



**THE SOCIETAL DIMENSIONS OF DOMESTIC COAL
COMBUSTION:
PEOPLE'S PERCEPTIONS AND INDOOR AEROSOL
MONITORING**

School of Geography
Archaeology and Environmental Studies

Climatology Research Group

THULIE NOMSA MDLULI

A thesis submitted to
the Faculty of Science, University of the Witwatersrand,
in fulfilment of the requirements
for the degree of
Doctor of Philosophy in Environmental Sciences

March, 2007

DECLARATION

I declare that this thesis is my own, unaided work except where acknowledged. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Thulie Nomsa Mdluli

05 March 2007

In memory of my late mother,
Mrs Angela Matilda Dlamini,

and

in appreciation of my husband, S'celo,
and
daughters, Mphile and Wandzi.

ABSTRACT

Air pollution is one of many issues that have a direct impact upon the economy and the well-being of society in South Africa. Domestic coal combustion contributes significantly to the air pollution problem in the country. Both qualitative and quantitative methods of data collection have been employed in this study. A questionnaire survey was conducted in 100 households in Doornkop (Soweto) and 100 households in KwaGuqa (Witbank). The observations were carried out simultaneously while the questionnaire surveys were being administered in both study areas. Interviews were also held with Eskom (the Electricity Supply Commission of South Africa) officials. Finally, the indoor concentrations and elemental composition of respirable particulate matter (PM₇) were measured in three different types of households: electrified without coal burning, electrified with coal burning, and un-electrified with coal burning.

The results show that township households, whether electrified or not, continue to burn coal. In both study areas, 80 % of electrified households burn coal for space heating and cooking. Although the major obstacles preventing people from discontinuing domestic coal combustion are poverty and the ready availability and social acceptability of coal, the social value of a fire inside township households cannot be underrated. Previously developed coal-supply networks still exist in the townships and makes coal utilisation very convenient. The findings also point to use of multiple fuels in the communities studied. The key fuels used for domestic energy supply are coal, electricity and paraffin. Emergent patterns of domestic coal combustion, driven in part by various societal dimensions, are also observed. Further, despite the previously observed increase in respiratory ailments in winter, township residents do not think that such increases are linked to domestic coal combustion. The study, as shown here, is in line with theories of the energy ladder which posits that as people's financial situations improve, their energy-use patterns change.

Indoor aerosol concentrations followed the same trends in all selected households with morning and evening peaks. These peaks are directly related to the making of coal fires. The highest aerosol levels, reaching a maximum of $2344.89 \mu\text{g.m}^{-3}$, are recorded in the un-electrified coal-burning household. Aerosol concentrations are slightly lower, averaging $1854.07 \mu\text{g.m}^{-3}$, in the electrified coal-burning household, implying a slight decrease in the amount of coal burnt. The lowest aerosol concentrations, averaging $478.74 \mu\text{g.m}^{-3}$, are recorded in the electrified household with no coal-burning. Elemental analysis reveals that the biggest contributor to respirable particles in KwaGuqa is soil dust followed by coal smoke, and then emissions from neighbouring steel smelters, whilst traffic emissions are the lowest contributor. Most importantly, it is people's activities that determine the type and levels of respirable aerosols that they are exposed to as compared to the fuel-use patterns and types of fuels used in their household.

In conclusion, electrification might phase out domestic coal combustion in the long term but only if the economic status of coal users improves. Alternatively, there is an opportunity to reduce emissions by introducing a low-smoke solid fuel, however, households will only use it if it is priced competitively and its heating and ignition properties are similar to, or better than, those of coal.

ACKNOWLEDGEMENTS

- Firstly, I thank God (Babe wami – with whom nothing is impossible) for all He has entrusted to me.
- I am eternally indebted to my husband who encouraged me to do a PhD – thanks, S’celo, for being who you are to me and for your love, patience and support, particularly during the course of this work.
- Thanks to Prof HJ Annegarn for giving me the opportunity of doing the PhD and to discover my passion for such research.
- I am grateful to my supervisor, Dr LB Otter, for her invaluable support and constructive criticism of my work despite a hectic schedule. Also, for taking me on as her student although I had already started the PhD.
- Thanks, too, to my co-supervisor, Prof CH Vogel, for her contribution and criticism – especially with the social aspect of this work even with her ever-occupied calendar.
- My sincere thanks go to the Director of the Climatology Research Group, Dr SJ Piketh, for believing in me and giving me the opportunity and funding to conduct this research.
- The invaluable contribution of the respondents in the Doornkop and KwaGuqa communities, without which this work would not have succeeded, is greatly appreciated.
- Thanks to Dr. O. Oyedele for helping with questionnaire data analysis; Mr. K. Sekonya for PIXE analysis; Mrs. W. Job for the production of maps; and the CRG team for moral support when visiting the township.

- Many thanks go to Ms KG Banda for helping with the final write-up and presentation of the thesis. Also, Jeannette Menasce is acknowledged for her assistance in proof-reading and correcting this thesis.
- Thanks also to my mother-in-law, Mrs OL Mdluli, and my dear friend, Mrs EA Essien, for helping with my little girls who were born during the course of the research.
- Thanks to my “blessing daughters”, Mphile and Wandzisa, for putting up with mommy’s demanding and eventful schedule – you’re such wonderful angels.
- The SysTem for Analysis, Research, and Training (START: www.start.org) is also thanked for the award of a doctoral fellowship that helped to support this research and to the Climatology Research Group for research funding.

CONTENTS

DECLARATION.....	I
ABSTRACT.....	III
ACKNOWLEDGEMENTS	V
CONTENTS.....	VII
LIST OF FIGURES	XI
LIST OF TABLES	XIII
PREFACE.....	XIV
ABBREVIATIONS, ACRONYMS AND GLOSSARY.....	XVII

CHAPTER 1: INTRODUCTION.....	1
1.1 BACKGROUND OF THE STUDY	1
1.2 STUDY SITES	3
• 1.2.1 <i>Rationale for Choosing the Study Sites.....</i>	<i>3</i>
• 1.2.2 <i>Socio-economic Status of the Study Sites.....</i>	<i>6</i>
1.3 RESEARCH GOALS	8
1.4 RELEVANCE OF THE STUDY.....	8

CHAPTER 2: LITERATURE REVIEW AND CONCEPTS	10
2.1 LITERATURE REVIEW	10
• 2.1.1 <i>The Importance of Aerosols as an Atmospheric Pollutant</i>	<i>10</i>
• 2.1.2 <i>The Elemental Composition of Aerosols.....</i>	<i>11</i>
• 2.1.3 <i>Major Sources of Aerosols.....</i>	<i>12</i>
• 2.1.4 <i>Impacts of Aerosols.....</i>	<i>13</i>

•	2.1.5	<i>Domestic Use of Energy</i>	18
•	2.1.6	<i>Indoor Air Pollution</i>	19
•	2.1.7	<i>Alternative Energy Sources in South Africa</i>	21
•	2.1.8	<i>Electrification in the South African Context</i>	24
•	2.1.9	<i>The Social Role of Coal Stoves in Township Households</i>	25
2.2	CONCEPTUAL FRAMEWORK		27
•	2.2.1	<i>Concepts on Energy Use at Household Level</i>	27
•	2.2.2	<i>People's Perceptions of Energy Use</i>	29
CHAPTER 3:	RESEARCH METHODOLOGY		32
3.1	STUDY DESIGN		32
3.2	QUESTIONNAIRE AND INTERVIEW DATA COLLECTION		32
•	3.2.1	<i>Questionnaire-Based Interviews</i>	33
•	3.2.2	<i>Observations</i>	34
•	3.2.3	<i>Detailed and Focused Interviews</i>	34
•	3.2.4	<i>Analysis of Interviews and Questionnaire Data</i>	36
3.3	INDOOR AEROSOL MONITORING		36
•	3.3.1	<i>Continuous Indoor PM₇ Measurements</i>	36
•	3.3.2	<i>Elemental Composition of PM₇</i>	38
3.4	ESTIMATING POPULATION EXPOSURE TO PM₇		42
CHAPTER 4:	RESULTS: SOCIETAL DIMENSIONS		45
4.1	FUEL-USE STATUS IN DOORKOP AND KWAGUQA		45
•	4.1.1	<i>Types of Fuels Used in the Study Areas</i>	45
•	4.1.2	<i>Coal Burning</i>	49
•	4.1.3	<i>Alternative Energy Sources</i>	54
•	4.1.4	<i>Affordability</i>	55
4.2	PEOPLE'S PERCEPTIONS PERTAINING TO DOMESTIC FUELS		58

•	4.2.1	<i>Electricity versus Coal Burning.....</i>	58
•	4.2.2	<i>Perception of Coal.....</i>	63
4.3		THE MULTI-FACETED SOCIETAL DIMENSIONS OF DOMESTIC COAL COMBUSTION	69
•	4.3.1	<i>Emerging Patterns.....</i>	69
•	4.3.2	<i>Conclusion and Linkage to the Energy Ladder</i>	73
CHAPTER 5:		RESULTS: INDOOR AEROSOL MONITORING IN KWAGUQA	76
5.1		DIURNAL PATTERN OF INDOOR AEROSOL CONCENTRATIONS	76
5.2		AEROSOL GENERATION AND DISPERSION RATES.....	83
5.3		EXCEEDANCES OF DEAT PM₁₀ STANDARD	87
5.4		RELATIONSHIP BETWEEN AEROSOL CONCENTRATION AND AMBIENT TEMPERATURE	88
5.5		ELEMENTAL ANALYSIS OF RESPIRABLE PARTICULATE MATTER.....	92
•	5.5.1	<i>Elemental Composition and Source Contributions.....</i>	92
•	5.5.2	<i>Source Contributions to Individuals under Study.....</i>	95
5.6		ESTIMATING POPULATION EXPOSURE TO AEROSOL POLLUTION	99
•	5.6.1	<i>Estimating Indirect Population Exposure to PM₇ Elements</i>	99
•	5.6.2	<i>Estimating Direct Population Exposure to PM₇ Elements</i>	103
CHAPTER 6:		CONCLUSIONS.....	106
6.1		SUMMARY	106
6.2		DOMESTIC COAL COMBUSTION: A PERSISTING REALITY....	107
•	6.2.1	<i>The Social Role of Domestic Coal Combustion.....</i>	108
•	6.2.2	<i>Perceived Health Effects of Domestic Coal Combustion.....</i>	109
•	6.2.3	<i>Poverty Issues</i>	110

•	6.2.4	<i>The Unreliability of the Electricity Supply</i>	<i>111</i>
6.3		ENVIRONMENTAL AND HEALTH BENEFITS OF ELECTRIFICATION	111
6.4		IMPLICATIONS FOR POLICY MAKERS.....	113
		REFERENCES.....	116
		APPENDIX 1: PILOT QUESTIONNAIRE	134
		APPENDIX 2: FINAL QUESTIONNAIRE	142
		APPENDIX 3: ESKOM INTERVIEW OUTLINE	149
		APPENDIX 4: CLEARANCE CERTIFICATE FROM THE NON- MEDICAL ETHICS COMMITTEE OF THE UNIVERSITY OF THE WITWATERSRAND	151
		APPENDIX 5: CALIBRATION CERTIFICATES FOR DUSTTRAK AEROSOL MONITORS.....	152

LIST OF FIGURES

Figure 1.1:	Maps showing the location of the study sites.....	5
Figure 2.2:	The energy ladder.....	28
Figure 3.1:	An example of the DustTrak aerosol monitors used to monitor aerosol concentrations in the selected households	37
Figure 3.2:	An individual wearing one of the PM ₇ personal monitors that were used.....	38
Figure 3.3:	X-ray excitation by charged particles.....	40
Figure 4.1:	Responses given by respondents in Doornkop and KwaGuqa when asked if coal smoke from domestic coal combustion affects people's health.....	64
Figure 4.2:	Responses of township households when asked if coal smoke affects people's health.....	65
Figure 4.3:	Percentage of households with respiratory ailments in Doornkop and KwaGuqa.....	66
Figure 4.4:	Ages of people suffering from respiratory ailments in the townships.....	68
Figure 4.5:	A pattern of fuel use that was observed to be followed by township households in this study	70
Figure 4.6:	A pattern of coal use that was observed to be followed by township households in this study	72
Figure 4.7:	A summary diagram of possible future fuel-use patterns derived from observations in township households in this study.....	73
Figure 5.1:	Average diurnal pattern of PM ₇ in KwaGuqa (August 2004) in the four (4) different households, where "EH" is an Electrified House and UEH is an Un-Electrified House	77
Figure 5.2:	Mean daytime and night-time aerosol concentration in electrified and un-electrified township houses	79
Figure 5.3:	Indoor PM ₇ concentration in coal-burning households – 05 August 2004, where "EH" is an Electrified House and "UEH" is an Un-Electrified House.....	80
Figure 5.4:	Indoor PM ₇ concentration – 24 August 2004, where "EH" is an Electrified House and "UEH" is an Un-Electrified House.....	80

