

The relationship between consumption rate and altitude was investigated and a slight positive relationship (r^2 = 0.168) was found, but the data is very scattered due to seasonal variation (p = 0.065). More biofuel is consumed at higher altitudes during summer than at lower altitudes sites, and during winter fuel is consumed at a similar rate at all sites. During the winter months of July and August there was even a slight negative relationship between consumption and altitude. On average the consumption rate increases by almost 4 kg person^{-1} month^{-1} with every 100m increase in altitude. Other factors that are suggested, from questionnaires and observations, to influence consumption rate are biofuel availability, biofuel preferences and poverty. Transportation can also influence the amount of fuel a household can obtain each month.

It appeared in this research that there does not seem to be an increase in consumption rate during winter except in Namibia and South Africa where consumption rates were higher between August and October. In Zambia consumption rates were slightly higher between May and July and a sharp increase in January. In Zimbabwe, consumption rates were higher than most countries and there was a fairly constant consumption throughout the year, just with a slight decline in September. Consumption rates in Mozambique, Botswana and Malawi were lower than the other countries and, although there was monthly variation, there was no specific seasonal trend.

Appendix A

Site	*Coordinates* Latitude	Longitude	*Altitude*
Bobole	*32.06*	*-25.06*	*33*
Save	*34.06*	*-21.06*	58
Inhangoma	*33.09*	*-16.01*	368
Chamasoa	*35.01*	*-15.09*	1129
Kathewela	*33.04*	*-13*	*1082*
Nyungwe	*34.01*	*-10.02*	*520*
Kalomo	*26.01*	*-17.03*	*296*
Kapiri	*28.08*	*-13.08*	*1261*
Isoka	*32.07*	*-9.07*	*1226*
Chapfuce	*30.01*	*-22*	618
Masvingo	*30.07*	*-19.07*	*1258*
Goromonzi	*31.04*	*-17.06*	1250
Karasburg	*18.07*	*-28*	*1007*
Rehoboth	*17.01*	*-23.03*	*1397*
Tsaxara	*16.06*	*-20.04*	*1624*
Khakhea	*23.05*	*-24.06*	*1048*
Mokobaxane	*24.09*	*-21.02*	*1670*
Tsau	*22.04*	*-20.01*	941
Middleburg	*25*	*-31.05*	*1253*
Kroonstad	*27.02*	*-27.06*	*1132*

Appendix B

Interviews

Interviews were undertaken in all sites over Southern Africa. The persons who were interviewed were those responsible for recording the data on a daily bases. Most of these interviewed people were women because they are the once who are responsible for collecting as well as recording the type of fuel everyday. Silas Mulaudzi and Phillip Tshikalanke conducted the interviews. Each household member was asked five questions and these questions are as outlined below.

1. What is your favorite fuel type, and why do you prefer it over others?

2. Do you buy the fuel (s) you use each and everyday or do you collect them free of charge?

3. Do you collect biofuel next to or far away from your settlement?

4. Do you use biofuel (s) in all cooking sessions, If not, why?

5. Do you use anything else as a source of domestic energy beside biofuels? If yes, what is that energy source?

6. If you use maize residues, when is your maize harvesting period?

Chapter 6

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