Figure 5.5:	Indoor PM ₇ concentration – 19 August 2004, where “EH” is an Electrified House and “UEH” is an Un-Electrified House.....	81
Figure 5.6a:	Time-dependent generation of aerosols from coal burning in both Electrified Houses (EH) and Un-Electrified Houses (UEH) in the daytime	84
Figure 5.6b:	Time-dependent dispersion of aerosols from coal-burning in both Electrified Houses (EH) and Un-Electrified Houses (UEH) in the daytime	84
Figure 5.7a:	Time-dependent generation of aerosols in both Electrified Houses (EH) and Un-Electrified Houses (UEH) at night-time	86
Figure 5.7b:	Time-dependent dispersion of aerosols from in both Electrified Houses (EH) and Un-Electrified Houses (UEH) at night-time	86
Figure 5.8:	Diurnal exceedances of the DEAT PM ₁₀ standard, where “EH” is an Electrified House and “UEH” is an Un-Electrified House.....	88
Figure 5.9:	A time-series trend of aerosols in relation to changes in ambient temperature obtained from daily mean values (August 2004) in the un-electrified house with coal burning	89
Figure 5.10:	A correlation between aerosol concentration and ambient temperature in the un-electrified house with coal burning	90
Figure 5.11:	A correlation between aerosol concentration and ambient temperature in the electrified house with coal burning	91
Figure 5.12:	A correlation between aerosol concentration and ambient temperature in the electrified house with no coal burning	91
Figure 5.13:	Estimated overall indirect population exposure in the townships, where “EH” is an Electrified House and “UEH” is an Un-Electrified House.....	103
Figure 5.14:	Source contributions to direct exposure to PM ₇ elements, where “EH” is an Electrified House and “UEH” is an Un-Electrified House; “CB” is Coal Burning and “NCB” is Non Coal Burning.....	104

LIST OF TABLES

Table 1.1:	Population of Doornkop and KwaGuqa	6
Table 1.2:	Types of Housing in Doornkop and KwaGuqa	6
Table 1.3:	Employment Figures for Doornkop and KwaGuqa.....	7
Table 4.1:	State of electrification in the studied areas.....	45
Table 4.2a:	Patterns of fuel use in Doornkop	46
Table 4.2b:	Patterns of fuel use in KwaGuqa	47
Table 4.2c:	An overview of the patterns of fuel use in Doornkop and KwaGuqa	47
Table 4.3:	The percentage of township households in Doornkop and KwaGuqa showing seasonal coal consumption patterns.....	50
Table 4.4:	Electrified households, their employment status and money spent on electricity units in Doornkop	56
Table 4.5:	Electrified households, their employment status and money spent on electricity units in KwaGuqa	57
Table 4.6:	Summary of electrified households, their employment status and money spent on electricity units in Doornkop and KwaGuqa.....	58
Table 5.1:	Spearman correlation coefficients between elemental concentrations measured by PIXE (correlation coefficients between 0.80 and 1.0 are highlighted in grey, n=19)	93
Table 5.2:	Enrichment factors of PM ₇	94
Table 5.3:	Source apportionment of PM ₇ in the township.....	97
Table 5.4:	Total elemental contributions to respirable air	98
Table 5.5:	Estimated daily time-activity data of the different population groups in the township based on personal observations during the questionnaire survey	100
Table 5.6:	Average indirect daily exposure to indoor respirable aerosols (PM ₇) in coal-burning households	101
Table 5.7:	Average indirect daily exposure to outdoor respirable aerosols (PM ₇)	102

PREFACE

The domestic combustion of solid fuels, such as coal, is a big contributor of aerosols to the atmosphere of most developing countries and South Africa is no exception. Domestic coal combustion has historical roots in South Africa that can be traced back to the apartheid era (1948-1994) where an inequitable distribution of modern energy sources occurred. Coal, as a cheap source of energy, was perceived as and became the predominant energy source used in urban black residential areas (townships) to meet household energy needs. With the consequent large-scale combustion of coal in the townships, air pollution became a concern. Domestic coal combustion has been identified by source-apportionment studies as the greatest single source of airborne aerosols among other pollutants in South African coal-burning townships.

In light of the above, the South African government has proposed alternative energy sources and embarked on the mass electrification of households. Studies have, however, shown that people continue to use traditional fuels (such as coal) in their households after electrification. The continuing usage of coal has been linked to persistent poverty and unemployment in the country. Thus, the challenge for South Africa is phasing out the use of coal at a domestic level to control the resultant air pollution and its adverse health effects. This may not, however, be as immediate as expected due to the continuing usage of coal after electrification in the townships.

The main aims of this study are to provide an assessment of the multi-faceted societal dimensions of domestic coal combustion in two township communities and to determine the levels of indoor respirable particulate pollution (PM₇) associated with coal combustion.

In order to achieve these aims, the specific objectives of the study are to:

1. investigate patterns of fuel use in various township households, including possible socio-economic factors ‘driving’ differential usage of coal as an energy source;
2. assess people’s perceptions pertaining to domestic coal combustion; and
3. measure the concentration and the elemental composition of indoor respirable aerosols (PM₇) in the selected township households and to derive estimates of population exposure.

This thesis is divided into the following chapters:

- *Chapter 1* introduces the study, outlining the air pollution problem associated with domestic coal combustion in South Africa. It also provides a description of the study areas and outlines the aims and objectives of the thesis and the relevance of the study;
- *Chapter 2* provides the literature review conducted and the conceptual framework underpinning this study;
- *Chapter 3* provides a description of data collection and analysis methods;
- *Chapter 4* presents and discusses the results obtained from the questionnaire survey, interviews and observations;
- *Chapter 5* presents and discusses the results from aerosol monitoring and personal sampling and also outlines the link between people’s perceptions and aerosol monitoring;
- *Chapter 6* provides the conclusions. Final lessons drawn from the study are presented. Furthermore, the policy relevance of this study is also mentioned in this chapter.

Parts of this thesis have been presented at the International Conference for Domestic Use of Energy (May 12-14, 2004 and April 3-6, 2006: Cape Town, South Africa);

the National Conference of the South African Association for Atmospheric Scientists (May 20-24, 2004: Cape Town, South Africa); the National Conference of the National Association of Clean Air (October 4-8, 2004: Johannesburg, South Africa) and the National Conference of the South African Association for Atmospheric Scientists (September 26-28, 2005: Richards Bay, South Africa). Most of the results presented in Chapter 5 were used in writing a journal article that was published in the Quarterly Journal of the National Electricity Regulator (2005:11-24).

ABBREVIATIONS, ACRONYMS AND GLOSSARY

ANC	African National Congress
ARI(s)	Acute Respiratory Infection(s)
BNM	Basa Njengo Magogo
CEG	Clean Energy Group
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
EPRI	Electric Power Research Institute
ERC	Energy Research Centre
Eskom	Electricity Supply Commission
LPG	Liquefied Petroleum Gas
LPM	Litres per minute
NASA	National Aeronautics and Space Administration
NRDC	National Research Defence Council
PIXE	Proton Induced X-ray Emission
PM ₁₀	Particulate matter having a diameter <10 µm
PM ₇	Particulate matter having a diameter <7 µm
PM _{2.5}	Particulate matter having a diameter <2.5 µm
SAFARI (2000)	Southern African Regional Science Initiative in 2000
SPSS	Statistical Package for the Social Sciences
TERI	The Energy and Research Institute
TWF	The World Factbook
UNDP	United Nations Development Programme
US	United States (of America)
USA	United States of America
WHO	World Health Organisation
WREC	World Renewable Energy Council
WRI	World Resources Institute
µg.m ⁻³	micrograms per cubic metre

CHAPTER 1:

INTRODUCTION

This chapter gives a brief background of the study, outlines the chosen study sites, details the aims and objectives, and discusses the relevance of this study.

1.1 BACKGROUND OF THE STUDY

Air pollution is the contamination of the atmosphere with harmful substances as a consequence of human activities (Elsom, 1987; Bowser, 2004). The consequences of air pollution in developing countries, especially with the use of cheap, traditional fuels (such as coal) pose a great challenge to energy and development practitioners (Doppegieter *et al*, 1998). With very little progress made on reducing energy-poverty, the resultant effect is the ongoing use of coal as a domestic energy source (Spalding-Fecher, 2005). The National Research Defence Council (NRDC) (NRDC, 2004) and World Health Organisation (WHO) (WHO, 2005) have established a link between air pollution, human health and the environment (context of use included).

Polluted air can be dangerous to human health and it poses a great risk – both at a global and local level (Burnett, 1997; Doppegieter *et al*, 1998; Metzner; 2003). Indoor smoke released from the combustion of solid fuels, like coal, contains a range of health-damaging pollutants that are able to penetrate deep into the lungs (Rollin *et al*, 2004; WHO, 2005). Indoor air pollution is responsible for 2.7 % of the global burden of disease (WHO, 2005). It is a problem mainly in developing countries where huge proportions of the population rely on polluting, solid fuels as primary sources of energy (Bruce 2002; Smith, 2002; WHO, 2005). There is a close inter-relationship, therefore, between household energy, poverty and health (Bruce, 2002). High concentrations of indoor air pollutants resulting from the use of

polluting fuels pose a major burden on the health of poor families in developing countries (WHO, 2005).

In southern Africa, air pollution and its consequences has been a concern in recent years and numerous studies have been conducted in the region to investigate and control air pollution. For example, the Southern African Regional Science Initiative (SAFARI) in 2000 contributed significantly to regional-scale aerosol mapping among other scientific results on air pollution (Swap *et al*, 2003). In South Africa, the combustion of fossil fuels (coal and petroleum) contributes significantly to the high levels of air pollution in the country and the region (Scorgie *et al*, 2003a). This is because about 77 % of the country's primary energy needs are provided by coal. Of South Africa's coal production, 2 % goes to domestic heating and cooking (Qase *et al*, 2000).

The combustion of fossil fuels releases unacceptable levels of air pollution in the country. Consequently, air pollution has had a direct impact upon the economy and the well-being of society in South Africa (Scorgie *et al*, 2003a). Domestic coal combustion, for instance, has been noted as the highest contributor of particulate pollution in the townships – black urban areas (Hoets, 1994; Annegarn *et al*, 1998; Scorgie *et al*, 2001). Although other activities contribute to air pollution problems in the townships, domestic coal combustion remains a significant source of both indoor and ambient air pollution (Annegarn and Sithole, 1997; Annegarn *et al*, 1998; Barnes, 2005; WHO, 2005). Of greater importance, is the fact that such combustion affects the health of exposed populations (Scorgie *et al*, 2001). Very little has been done, however, in terms of aerosol monitoring at household level.

Faced with these challenges, the government of South Africa has proposed alternative energy sources in a bid to phase out domestic coal combustion (Britton, 1998; Hoets, 1998; SurrIDGE, 2004). It was expected that the electrification of households would reduce or eliminate household consumption of coal (Hoets, 1994; 1998; van Horen *et al*, 1993; Spalding-Fecher and Matibe, 2003). Studies have shown that coal combustion, however, persists after the electrification of households (Hoets, 1998; Qase *et al*, 2000; Mdluli *et al*, 2003). The question that

arises then is why does it persist? Terblanche *et al* (1993a) stated that this was due to a lack of resources to create an infrastructure for complete transition to electricity and the lack of money to maintain the system. Hoets (1998) stated that it was because township households do not have electric appliances. Other studies have alleged that electricity is too expensive for township households (Hoets, 1994; Winkler *et al*, 2000; Scorgie *et al*, 2001). Another study linked poverty to the persistence of coal use at domestic level (Annecke, 1999). With this as the background, the study sites and their socio-economic status are addressed below.

1.2 STUDY SITES

1.2.1 Rationale for Choosing the Study Sites

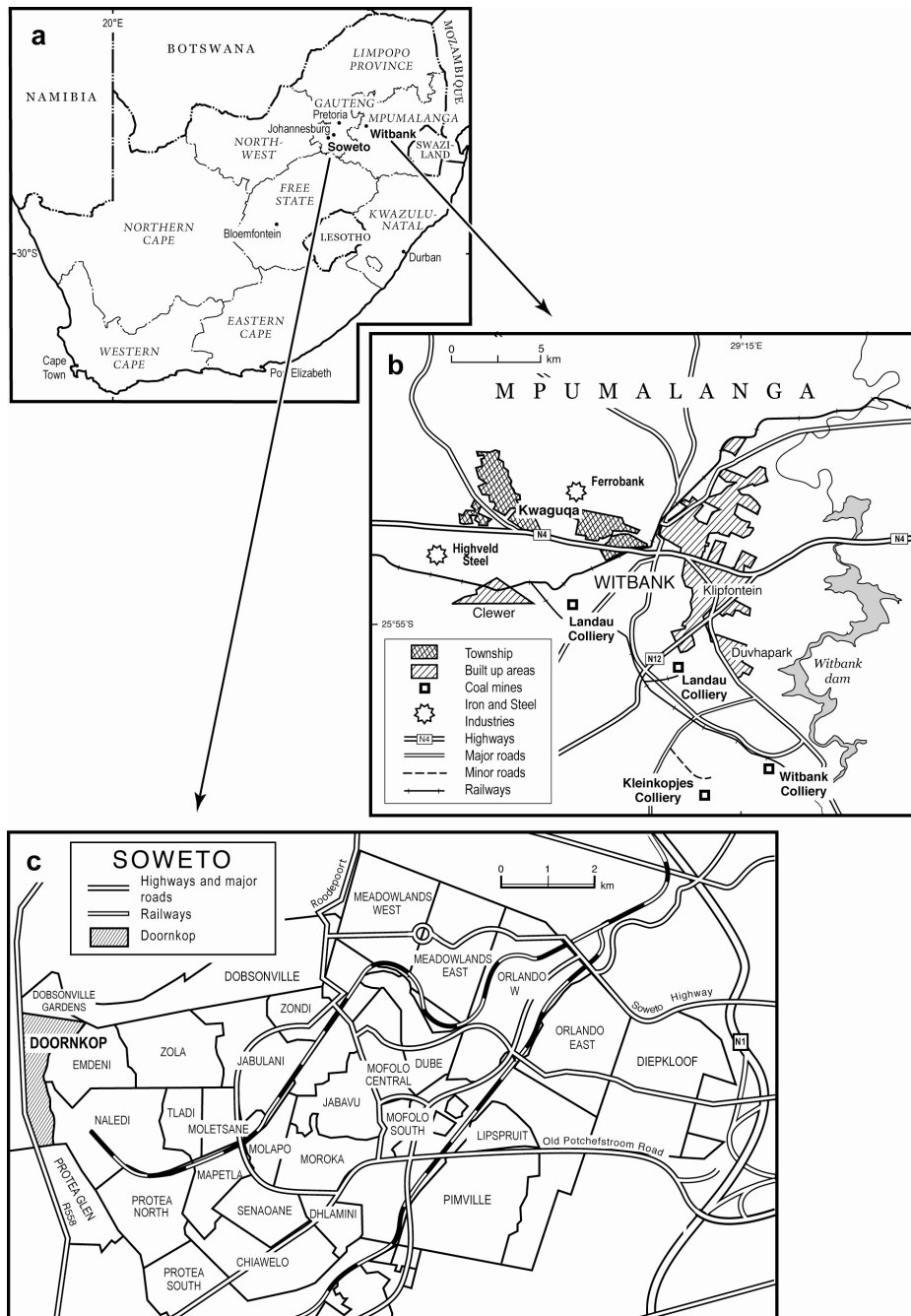
South African society is characterised by great inequalities resulting from apartheid policies enforcing a racially divided society (ERC, 2004). Domestic coal combustion has historical roots in South Africa as it can be traced back to the apartheid era where inequitable distribution of modern energy sources occurred (ANC, 1994). Preference was given to white people in the electrification process. Several backlogs in the distribution of services, such as electricity provision, in the black urban areas (townships) occurred (Scorgie *et al*, 2003b). Other studies have revealed that poor households burn any fuel that they can find (WHO, 2004). Consequently, coal as a cheap source of energy was perceived as, and became, the predominant energy source used in townships to meet household energy needs (Hoets, 1994).

After 1994, the government set out to reduce this inequitable distribution of modern energy through what it termed the Energisation Programme as spelt out in its White Paper on Energy Policy and its related policies (DME, 1998). Though South Africa can boast of success stories of electrification in Africa, with records of 80 % electrification in urban areas (Spalding-Fecher, 2002), people continue to use traditional fuels (such as coal) in their households. Studies have linked this to micro- and macro-economic issues of persistent poverty and unemployment in the country. Annecke (1999) has, for example, argued the need to examine energy and

women issues at a household level to examine differences in perception and utilisation of energy sources.

The challenge for South Africa is that air pollution at domestic level is a critical issue for development and human health because of the persistent use of coal as a dominant energy source. Of the total population in South Africa, 60 % (~24 million people) use coal and wood as major sources of household energy at household level (Doppegieter *et al*, 1998). The use of coal is more prevalent in the townships (Hoets, 1998; Scorgie *et al*, 2001).

This study examines two townships located in the Gauteng and Mpumalanga Provinces – both representative of high coal-use areas in the country (Spalding-Fecher, 2005). These townships are located in Soweto and Witbank (Figure 1.1). The specific townships that were chosen for this study were Doornkop and KwaGuqa, respectively. Soweto is a large township situated close to Johannesburg and numerous studies pertaining to domestic coal combustion have been conducted in the area (Annegarn and Sithole, 1997; Annegarn *et al*, 1998; Scorgie *et al*, 2003a). Witbank is the ‘heart’ of coal-mining in the country and it is located 120 km from Johannesburg. In the next section a brief socio-economic background to the study areas is provided.



- a Map of South Africa showing Soweto and Witbank;
- b Location map of Witbank showing the position of KwaGuqa and the coal mines;
- c Location map showing Doornkop in Soweto.

Figure 1.1: Maps showing the location of the study sites

1.2.2 Socio-economic Status of the Study Sites

1.2.2.1 Population

Townships in South Africa are densely populated areas; Doornkop and KwaGuqa are no exception (Table 1.1). The population density is almost identical in both the townships under study. Townships are also characterised by acute housing shortages and overcrowding. Most township housing consists of rows of identical, single-storey “matchbox” houses with few trees, gardens, parks or playgrounds (Soweto Project, 2001). There is also a large proportion of informal housing which includes extensive backyard squatting and squatter settlements (Table 1.2).

Table 1.1: Population of Doornkop and KwaGuqa

Township	Total Population	Area Size (km ²)	Population Density (No. of people/km ²)
Doornkop	8 736	1.4	6240
KwaGuqa	78 150	12	6513
Source: SuperCROSS (1993-2006)			

Table 1.2: Types of Housing in Doornkop and KwaGuqa

Township	Formal Housing	Informal Housing	Traditional Housing	Backyard Housing	Total
Doornkop	2 227	14	14	36	2 290
KwaGuqa	12 273	8 310	557	748	21 889
Source: SuperCROSS (1993-2006)					

1.2.2.2 Employment

In South Africa, unemployment parallels poverty closely (UNDP, 2000). There is a high average unemployment rate of 27 % in South Africa (TWF, 2005). Most of the unemployed population lives in the townships, and they are known as “the urban poor” (van Horen *et al*, 1993; Engelbrecht *et al*, 2000). Doornkop and KwaGuqa, however, have much higher unemployment rates than the national average

(Table 1.3). Most township residents who have jobs commute to neighbouring cities by bus, train or taxi (Soweto Project, 2001). Residents from Soweto, for example, commute to Johannesburg and those from KwaGuqa commute to Witbank. There is no reliable railway transport in KwaGuqa so residents use mostly buses and taxis.

Table 1.3: Employment Figures for Doornkop and KwaGuqa

Township	Employed Population	Unemployed Population	Unemployment Rate (%)
Doornkop	2 677	1 852	40.9
KwaGuqa	18 434	16 697	47.5
Source: SuperCROSS (1993-2006)			

1.2.2.3 Energy-use patterns

A dominant feature of energy-use patterns in township households is their tendency to include multiple sources of energy to meet their needs (Eberhard and van Horen, 1995). Even in electrified households, coal fires are widely used for heating and cooking, producing a series of air pollution problems. The majority of Soweto's formal houses have electricity, making Soweto a relatively advanced township in terms of electricity availability in South Africa (Eberhard and van Horen, 1995). KwaGuqa also has a fair amount of electrification. Despite electrification, studies have shown, however, that coal is predominantly used as a household fuel in these townships (Terblanche *et al*, 1993a; Hoets, 1994; Scorgie *et al*, 2001) even though reports indicate that coal is dirtier and less convenient (van Horen *et al*, 1993).

The ongoing use of coal, despite electrification, was studied in Doornkop (April 2004) and Witbank (June 2004). The two sites were chosen for comparability. Factors compared include perceptions of coal users across sites, the economic reasons for electricity use and whether the proximity to coal fields influenced coal usage as well as any differences in coal usage. Eberhard and van Horen (1995) and Qase *et al* (2000) noted that townships within a distance of 150 km to coal mines burn more coal than those further away. So it was assumed that respondents at

KwaGuqa would burn more coal than those in Doornkop because of its close proximity to coal mines.

1.3 RESEARCH GOALS

The main aims of this study are to:

- a. provide an assessment of the multi-faceted societal dimensions of domestic coal combustion in two township communities.
- b. determine the levels of indoor respirable particulate pollution (PM₇) associated with coal combustion and electricity.

In order to achieve these aims, the specific objectives of the study are to:

1. examine patterns of fuel-use in various township households, including possible socio-economic factors ‘driving’ differential usage of coal as an energy source;
2. assess people’s perceptions pertaining to domestic coal combustion; and
3. measure the indoor concentration and the elemental composition of respirable aerosols (PM₇) in the selected township households and to derive estimates of population exposure.

1.4 RELEVANCE OF THE STUDY

After the implementation of the mass electrification programme in South Africa it was expected that household coal-burning would reduce significantly (Spalding-Fecher, 2005). This has not happened as observations show that electrified households continue to burn coal (Terblanche *et al*, 1993; Hoets, 1994; Britton, 1998; Scorgie *et al*, 2001). This study contributes to this debate by assessing the behaviour and energy-use practices in two township communities in Doornkop (Soweto) and KwaGuqa (Witbank). It contributes to the wider body of knowledge on energy usage in South Africa. Obtaining such information has been challenging

as noted by Scorgie *et al* (2003a). The study also provides information as to why electrified households continue to burn coal and assesses why such behaviour persists (Hoets, 1994).

Moreover, the importance of people's perceptions and local knowledge in reducing or phasing out domestic coal combustion is highlighted in this study. This type of information may inform decision- and policy-makers of where to focus strategies and interventions designed to reduce air pollution in the townships, on electrification or on awareness campaigns about disadvantages of domestic coal combustion.

Finally, the concentrations of indoor respirable particulate matter (PM₇) from domestic coal combustion in township households are presented in this study – a first in South Africa. This information gives an indication of how much PM₇ each household is likely to contribute to the PM₇ pollution in the township. Further, the elemental composition of PM₇ – which has not been analysed before – particularly for township air, is also given in this study. Additionally, estimates of exposure to PM₇ pollution were made for different population groups residing in the townships. Estimating population exposure to air pollution is the important link between human health and pollution monitoring (Spalding-Fecher and Matibe, 2003). This study, therefore, is a valuable contribution to the body of knowledge and a necessary guide for policy makers in South Africa.

* * * * *

Chapter 1 is the introduction to the study. In this chapter the background, the research goals as well as the relevance of the study have been provided. An overview of the areas examined here, including some baseline socio-economic data, was provided. The next chapter outlines the literature review used to frame this study and also highlights the conceptual framework applied.

CHAPTER 2:

LITERATURE REVIEW AND CONCEPTS

This chapter presents the literature review used to frame this research and provides the conceptual framework underpinning this study.

2.1 LITERATURE REVIEW

2.1.1 The Importance of Aerosols as an Atmospheric Pollutant

Atmospheric aerosols refer to solid and liquid particles suspended in the air (EPRI, 2003). Aerosols (fine particulate matter) and dust, because of their stability and negligible fall velocities, are probably the most common and persistent of air pollutants (McCormick and Baulch, 1962). They are one of the biggest air pollution problems because they can have adverse effects on human health (EPRI, 2003) and they act as sites for chemical reactions – which may affect human health – to take place in the atmosphere (NASA, 1996). For example, urban air pollution is a major public health concern in Johannesburg (Mathee and von Schirnding, 2003) and polluted air impacts directly on people's health and generally affects the poorest (McDonald, 2002). Particulate matter or aerosols have been singled out in recent studies on the effects of chronic exposure to air pollution to be the pollutant most responsible for the life-shortening effect of dirty air, although other pollutants may also play an important role (Terblanche *et al*, 1993a; Dockery and Pope, 1994; Terblanche *et al*, 1994; EPRI, 2003; Scorgie *et al*, 2003a).

Particulate air pollution is a complex mixture of fine- and coarse- particles of varying origin and chemical composition. Coarse particles (ranging from 2.5 μm to 100 μm in diameter) usually comprise smoke and wind-blown dust from industrial processes, agriculture, construction and road traffic, as well as plant pollen and other natural sources. Fine particles (<2.5 μm in diameter) generally come from the

combustion of fossil fuels. These particles include soot from vehicle exhausts, particles released from domestic coal combustion and those from coal-fired power plants (Dockery and Pope, 1994; WRI, 1999b).

In the United States of America (USA), high concentrations of aerosols are an important air pollution issue (Liu *et al*, 2005). Fine particulate matter poses the greatest health risk, causing respiratory and cardiovascular damage. In many states of the USA, fine particulate levels continue to exceed health standards (Liu *et al*, 2005). In the southern African region there are different major sources of aerosols and trace gases, hence there has been a focus of intensive environmental research directed toward aerosol emissions, transports and impacts (Billmark *et al*, 2003).

2.1.2 The Elemental Composition of Aerosols

The elemental composition of aerosols is important to determine the sources of aerosols (Liu *et al*, 2005). Knowing the composition of typical activities (such as coal combustion) helps in identifying sources of aerosols. For instance, coal is composed largely of carbon, hydrogen, nitrogen, oxygen and sulphur, with small amounts of other material ranging from aluminium to zirconium and ash (Maryland Energy Administration, 2003). Whilst aerosols released from coal combustion would be composed mainly of the above-named elements that form the composition of coal, aerosols released from steel smelters are composed mainly of iron (Fe) elements (Prati *et al*, 2000).

The elemental composition of aerosols also helps to identify the pH of aerosols and hence the pH of cloud water (Olszyna *et al*, 2005). It is also important to determine the toxicity of atmospheric aerosols and the effects they may have on the environment and human health (EPRI, 2003). Knowledge of the elemental composition of aerosols informs policy makers so as to make sure that regulation of particulate matter will in fact improve public health (NASA, 1996).

2.1.3 Major Sources of Aerosols

Aerosols have both natural and anthropogenic (human-induced) sources. Natural sources include wind-blown dust and sea salt. For instance, sea-salt components in total aerosol populations, as well as sea-spray aerosols, were obtained in measurements conducted by Patterson *et al* (1980) and McKendry *et al* (2004) over remote continental and marine regions. In China, intense dust storms were noted by Wang *et al* (2004) to be one of the major contributors to the aerosol burden.

Anthropogenic aerosols have multiple sources and vary widely in composition (EPRI, 2003). In a study conducted by Bogo *et al* (2003) it was noted that traffic emissions are an important contribution to the PM_{2.5} aerosol. Emissions from steel smelters were noted by Prati *et al* (2000) to contribute to aerosol concentrations in the atmosphere, although traffic emissions were also a significant contributor, in Genoa (Italy). Re-suspended road dust, motor vehicle and diesel emissions, combustion of oil and coal, ferrous and non-ferrous smelters as well as sea spray were noted to be dominant sources in a study conducted by Swietlicki *et al* (1996b) in India. Veld fires, combustion of oil (St Denis *et al*, 1994; Andreae *et al*, 1996) and domestic combustion of biomass fuels (Marufu *et al*, 1997; Guazzotti *et al*, 2003; Ludwig *et al*, 2003) are also major aerosol sources.

Outdoor fires (such as wildfires and prescribed burns) emit substantial amounts of aerosols into the atmosphere (Gao *et al*, 2003; Dennis *et al*, 1994). Some events are extreme and the contributions of such fires to air pollutant concentrations are readily observable. In Texas, for example, fine particulate matter emission estimates from outdoor fires were 40 000 tons/year, which is likely to represent a significant fraction of that state's emission inventory (St Denis *et al*, 1994). In Amazonia, biomass burning dominates aerosol measurements with concentrations up to 400ug/m³ and particle numbers exceeding 13 000 particles per cc during the dry season (for further details see nobre@cptec.inpe.br). Domestic biomass burning is also a big source of aerosols since it provides about 15 % of the world's primary energy and it is the major fuel used in most developing countries (Marufu *et al*, 1997). In southern Africa, biomass burning is pervasive and it is a common land

management practice (Anyamba *et al*, 2003). Billmark *et al* (2003) recorded significant amounts of aerosols during intense seasonal biomass burning in southern Africa.

The combustion of fossil fuels is another big contributor of aerosols in the atmosphere (Lindesay, 1992; Swietlicki *et al*, 1996b; Eck *et al*, 1999). In South Africa, for instance, domestic coal combustion was identified, based on qualitative observations and quantitative source apportionment studies, as being the greatest single source of airborne particulate matter within urban black residential areas (townships) in South Africa (Annegarn *et al*, 1998; Scorgie *et al*, 2001). In South Africa it is known that human exposure to suspended particulate pollutants, in some cases, exceed health standards by three to six times (Britton, 1998). This is so because a large proportion of the South African population living in townships relies heavily on coal as a source of domestic energy. What compounds the problem is that South African coal is low in carbon and sulphur, but high in particulate matter (Scorgie *et al*, 2001) so a large amount of aerosols is released from coal combustion.

In Soweto domestic coal burning was estimated to account for ~57 % to ~75 % of the ambient, winter respirable particulate concentrations (PM_{2.5}), resulting in concentrations as high as 110 µg/m³. Unfortunately, the combustion of bituminous coal also emits a large amount of gaseous and particulate pollutants such as sulphur dioxide (SO₂), heavy metals, total and respirable particulates including inorganic ash, carbon monoxide (CO), polycyclic aromatic hydrocarbons, nitrogen dioxide (NO₂) and benzo (a) pyrene. These pollutants reduce the quality of the air and have adverse health implications (Scorgie *et al*, 2001; Sunyer, 2001).

2.1.4 Impacts of Aerosols

Aerosols can have ambient concentrations that are toxic to the environment (Swietlicki *et al*, 1996b). Impacts can vary from severe health consequences to more local damages. Aerosols, for example, cause visibility impairment by light extinction and scattering that consequently affects the amount of sunlight that

reaches the earth's surface (Kim *et al*, 2003; Olszyna *et al*, 2005). High concentrations of aerosols can also damage clothing at a more local scale (Zheng *et al*, 2004). Other studies have shown the impacts of aerosols on climate and human health (Keil and Haywood, 2003; Zheng *et al*, 2004) and these impacts are outlined in detail in the next sections.

2.1.4.1 Impacts of Aerosols on Climate

Aerosols have an influence on climate processes (Keil and Haywood, 2003) as they have direct and indirect effects on the earth's radiation budget. The direct effect is where aerosol particles scatter and absorb solar and thermal radiation (Charlson *et al*, 1992). Aerosols from biomass burning have been identified as inducing climate change in southern Africa because they effectively scatter incoming solar radiation (Piketh *et al*, 1996). Such aerosols usually have a lengthened atmospheric residence time (Turco *et al*, 1983), hence their scattering effect on incoming solar radiation is prolonged. Moreover, sulphate and organic aerosol particles from fossil-fuel combustion (as well as smoke particles from biomass burning) have been observed to be the main contributors to radiative forcing (Hobbs *et al*, 1997). For example, black carbon aerosol, a by-product of combustion, is the light-absorbing fraction of atmospheric aerosols (Babu *et al*, 2004). The light-absorbing properties of aerosols can possibly affect the temperature lapse rate by converting light energy into heat, hence affecting the convective activity and atmospheric dynamics (Anderson *et al*, 1996).

Further, aerosols indirectly affect the radiation budget through changing the particle size and life time of cloud droplets by acting as cloud condensation nuclei, leading to cloud and albedo change (Twomey, 1977). Sulphate aerosols, for instance, have a cooling effect on the atmosphere and they act as cloud condensation nuclei (Li *et al*, 2003). Cloud condensation nuclei can alter a number of cloud radiative factors and the equilibrium of cloud liquid-water content (Anderson *et al*, 1996). Biomass-burning aerosols can act as effective cloud condensation nuclei and change cloud albedo through altering their microphysics (Reid *et al*, 1999). Cloud albedo is increased through the increase in the number of cloud droplets and the decrease in

the radius of each droplet (Keil and Haywood, 2003). Consequently, the precipitation efficiency is reduced, allowing for longer cloud lifetimes and an increase in the amount of time required for precipitation to form, particularly in warm clouds (Reid *et al*, 1999).

2.1.4.2 Impacts of Aerosols on Human Health

Human health is greatly affected by aerosols (Swietlicki *et al*, 1996b; Zheng *et al*, 2004). Statistical associations between health effects and ambient concentrations of aerosols, especially finer particles (PM₁₀) have been well established (Zheng *et al*, 2004). However, because aerosols have various sources and composition, it is unlikely that all components are equally harmful to human health (EPRI, 2003). Despite the statement by the Electric Power Research Institute (EPRI) (EPRI, 2003) that adverse health impacts appear to be associated with carbon-containing aerosols and not the sulphate component primarily derived from coal combustion, health impacts of aerosols released from coal combustion are well documented (Zheng *et al*, 2004; Annegarn *et al*, 1998). They result mainly where coal is commonly burnt in poorly ventilated stoves, directly exposing residents to the emissions (Annegarn *et al*, 1998; WRI, 1999a; Finkelman, 2000; Spalding-Fecher, 2002; Scorgie *et al*, 2003a). International examples include arsenic poisoning, hearing loss in children, dental fluorosis, skeletal fluorosis, human selenosis, kidney disease (known as Balkan endemic nephropathy) and lung cancer that was recorded in China in homes where coal is used for heating and cooking (Finkelman, 2000).

In the United States of America, bronchitis, tightness in the chest and wheezing were observed as acute and short-term effects, whilst lung cancer and cardiopulmonary disease were termed the chronic effects of exposure to dirty air (WRI, 1999a). Dockery *et al* (1993) concluded that fine-particulate air pollution, or a more complex pollution mixture, contributes to high mortality in certain US cities. Similarly, von Klot *et al* (2002) observed that the prevalence of asthma symptoms was associated with ambient particle concentrations of particulate matter and gaseous pollutants.

In South Africa, indoor aerosols released from coal burning cause unacceptable community health risks and environmental pollution (Annegarn *et al*, 1998; Britton, 1998; Spalding-Fecher, 2002). In townships, domestic coal combustion is uncontrolled and it adds an unquantifiable contribution to the atmospheric pollution load and health risk that is already an issue in the country (Scorgie *et al*, 2003a). Domestic coal combustion has been noted locally to pose a major threat to human health in the townships and other highly populated areas that burn coal heavily during the winter season (DANCED, 2000). For instance, domestic coal combustion has been established as one of the risk factors for the development of acute respiratory tract infections (Scorgie *et al*, 2001).

Recent epidemiological data have indicated that acute respiratory tract infections are one of the leading causes of death in black South African children. The mortality rate of acute respiratory tract infections in South Africa is reported to be 270 times greater than for children in Western Europe. When controlled for socio-economic status, age and gender, the risk in the rural winter population exposed to coal and/or wood cooking and heating fires of developing acute respiratory tract infections was found to be four times higher than the risk among electricity users (Scorgie *et al*, 2001). Human health problems associated with domestic coal burning include increased asthma attacks, acute and chronic bronchitis, coughing, and wheezing, among others (Matooane *et al*, 2004; Oosthuizen *et al*, 2004; Barnes, 2005). As a result, numerous studies have been conducted to introduce measures to reduce air pollution from domestic coal combustion at national level (Terblanche *et al*, 1994; Scorgie *et al*, 2003a), some of which are further developed in this thesis (Section 2.1.7).

2.1.4.3 Impacts of Aerosols on Socio-Economics

The use of polluting fuels is also a socio-economic issue. WHO (2005) stated that the use of polluting fuels poses a major burden on the health of poor families in developing countries. The dependence on such fuels is both a cause and a result of poverty as poor households often do not have the resources to obtain cleaner, more efficient fuels. Reliance on simple household fuels and appliances can compromise

health and thus hold back economic development, creating a vicious cycle of poverty (WHO, 2005).

Costs associated with inhalation exposures to air pollution include direct and indirect costs. Direct costs are associated with health spending, that is, cost of hospital admissions and medication. Indirect costs include financial losses due to reduced productivity resulting from the restricted activity of economically active persons (Scorgie *et al*, 2003b). Coal-burning emissions are associated not only with health risks (Terblanche, 1994), but with economic impacts (increased sick days), educational impacts (high rates of absenteeism), and broader environmental impacts (like visibility reductions) (Scorgie *et al*, 2001). In South Africa, financial costs associated with health impacts due to exposures to air pollution from domestic coal burning in 1994 were estimated by van Horen (1996, cited in Scorgie *et al*, 2001) to be in the range of R137 to R549 million 1995 Rand, with a central estimate of R301 million.

Domestic coal combustion is a socio-economic problem because it affects poor people who cannot afford clean and safe sources of energy (Annegarn *et al*, 1998; WHO, 2005). This was demonstrated by the implementation of the electrification programme in South Africa. The programme greatly increased access to electricity (Spalding-Fecher, 2002) but many people cannot afford to use it in the townships (Hoets, 1994). Its distribution is thus uneven, both within the communities and within households. Moreover, the costs of converting to electric appliances is high and households that connect to the supply system tend to use electricity for low-energy consumption items like television and lights and still burn coal for space heating and cooking (Hallows and Butler, 2002).

Furthermore, poor people usually earn daily cash income with no medical or pension assistance, based on the principle of “no work, no income” (UNDP, 2000). Consequently, if they are ill, they do not earn an income and hence they cannot secure proper medical treatment, which aggravates the suffering and results in even more loss of productivity. These people do not have the economic liberty to change their lifestyles. For instance, in a study conducted in the township of Qalabotjha in

Villiers, Free State Province it was noted that people were increasingly becoming concerned about coal smoke: a growing number of people was possibly prepared to give up coal to get rid of smoke but not necessarily their coal stove (Hoets 1998; Scorgie *et al*, 2001). The coal stoves are not well ventilated and they are part of the problem but, because of a lack of economic strength, people were not able to surrender them for alternative energy sources.

2.1.5 Domestic Use of Energy

Approximately half the world's population, around 3000 million people, and 75 % of households in developing countries are reliant on biomass fuels (such as wood, cow dung and crop residues) and coal for their domestic energy requirements (WRI, 1998). Although accurate data are scarce, estimates suggest that wood provides around 15 % of the energy needs in developing countries, and as much as 75 % in tropical Africa. In more than 30 countries, wood provides more than 70 % of the energy needs, and in 13 countries it is over 90 % (WRI, 1998). Over the last 25 years, the trend in global bio-fuel use has changed little, and, in some parts of the world, where poverty and the prices of alternative fuels such as (kerosene and bottled gas) have increased, the use of biomass has increased (WHO, 2005).

In many African countries, household energy is derived primarily from solid biomass fuels (Bailis *et al*, 2003). Domestic energy in sub-Saharan Africa is largely derived from wood fuels burned in simple stoves with poor combustion characteristics (Bailis *et al*, 2003). With the exception of South Africa, whose domestic energy consumption is dominated by coal, bio-fuels dominate national energy supplies in sub-Saharan Africa (Bailis *et al*, 2003).

In South Africa 60 % of the total population (about 24 million people) use coal and wood as major sources of household energy (Doppegieter *et al*, 1998). This comprises an estimated 3.3 million tons of coal, which is 3 % of the total annual utilisation in the country. This small amount, however, causes an apportionment of 36 % of the average national particulate emissions and >20 % of total air pollution related to coal use (CEG, 2004). A source apportionment study in Soweto, for

example, indicated that domestic coal combustion contributed approximately 70 % of the ambient total particulate matter (PM₁₀) loading (Annegarn *et al*, 1998). A similar study in the Vaal Triangle showed that domestic coal combustion contributed 36.5 % to the atmospheric load of particulate pollution, rising to 65 % in winter (Engelbrecht *et al*, 1998). In Qalabotjha, another township in South Africa, residential coal combustion is the single largest contributor to particulate pollution, accounting for 62.1 % of PM_{2.5} and 42.6 % of PM₁₀ (Engelbrecht *et al*, 2002). Biomass combustion contributed 13.8 % of PM_{2.5} and 19.9 % of PM₁₀ (Engelbrecht *et al*, 2002). Consequently, air pollution levels in the townships can also be considered to be potentially life-threatening and the use of coal is now the most important health risk factor (Doppegieter *et al*, 1998). Unacceptable levels of indoor air pollution are released from the combustion of coal in South African townships (Barnes, 2005).

2.1.6 Indoor Air Pollution

As dangerous as polluted outdoor air can be to human health, indoor air pollution poses a greater risk on a global level (Doppegieter *et al*, 1998). Indoor air pollution has received increasing attention in recent years as a major public health concern (Rollin *et al*, 2004; WHO, 2005) because it is one of the major causes of death and disease in the world's poorest countries (Doppegieter *et al*, 1998; Smith, 2002; WHO, 2004). Cooking and heating with solid fuels (including coal, wood, dung and crop waste) on open fires or poorly ventilated stoves leads to indoor smoke and thus indoor air pollution (WHO, 2005).

The indoor smoke released from the combustion of solid fuels contains a range of health-damaging pollutants, including small soot or dust particles that are able to penetrate deep into the lungs. This is a problem particularly in most low-income households as they cannot afford to rely exclusively on electricity for cooking and heating (Stein, 2000; Spalding-Fecher *et al*, 2002). WHO (2005:1) states that

“Every year, indoor air pollution is responsible for the death of 1.6 million people – that is, one death every 20 seconds”.

The WHO has assessed the contribution of a range of risk factors to the burden of disease and has revealed that indoor air pollution is the 8th most important risk factor. Indoor air quality, therefore, is an important determinant of health and well-being (WHO, 1999).

In South Africa, most households (>50 %) depend on coal combustion, wood and paraffin for heating and cooking – especially in winter – yet it causes the most serious indoor pollution (Stein, 2000). Moreover, apart from causing indoor pollution, low-cost fuels are a common cause of residential fires and the cause of fatal poisoning of young children as is the case in many township homes in South Africa (Stein, 2000; Barnes, 2005; WHO, 2005). The control of indoor air quality, however, is often inadequate, due to the poor articulation, appreciation and understanding of basic principles and action related to indoor air quality (WHO, 1999). Yet the importance of monitoring indoor air pollution, where indoor sources of air pollution are substantial, cannot be over-emphasised because using outdoor concentrations alone underestimates actual personal exposure (WHO, 1999).

The use of coal as a domestic fuel in residential townships is a major source of air pollutants (van Nierop, 1995; van Horen *et al*, 1996). Domestic coal combustion is both an indoor and outdoor source of air pollution because stove chimneys release emissions outside the houses into the surrounding atmosphere (Annegarn *et al*, 1998). Nevertheless, because the stoves are usually poorly ventilated (Scorgie *et al*, 2001), a substantial amount of air pollution is also released indoors. Of importance, in affecting human health, is the low elevation at which these emissions occur (Mdluli *et al*, 2003) as low-level emissions have a greater impact on human health (Spalding-Fecher and Matibe, 2003).

Moreover, the fact that these emissions are usually released in confined spaces of homes further compounds the problem (Doppegieter *et al*, 1998). The same authors further state that, in such circumstances, exposure to pollutants is often higher

indoors than outdoors. Yet, despite reports that indoor air pollution in poorly ventilated homes claims the lives of 1.6 million people per year in poor countries, it remains a silent and unreported killer (WHO, 2004). South Africa is no exception, with the epidemic of respiratory diseases resulting from indoor air pollution exposure remaining largely unseen and undocumented (Stein, 2000). This is so despite statements that there is a close association between indoor air pollution and acute respiratory tract infections (Scorgie *et al*, 2003a; Barnes, 2005).

Reports on air pollution from domestic coal combustion in South Africa have mostly involved research on *ambient air pollution* (Terblanche *et al*, 1993; Annegarn and Sithole, 1997; Annegarn *et al*, 1998; Engelbrecht *et al*, 2000; 2001) and not *indoor air pollution*. Rollin *et al* (2004) and Barnes (2005), for example, measured indoor air pollution from biomass combustion in rural South Africa. This has happened despite the knowledge that indoor air pollution is of particular importance in coal-burning households as these are the micro-environments where infants, children and the elderly spend their time (Terblanche *et al*, 1993; WHO, 2005). Efforts are, however, being made to reduce impacts of pollution from domestic coal combustion. In a series of studies conducted by Terblanche *et al* (1994), the principal finding was that measures should be implemented as a matter of urgency in South Africa to reduce human exposure to hazardous air pollutants emanating mainly from wood and coal burning for domestic cooking and heating. The South African government, therefore, as is shown below, has proposed alternative energy sources to coal.

2.1.7 Alternative Energy Sources in South Africa

Alternative energy sources to coal have been proposed and researched in South Africa (Hoets, 1994; Terblanche *et al*, 1995; van Horen *et al*, 1996; Britton, 1998; Scorgie *et al*, 2001; 2003a; Surridge, 2004) to reduce air pollution and its resulting consequences. A few reports of whether or not the householders would be willing to accept them have also been made (Hoets, 1994; 1998).

Low-smoke Fuels

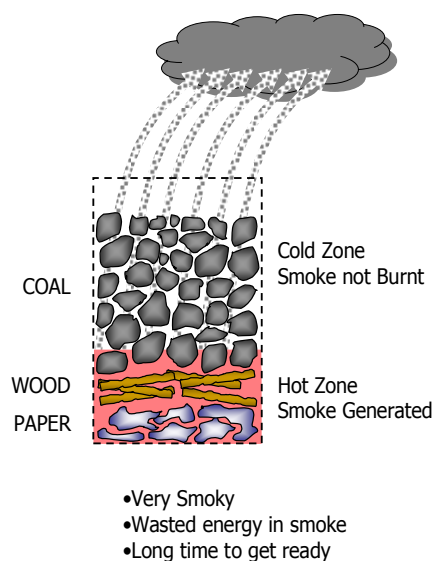
Due to the necessity to reduce air pollution, the South African government and other agencies in the country have conducted a series of studies in an effort to introduce measures to reduce air pollution. For instance, low-smoke fuels were investigated by the Department of Minerals and Energy (DME) as a means of reducing air pollution caused by household coal combustion (Spalding-Fecher, 2002; Scorgie *et al*, 2003a; Surridge, 2004). These low-smoke fuels were developed as alternatives to coal to address public health issues and to reduce smoke emissions, hence reducing indoor air pollution (Engelbrecht *et al*, 2001; Spalding-Fecher, 2002). A description of the low-smoke fuel referred to here is available in Hoets (1994) and Engelbrecht *et al* (2001).

Macro-scale experiments were undertaken to test, *in situ*, the low-smoke fuels in the isolated township of Qalabotjha in Villiers, Free State Province, during July 1997 (Scorgie *et al*, 2001; Spalding-Fecher, 2002). Residents used 200 tons of low-smoke fuels over a 20-day period during the winter of 1997 (Surridge, 2004). The aim of the experiment was to determine the social acceptability and technical performance of the low-smoke fuels in the field. Both indoor and outdoor air pollution concentrations were measured before, during and after the low-smoke fuel replacement, social surveys were undertaken and marketing strategies were also reviewed as part of the experiment. Reductions in ambient particulate concentrations were noted to occur by some researchers during the low-smoke fuel-burning period of the experiment. This was taken as an indication of the potential success of the fuels implemented (Scorgie *et al*, 2001). The main outcome of that investigation, as stated by Surridge (2004), was that low-smoke fuels have a role to play in reducing air pollution to acceptable levels. Moreover, according to Hoets (1994), a low-smoke fuel which is competitively priced against standard township coal would be highly acceptable to coal users.

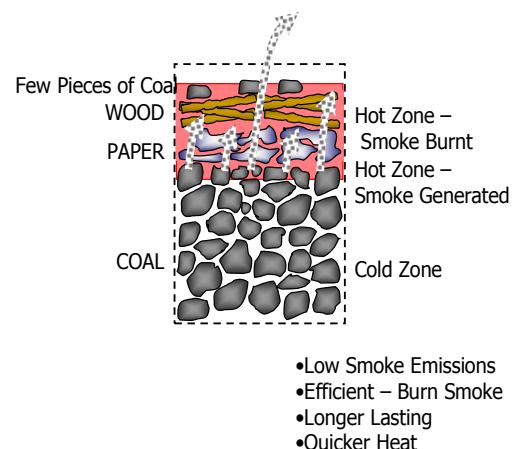
The success of the low-smoke fuels programme, according to Surridge (2004), led to the formulation of an Integrated Household Clean Energy Strategy called “Basa Njengo Magogo” (BNM). BNM is a top-down ignition method for coal fires

(Figure 2.1) and it is the least-cost option for decreasing smoke emissions. In the classical bottom-up fire-ignition approach, the order of laying the fire is paper, wood then coal. In the BNM approach, the order of laying the fire is coal, paper then wood, and few lumps of coal on top at an appropriate time after the fire has been lit. The principle is that smoke is generated at the hot/cold boundary. In the classical bottom-up coal fire ignition process, the smoke rises through the cold coals and thus escapes. In the top-down ignition process, the smoke rises through the hot zone and is consequently burnt. Controlled laboratory tests of the BNM methodology were undertaken by the CSIR during 2004 (Surridge, 2004). These tests showed an 80 % to 90 % reduction in the smoke emissions, a shorter time to cooking and less coal burnt, confirming field observations.

Classical Fire-lighting Methodology



Basa njengo Magogo Methodology



Source: Surridge (2004).

Figure 2.1: The BNM method of ignition as opposed to the classical fire-lighting method

Studies have also shown that inhabitants of electrified areas still burn considerable amounts of solid fuel despite the fact that electrification in South Africa is a high priority (Britton, 1998). The reason for this, as given by Hoets (1994) and Britton

(1998), are that people cannot afford to pay for electric appliances and electricity consumption and that many residents prefer the tradition of using coal and other solid fuels. These aspects are more clearly explored below and elsewhere in this thesis.

2.1.8 Electrification in the South African Context

It has been noted earlier that usage of solid fuels declines in response to electrification (Heltberg, 2004). Electrification has been alleged to play a major role in the elimination of township pollution caused by coal combustion in coal stoves and braziers in South Africa (Terblanche *et al*, 1993b; Hoets, 1994; Spalding-Fecher, 2002; Matooane *et al*, 2004). There has also been a mass electrification programme in the country that was initiated by Eskom (the Electricity Supply Commission of South Africa) in 1991. Eskom is the key electricity service provider in South Africa. According to Spalding-Fecher (2002) electrification has been one of the most successful elements of the South African Reconstruction and Development Programme. The mass electrification programme has brought electricity to more than 4 million homes since 1991. The introduction of electricity into township households has also had significant environmental and health benefits (Spalding-Fecher and Matibe, 2003).

Due to mass electrification of households, the share of South Africa's population with access to electricity has been increased from 35 % in 1990 to 66 % at the end of 1999. It was anticipated that households that have access to electricity would switch from coal and bio-fuel combustion to using electricity almost exclusively (Matooane *et al*, 2004), with a concomitant improvement in air quality. Moreover, the South African government went beyond just providing an alternative energy source (electricity) by providing a portion of the electricity free to low income households (Howells *et al*, 2005; Spalding-Fecher, 2005). The expectation was that as households increased their consumption of electricity, they would reduce – although not eliminate – the consumption of other household fuels (van Horen *et al*, 1993; Spalding-Fecher and Matibe, 2003). The average monthly electricity consumption of 138 kWh in low-income households is, however, much lower than

had been expected (Spalding-Fecher and Matibe, 2003). This implies that there has been a slower shift than expected to complete electrification. The main reason is that electricity is too expensive for township households (Hoets, 1998) and this concurs with Barnes (2005) who also states that the shift to complete electrification is usually slower in poorer areas.

Electrification may, therefore, not solve the problems posed by domestic coal combustion since township households use electricity only for activities that draw low amounts of power like lighting and entertainment (television and radio) and still burn coal for cooking and space heating (Hoets, 1994; Winkler *et al*, 2000). One disadvantage of using electricity could be that the electricity supply in the townships is unreliable because of blackouts and vandalism (BNM, 2003). Further, it has been recorded (Hoets, 1994; Scorgie *et al*, 2001) that people in township households dislike electricity because it is too expensive and they cannot afford to buy electric appliances. Thus, the reduction in coal use reflects a socio-economic transition beyond simply a change in availability of electricity (Spalding-Fecher, 2005) or electric appliances. Moreover, income levels as well as price changes affect demand for electricity (Spalding-Fecher, 2005). Notably, poverty hinders interventions to reduce indoor air pollution (Barnes, 2005) hence, if people are poor, the effects of electrification may be insignificant. Nevertheless, the assumption that electrification could phase out or reduce the use of coal ignores the social role played by coal stoves in township homes (Hoets, 1994).

2.1.9 The Social Role of Coal Stoves in Township Households

Under colonial and apartheid governments many black South Africans were forcibly removed from their ancestral lands and settled in townships (McDonald, 2002; Mathee and von Schirnding, 2003). In the townships there were backlogs in the distribution of services (such as electricity and waste removal) (Scorgie *et al*, 2003b) and a large proportion of the households could not afford to use electricity (Mathee and von Schirnding, 2003) where electrification had occurred. Consequently, coal was predominantly used in townships in South Africa to meet household energy needs (Scorgie *et al*, 2003b; Spalding-Fecher, 2005). As a result

of using coal for decades, there is a large infrastructure to utilise coal in the townships (BNM, 2003) and investments in coal stoves have been made (Hoets 1994; BNM, 2003). Moreover, the multi-functional ability of coal (cooking while simultaneously heating the house) has made coal usage even more convenient and preferable and so people continue to use it (Scorgie *et al*, 2003a). Previous estimates show that the size of the household coal market was close to one million tons per annum in the year 2000 in South Africa (Qase *et al*, 2000).

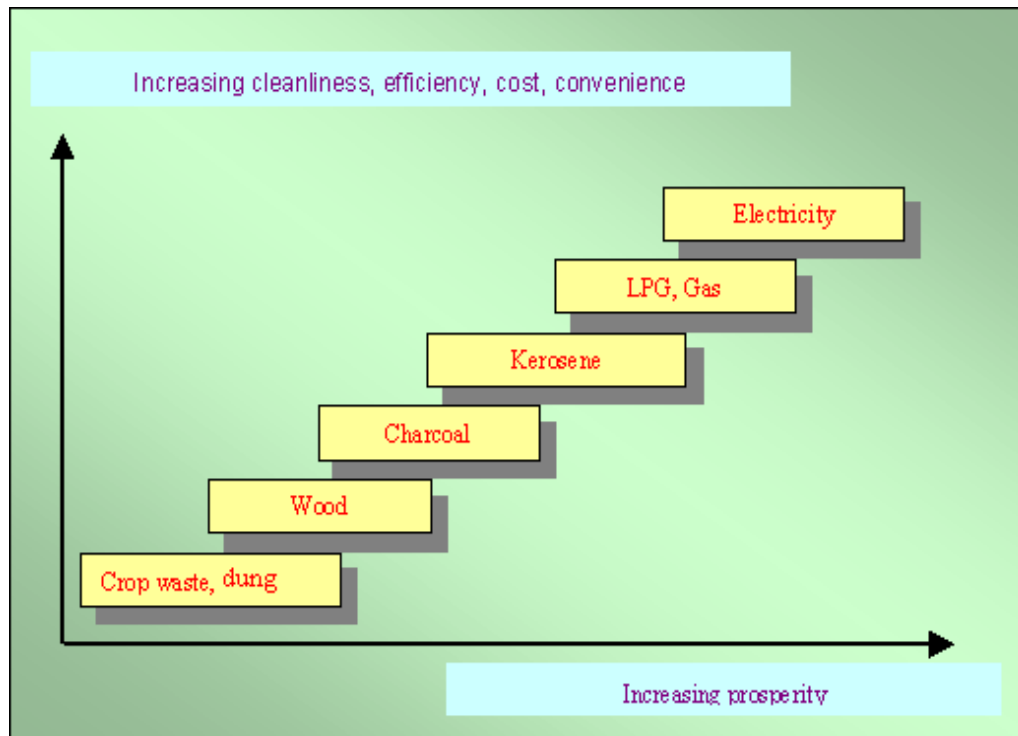
In China, 1990 estimates show that 16 % of the total national commercial energy consumption was utilised by the household sector (Bach and Fiebig, 1998). A large majority of households in China (71 %) cooked with coal and only 29 % with gas. In India, livelihood patterns are characterised by biomass-based systems (TERI, 2000a). In 1999, fuel-wood consumption was around 200 million tonnes per annum and cooking was the largest energy-consuming end-use in the domestic sector, accounting for almost 90 % of the total domestic energy use (TERI, 2000a).

Among poor households, the most important criteria affecting people's choices of commercial fuels are the cost and availability of different energy options (ERC, 2004). Consequently, coal is the fuel of choice for thermal applications in low-income households because it is more affordable and cost effective as it supports both cooking and space heating (Qase *et al*, 2000; Scorgie *et al*, 2001). Furthermore, several households have already invested in the requisite appliances for coal and sometimes low-income households find it too difficult to forego their current investments in coal stoves. Other township households have apparently developed attachments to their coal stoves such that, even if they had sufficient financial resources, they would find it difficult to abandon them (Qase *et al*, 2000). For some, their coal stove is the biggest single household investment they make (Hoets, 1994). In China, for instance, households continued to use their coal stoves in 1990 after it had been reported that their stoves were inefficient (Bach and Fiebig, 1998). Burning coal indoors, however, causes high levels of indoor air pollution that could be detrimental to human health (Spalding-Fecher and Matibe, 2003). Against this brief background, the conceptual framework for this work is provided below.

2.2 CONCEPTUAL FRAMEWORK

2.2.1 Concepts on Energy Use at Household Level

The dominant feature of energy use in poor households is the use of multiple sources of energy (Eberhard and van Horen, 1995). Household energy is defined as energy consumed by people in their homes for cooking, space and water heating, lighting and recreational activities (Terblanche *et al*, 1994). Household energy sources that are low on the energy ladder are available at a low cost but are, however, low in combustion efficiency and cause high adverse impacts (Terblanche *et al* 1995). With development, there is generally a transition up the ‘energy-ladder’ (Figure 2.2) to fuels which are progressively more efficient, cleaner, convenient and expensive. The energy ladder is a concept used to describe the way in which fuel-using households will move to more sophisticated and cleaner fuels as their economic status improves (Hosier and Dowd, 1987). Coal is situated in the lower segment of the ladder at the level of wood, whilst electricity is situated at the top of the energy ladder and is considered to be the safest fuel in terms of indoor air quality (Barnes, 2005).



Source: Bruce (2002).

Figure 2.2: The energy ladder

The energy ladder, however, does not seem to be entirely appropriate to developing countries since it is regarded to be too simplistic (Terblanche *et al*, 1994). Evidence shows that in developing countries, households do not necessarily move up the energy ladder when income increases rather they tend to increase the security of their usual supplies (Terblanche *et al*, 1994). Moreover, Bruce (2002) noted that poor households use multiple sources of energy; hence, there is not a simple linear progression up this ladder. Households tend to carry out more tasks with more modern fuels because the use of modern fuels eliminates time spent in gathering wood or other less efficient energy sources (Bruce, 2002). However, the problem remains that almost half of the world's population relies predominantly on fuels at the lower end of this energy ladder, and, for many, the prospects of moving up the ladder in the short term appear limited (Bruce, 2002). Furthermore, it is unlikely that many of the poorest households in developing countries will progress up the energy ladder towards the exclusive use of cleaner-burning fuels in the foreseeable future (Barnes, 2005).

Other studies have ascribed the ongoing use of coal in South African households to its availability rather than the affordability and availability of alternative fuels (Qase *et al*, 2000). It is rarely true, however, that the depletion of resources is the driving force for resource substitution (Ausubel *et al*, 1989). From a historical perspective, energy substitution, for instance, has been driven by the availability of a set of new technologies that enabled an alternative energy source to satisfy better, and at an acceptable cost, the end-use demand of society (Ausubel *et al*, 1989). It is also important to note that energy provides little or no utility in its own right, but is used by people to fulfill a number of different needs or to provide services such as lighting, space heating and cooking (Eberhard and van Horen, 1995). As a result, people are attached more to what the energy source provides rather than the energy sources themselves (Hosier and Dowd, 1987). This is one of the reasons energy expenditure occupies a prominent place in the economies of poor households (Eberhard and van Horen, 1995).

Other studies have shown that households move up the energy ladder as their economic status improves (Hosier and Dowd, 1987; Bruce, 2002; Jack, 2004). This linear progression, though, may not happen in all cases. In Zimbabwe, for instance, it was found that although households do move away from wood to kerosene and electricity as their economic status improves, a large number of other factors are important in determining household fuel choice (Hosier and Dowd, 1987). These include fuel efficiency and its amount and availability on a daily basis. In South Africa, multiple fuel use is a common pattern amongst poor households (Annecke, 1999). In addition, several scholars find that urban dwellers are more likely to use cleaner fuels irrespective of their economic statuses (Jack, 2004).

2.2.2 People's Perceptions of Energy Use

Having outlined some of the socio-economic issues, attention is finally turned to examine how 'perceptions' can also impact on energy use. People's perceptions focus on particular risks because of their attachment to place, beliefs, values and moral behaviour and not necessarily on the actual or perceived amount of danger (Luginaah *et al*, 2002). People's perceptions are also an important factor when

examining the effects of their decisions on local environmental quality and understanding their behavioural patterns (Rogan *et al*, 2005). Perceptions are an important determinant of why people behave the way they do (O'Connor *et al*, 1999). First-hand environmental experiences are a significant influence on people's perceptions and behaviour (Rogan *et al*, 2005).

In almost all developing countries it is women, for example, who provide fuel for the family and carry out cooking and many other tasks that require energy use in the home (WREC, 1996; Bruce, 2002). In South Africa, for instance, women do the cooking in most households (ERC, 2004). Women who use coal as an energy source, therefore, have a profound knowledge of domestic coal combustion. This local knowledge is a reliable source of information (Lykke, 2000). In a study conducted by Mehlwana and Qase (1996) it was discovered, however, that little was known about women's perceptions of energy and the use of energy appliances in South Africa. This was an unfortunate situation because women are the principal end-users and managers of household energy in most cases. Furthermore, women are more adversely affected by the unaffordability of electric power sources, as well as by expending time and energy to obtain alternative energy sources (Bond and Hallows, 2002).

One of the reasons women's perceptions of energy use are not known could possibly be that the use of electricity and appliances is relatively new to most poor households (ERC, 2004). South African energy users from low-income households are poorly informed about good energy-use practices and options, hence they do not benefit optimally from the electricity tariff (ERC, 2004). The perceptions of poorly informed energy users would be inadequate to inform the body of knowledge unless they receive energy education and information (O'Connor *et al*, 1999). An energy-literate public is needed to make well-reasoned decisions about energy options and to use natural resources wisely (ERC, 2004).

* * * * *

Chapter 2 provided a literature review and outlined the conceptual framework underpinning this study. Key issues raised from the literature included:

- Aerosols are an important atmospheric pollutant whose elemental composition and sources have a bearing on how they impact on the environment,
- Atmospheric aerosols impact on climate, human health and the socio-economic statuses of human beings,
- Domestic use of energy (biomass and coal in particular) contributes significantly to the amount of aerosols in the atmosphere and it causes significant indoor air pollution,
- In South Africa, therefore, alternative energy sources to coal have been proposed and researched and these include low-smoke fuels and electrification,
- Domestic coal combustion has, however, persisted after electrification and the reasons for this need to be explored.

The conceptual framework of energy use at household level that is provided in this chapter is the concept of the energy ladder. This frame is used to assist in an exploration of coal usage in households in South Africa. Finally, the importance of people's perceptions of energy use at household level was outlined. The next chapter presents the methods used for collecting and analysing data in this study.

CHAPTER 3:

RESEARCH METHODOLOGY

This chapter outlines, in detail, the process and method used for data collection and analysis. Also explained in this chapter is the reliability and validity of the process and methods used.

3.1 STUDY DESIGN

A questionnaire survey was conducted in 100 households in Doornkop Township and 100 households in KwaGuqa Township. The questionnaire survey was conducted in April 2004 in Doornkop and in June 2004 in KwaGuqa (both months being fairly representative of stable atmospheric conditions (Tyson and Preston-Whyte, 2000)). During the administration of the questionnaire survey, observations were conducted simultaneously in the townships. Interviews were also conducted with officials from Eskom to assess their views and goals pertaining to domestic coal combustion.

Moreover, indoor respirable aerosol (PM₇) monitoring was carried out in four households in KwaGuqa. Continuous ten-minute-average values of PM₇ concentration were recorded using DustTrak aerosol monitors in August 2004. Of the households selected for PM₇ monitoring, one (1) was electrified with no coal combustion, two (2) were electrified with coal combustion and one (1) was un-electrified with coal combustion. In addition, personal sampling was carried out simultaneously with the aerosol monitoring.

3.2 QUESTIONNAIRE AND INTERVIEW DATA COLLECTION

Information that was used to generate the questionnaires and interviews was collected by using both primary (official documents) and secondary research

(published literature). This comprised an analysis of available sources of literature. Official documents were obtained from the Department of Minerals and Energy (a South African government department) and published literature was obtained from the libraries of the University of the Witwatersrand and the internet. This section involved documenting available information in order to provide a baseline for interviews.

3.2.1 Questionnaire-Based Interviews

Firstly, a *questionnaire* (Appendix 1) was produced based on the information gathered in the literature review and 10 pilot questionnaire-based interviews were conducted initially in each study area to pre-test the questionnaire. This was done in order to determine whether the respondents understood the questions and to see if the questions met the inputs possibly expected from the research frame that was designed. After pre-testing the questionnaire, the questions were adjusted and a second, more appropriate questionnaire was created (Appendix 2). The questionnaire-based interviews were conducted with a population sample of 100 households in each of the two (2) study areas. The population samples were chosen using, first, stratified random sampling (Kitchin and Tate, 2000; Russell, 2000) to choose parts of the township that burn coal. Then, systematic random sampling (Kitchin and Tate, 2000) was used to choose the individual households to be interviewed. The first house was chosen at random then every 10th house on the same row was chosen. Approval of the research process, consent requirements and other inputs was granted by the Non-Medical Ethics Committee of the University of the Witwatersrand (see clearance certificate in Appendix 4).

The most important advantage of using questionnaires for data collection is their low cost (Monn, 2001). The limitation of questionnaires is that they ask a rigid set of simple questions, which force the respondents' answers into particular categories that they may not have thought of unprompted or may not want to use. Questionnaires are a recognised research method which enables the exploration of people's views (Kitchin and Tate, 2000). Furthermore, questionnaire data are

relatively easily managed – as opposed to more participatory approaches – hence they are suitable for large population samples (Yin, 1994; Stroh, 2000).

3.2.2 Observations

The difference between observation and interviewing is that in *observation* researchers *monitor the process* as events unfold, whereas with interviews they ask specific targeted questions that require a *response*. Observation is a key tool in research methods as it enables a systematic noting and recording of events, behaviours and artefacts in a social setting (Kitchin and Tate, 2000). Nachmias and Nachmias (1987) state that the major advantage of observation as a research technique is its directness. Rather than asking people about their views and feelings, the researcher watches what the respondents do and listens to what they say.

In this study, the researcher observed the populations of Doornkop and KwaGuqa to record their time-activity patterns. The amount of time the different population groups spent indoors and outdoors was monitored so that a time-activity profile could be constructed highlighting periods when people were most exposed to air pollution. People's movements were observed as well as their fuel-use patterns to complement and 'thicken' information derived from the questionnaire survey.

3.2.3 Detailed and Focused Interviews

After conducting the questionnaire-based interviews, detailed and focused *interviews* with open-ended questions (Bechtel *et al*, 1987; Kitchin and Tate, 2000; Stroh, 2000) were conducted with Eskom stakeholders to assess their views and goals appertaining domestic coal combustion in the areas identified (Appendix 3). Interviewing and more participatory interaction is a research strategy that aims to move away from fixed answer questions. Interviews aim to be a conversation that explores an issue with a participant rather than to test knowledge or categorise hence they provide answers to the “why” questions rather than just the “how” questions (Kitchin and Tate, 2000). The use of open-ended questions helped to stimulate conversations.

Interviews have a number of limitations. First, it is difficult to know who to recruit, knowing which people will be appropriate for the research objectives and how to convince people that their contribution is worthwhile and important (Stroh, 2000). This is due to the length of time that an interview will take. Analysis of the responses is time-consuming. There are also problems of ensuring ‘objectivity’ in responses. In this case, inputs from the energy sector were obtained from Eskom. The organisation has separate departments that deal with environmental issues and electricity supply that enabled the targeting of relevant people for the interviews.

Moreover, designing an interview schedule can prove problematic because it is difficult to devise topics that can form questions without them becoming leading questions. It can be easy to focus on the topic – which is the main object of the research – early in the interview, thereby pre-determining the outcome of the interview session (Stroh, 2000). This limitation was overcome by asking and prompting questions in the order that they appeared in the interview outline and adjusting the interview schedule according to the learning experience of the interview process.

Despite these limitations, interviews are the most ubiquitous method in environmental studies and they present a number of difficulties – as with questionnaires (Bechtel *et al*, 1987). They both assume the availability of environment-related knowledge and attitudes of the respondent and the latter’s ability to share with the researcher. These are assumptions that are by no means tenable. In the townships for instance, a large majority of the respondents lacked technical environment-relevant information (for example, knowledge about air pollution impacts on human health). Another disadvantage is that it may be possible in asking questions about the environment to expect that people have had a similar experience with an environmental attribute. Moreover, it is difficult for a person to answer a question about an environment that he or she has never experienced (Bechtel *et al*, 1987; Yin, 1994) as was the case in this study when respondents failed to answer questions about low-smoke fuels that they had not seen or used before.

3.2.4 Analysis of Interviews and Questionnaire Data

Data collected from the interviews were transcribed from audio tapes into a computer using Microsoft Word 2003. The researcher drew themes from the data and then interpreted and analysed them according to each theme. Data collected from the questionnaires were compiled and coded. A codebook was developed as an outline. This outline gave details of each research question, the labels associated with each question, and the numerical values assigned to them. The data were then captured into a computer using Microsoft Access 2003. Once captured, the data were exported from Microsoft Access into SPSS (Statistical Package for the Social Sciences 2000) and analysed using SPSS.

3.3 INDOOR AEROSOL MONITORING

Indoor aerosol monitoring was conducted at KwaGuqa. For the purposes of this research, PM₇ concentrations were measured because PM₇ includes all respirable particulate matter (Volkwein *et al*, 1999; Volkwein and Thimons, 2001). Monitoring PM₇ enabled an observation of the daily concentrations of indoor particulate matter as well as comparisons with national and international air quality standards.

3.3.1 Continuous Indoor PM₇ Measurements

Four houses were selected during August 2004 for indoor aerosol monitoring during the questionnaire survey. These houses consisted of two (2) electrified houses that burn coal; one (1) electrified house that does not burn coal and an un-electrified house that burns coal. These household units were chosen to observe expected differences in indoor respirable particulate matter (PM₇) concentrations in the houses. These houses had a similar construction pattern, design and other dimensions.

One (1) DustTrak aerosol monitor (model 8520, obtained from Envirocon Instrumentation cc, SA) (Figure 3.1) was placed in each of these houses to collect continuous 10-minute average PM₇ measurements for the month of August 2004.

PM₇ sized inlets were fitted into the mouth of the monitors to ensure the selection of PM₇ aerosols only. These DustTrak aerosol monitors were calibrated by TSI in Arlanda Stad, Sweden on 14 April 2004 (the calibration certificates are in Appendix 5). The DustTrak aerosol monitor in the un-electrified household was powered by a rechargeable battery that was changed every second day, while the aerosol monitors in the electrified households were connected to the electricity supply of each household (although the aerosol monitors also had standby batteries to ensure that data were being collected even when electricity supply was not available). The data were downloaded every second day at each house, using the Trakpro software that comes with the DustTrak aerosol monitors.



Figure 3.1: An example of the DustTrak aerosol monitors used to monitor aerosol concentrations in the selected households

At KwaGuqa, the electrified houses are separated from the un-electrified houses by about 20 m. The distance between each house is about 10 m to allow for easy ventilation, while houses by the roadside are about 15 m away from the road. Both the electrified and un-electrified houses are made from concrete bricks with iron roofs, glass windows and wooden doors. Each house consists of two bedrooms and a living area (where the coal stoves are normally situated). Each household has an average of eight occupants, including children. The average dimension of the living area where the DustTrak aerosol monitors were located during the monitoring of PM₇ was 16 m². The houses are constructed with provision for an open, direct coal-

fired stove with its smoke stack extended above the rooftop to allow for venting off of the smoke.

3.3.2 Elemental Composition of PM₇

During 20 to 26 August 2004, PM₇ personal monitors were loaded with nucleopore filters (37 mm diameter, pore size 0.8 μm). These PM₇ personal monitors (Figure 3.2) were simultaneously given to one individual from each of the selected households to analyse the elemental composition of inhaled air. These monitors had battery-operated Gillian sampling pumps (model 8000485-5, obtained from Envirocon Instrumentation cc, SA) that pumped respirable air onto pre-weighed nucleopore filters. The flow-rate of the Gillian pumps was 1.7 L.min⁻¹. Before exposure, the filters were housed in cassettes to avoid contamination and the cassettes were changed daily. After exposure, the filters were removed from the cassettes and stored at room temperature in plastic Petri dishes until taken for analysis.

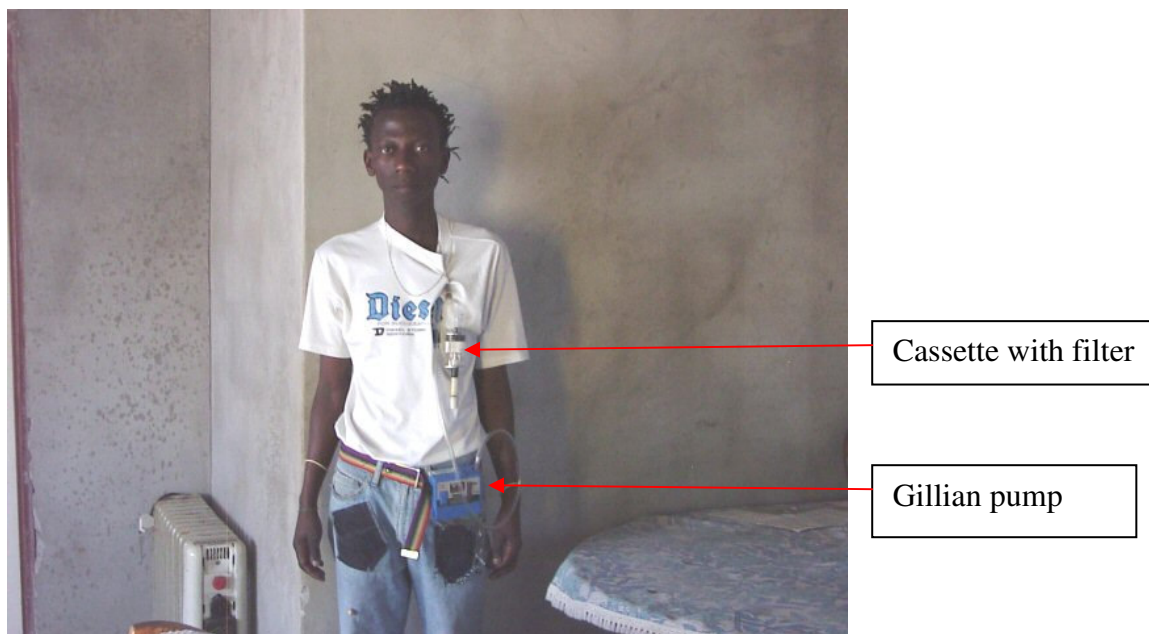
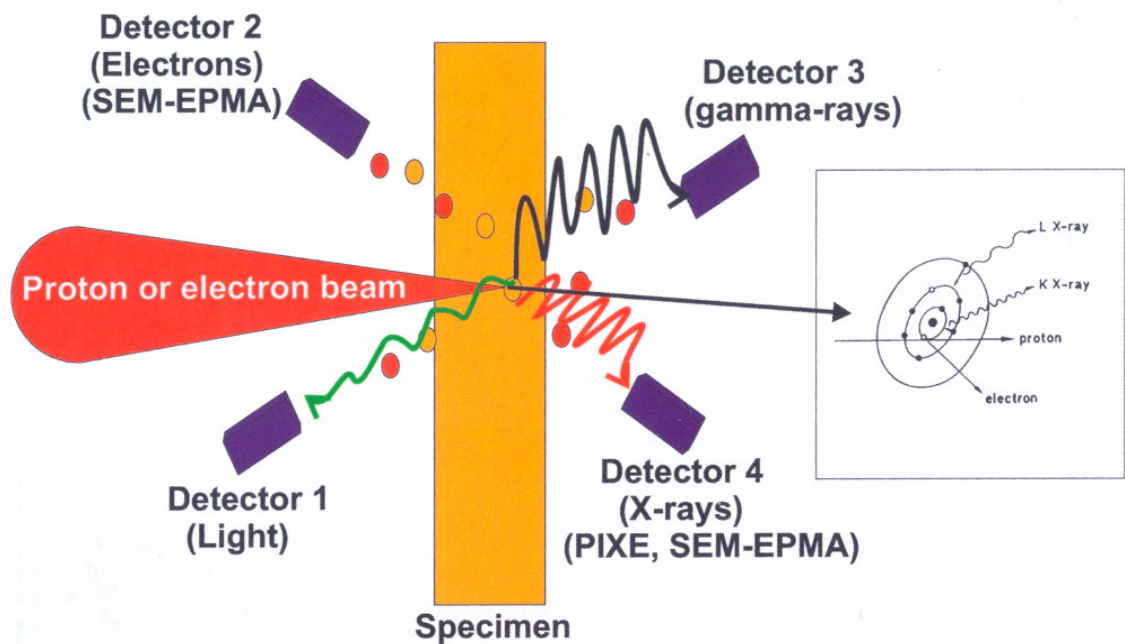


Figure 3.2: An individual wearing one of the PM₇ personal monitors that were used

The elemental composition of the exposed nucleopore filters was then analysed using Proton Induced X-ray Emission (PIXE) analysis at the iThemba Accelerator Centre. PIXE is a technique used for determining the elemental composition of environmental and biological samples, and the relative mass ratio of the detected elements (Johansson and Campbell, 1988). PIXE has established itself as a powerful routine analytical technique in the study of atmospheric aerosols because it is a fast and multi-elemental method of analysis with high sensitivity (Swietlicki *et al*, 1996). Moreover, the technique is largely non-destructive, so that samples can later be analysed by an alternative method if required. PIXE is especially suited to analysis of atmospheric particles because a broad range of elements can be detected from small quantities of material owing to low detection limits.

Exposed filters were analysed by bombarding the collected sample with protons from a nuclear accelerator (Figure 3.3). Characteristic X-rays are emitted from the bombarded sample and are detected by a silicon-drifted lithium detector that converts the energy of the X-ray into a voltage pulse. The amplitude of the pulse is proportional to the X-ray energy (Johansson and Campbell, 1988).



The inset on the right depicts what happens at atomic level.
Source: Cumbane (2001).

Figure 3.3: X-ray excitation by charged particles

Spectra were fitted for ten elements: Al, Si, S, K, Ca, Mn, Fe, Cu, Zn and Pb. Collected spectra are resolved into the detected elements by describing the X-ray spectra as Gaussian distribution peaks on a continuum. This yields a quantitative value that can be related to elemental concentrations (Johansson and Campbell, 1988). The flow-rate ($1.7 \text{ L}\cdot\text{min}^{-1}$) from the Gillian pumps, and the amount of time during which the filter was exposed were then used to calculate the average volume of air passing through each filter and hence the corresponding indoor elemental concentration in $\mu\text{g}\cdot\text{m}^{-3}$.

In order to investigate the relative contribution from different sources to the respirable aerosols, the enrichment factor (EF) of an element, X, in the aerosol relative to the crustal material was calculated as:

$$EF = \frac{[X]_{sample} / [Si]_{sample}}{[X]_{crust} / [Si]_{crust}}$$

Where:

$[X]_{sample}$ is the average concentration of the element, X, in the sample;

$[Si]_{sample}$ is the average concentration of Si in the sample;

$[X]_{crust}$ is the average concentration of element, X, in the reference sample (the earth's crust), and

$[Si]_{crust}$ is the average concentration of Si in the reference sample.

Si was used as a reference element and its concentration value in crustal matter was taken from Mason and Moore (1982). Elements with an enrichment factor value near 1.0 show strong influence of the crustal component, whereas a high value for the enrichment factor may indicate an additional source of that element other than soil dust (Braga *et al*, 2004).

Source contributions of the elements to the respirable aerosols were calculated as:

$$[X]_{soil} = [X]_{measured} \times [X/Si]_{crustal}$$

and

$$[X]_{non-crustal} = [X]_{measured} - [X]_{soil}$$

Where:

$[X]_{soil}$ is the concentration of the element contributed by soil dust;

$[X]_{measured}$ is the measured concentration of the element in the sample;

$[X/Si]_{crustal}$ is the ratio of the element to Si in the earth's crust, and

$[X]_{non-crustal}$ is the concentration of the element from different anthropogenic sources (Piketh, 2000).

Anthropogenic sources identified were wood burning, coal combustion and traffic emissions.

3.4 ESTIMATING POPULATION EXPOSURE TO PM₇

This study has used the two most important bodies of knowledge in environmental management research: local knowledge and scientific knowledge. Local knowledge was obtained from the questionnaires, whilst scientific knowledge was obtained by the use of DustTrak aerosol monitors and personal samplers. The importance of the questionnaire was to give information about fuel-use patterns and the population's activities in the townships, among others. Such information is useful to broaden the understanding of people's behaviour and to resolve possible conflicts (Trakolis, 2001). Aerosol monitoring (scientific knowledge) gave concentrations of indoor respirable aerosols in township households. The integration of the local knowledge of coal users in the townships and the scientific knowledge enabled an estimation of population exposure to air pollution (PM₇) in the townships.

Personal exposure to PM₇ was estimated both directly and indirectly. In the direct approach, exposure levels are determined on an individual by using a personal sampler or a biological marker; in the indirect approach, exposure levels are either measured by stationary instruments or determined by models (Monn, 2001). In this study, results from personal samplers' were used to estimate direct exposure and results from DustTrak aerosol monitors were used to estimate indirect exposure.

Given that no method of estimating exposure was obtained from the South African literature, a method described in WHO (1999) was used. In this method, arithmetic means of selected concentrations from monitoring data were used to indicate population exposure. In this study, daily concentrations of PM₇ as well as the

estimated amount of time that people spend inside their houses were used to assign population exposure to PM₇, as presented in the formula below:

$$Exposure = \frac{(x_d)(t_n)}{24}$$

Where:

x_d is the daily mean concentration ($\mu\text{g}\cdot\text{m}^{-3}$), and

t_n is the number of hours a population group is exposed.

A more complex method would be to divide the population into groups and to assess exposure of the groups separately (WHO, 1999). This method was used in this study to improve the understanding of the distribution of adverse health effects in the different population groups. This approach based on population groups enables the exposure of, and the health effects on, the whole population to be assessed more accurately and separately (WHO, 1999).

Questionnaires are important tools for assessing exposure because they can be used to identify contact with emission sources and frequency of the contacts (Monn, 2001). This is especially important for the identification of contacts to indoor sources to obtain data on time-budget and time-activity patterns (Monn, 2001). In this study, questionnaires were used to obtain time-activity patterns. Based on results from indoor PM₇ monitoring in township households and approximate time-activity patterns, indirect indoor population exposure and indirect outdoor population exposure to aerosol pollution has been estimated. The direct population exposure to PM₇ elements has also been estimated, based on results obtained from PIXE analysis.

* * * * *

This chapter has outlined the methodologies used in this study as well as their relevance and limitations. The methods used were:

- Questionnaire-based interviews,
- Detailed and focused interviews,
- Continual indoor PM₇ measurements,
- Elemental analysis of PM₇ and calculations of source contributions and,
- Estimating population exposure to PM₇ pollution.

The next chapter discusses and analyses findings from the studied areas of Doornkop and KwaGuqa. The chapter attempts to compare and contrast fuel use and assesses the societal dimensions of fuel use in the studied areas.

CHAPTER 4:

RESULTS: SOCIETAL DIMENSIONS

This chapter discusses and analyses findings from the study sites, Doornkop and KwaGuqa. The chapter attempts to compare and contrast fuel use and assesses if a common pattern emerges that could be termed as a societal dimension of fuel use in the studied areas.

4.1 FUEL-USE STATUS IN DOORNKOP AND KWAGUQA

4.1.1 Types of Fuels Used in the Study Areas

In examining the state of electrification in the two studied communities, the following figures were obtained as illustrated by Table 4.1. It is noted that 79 % of households selected for the interviews were electrified and 21 % were un-electrified in Doornkop. In KwaGuqa, 91 % of the households were electrified and 9 % were un-electrified. This finding compares well with the figures of national electrification that show a high incidence of electrification in South African townships of up to 66 % at the end of 1999 (Spalding-Fecher, 2002).

Table 4.1: State of electrification in the studied areas

Township	Electrified houses (%)	Un-electrified houses (%)
Doornkop	79	21
KwaGuqa	91	9

Various fuel types were found to be used for a variety of activities in the two study areas (Table 4.2). Some households used more than one fuel for one specific energy need; for instance, some un-electrified households use both paraffin and candles for lighting. This finding is in line with that of Annecke (1999) who also found that multiple fuel use has become a common pattern in South Africa,

especially amongst the poor. This trend is not in line with the conceptual framework for household energy use on the energy ladder that illustrates a linear transition of fuel patterns and choices. Terblanche *et al* (1994) and Bruce (2002) noted, though, that this linear progression may not happen in all cases as explained by the concept of the energy ladder. In Zimbabwe, for instance, the linear progression up the energy ladder did not occur and it was found that there are a large number of other factors, like fuel efficiency, that determine household fuel choice (Hosier and Dowd, 1987).

Fuel-use patterns recorded from Doornkop (Table 4.2a) and KwaGuqa (Table 4.2b) reveal that all electrified households use electricity for lighting. The number of electrified households using electricity decreases though when it comes to cooking and space heating. Paraffin is largely used for cooking and heating water and, to a lesser extent, for lighting, although in Doornkop 19 % of the households used paraffin for space heating. Regarding space heating, “other” in Tables 4.2a and 4.2b signifies the use of blankets to keep warm. Liquefied Petroleum Gas (LPG) is not a popular fuel in the townships as it is said to be expensive as the average household monthly income amounted to approximately R3 721.00 in 2001 in Kwaguqa (IDP, 2007) and approximately R1 000.00 in Doornkop (Roux and Vahle, 2002). Most un-electrified households use candles for lighting.

Table 4.2a: Patterns of fuel use in Doornkop

Purpose	Fuel						
	Electricity %	LPG %	Paraffin %	Candles %	Coal %	Wood %	Other %
Lighting	79	0	3	21	-	-	0
Cooking	43	3	64	-	20	2	0
Space Heating	16	0	19	-	57	3	18
Heating Water	51	3	51	-	20	2	1

Table 4.2b: Patterns of fuel use in KwaGuqa

Purpose	Fuel						
	Electricity %	LPG %	Paraffin %	Candles %	Coal %	Wood %	Other %
Lighting	91	0	3	7	-	-	0
Cooking	74	4	20	-	45	2	1
Space Heating	33	2	4	-	57	2	13
Heating Water	71	1	15	-	37	1	0

An overview of fuel-use patterns in both study areas is presented in Table 4.2c. In Doornkop, 44 % of the coal-burning households burnt coal in stoves, 15 % burnt coal in “*imbawulas*” (braziers) and 1 % burnt coal in a fireplace. In contrast, in KwaGuqa, 52 % of the coal-burning households burnt coal in stoves, and 6 % in *imbawulas*. In both study areas, 80 % of electrified households burnt coal.

Table 4.2c: An overview of the patterns of fuel use in Doornkop and KwaGuqa

Purpose	Fuel						
	Electricity %	LPG %	Paraffin %	Candles %	Coal %	Wood %	Other %
Lighting	85	0	3	14	-	-	0
Cooking	58.5	3.5	42	-	32.5	2	0.5
Space Heating	24.5	0.5	11.5	-	57	2.5	15.5
Heating Water	53.5	1.5	33	-	28.5	1.5	0.5

Coal was used primarily for space heating and then for cooking, while electricity was used primarily for lighting in both study areas. Although Rollin *et al* (2004) recorded a decline in solid fuel use after electrification in the rural areas in South Africa, this study confirmed a significant persistence of domestic coal combustion in township homes after electrification as has been noted in several other studies by Hoets (1994; 1998), Qase *et al* (2000) and Scorgie *et al* (2003a). This result shows that electrification has not phased out domestic coal combustion in the townships. This is mainly because township people cannot afford to use electricity for all their energy needs. Providing electricity to households does not increase the people's income and, therefore, does not change their economic status so that they can afford to use electricity. The assumption that electrification would discontinue or reduce the burning of coal is, therefore, not necessarily true.

More township households in KwaGuqa were able to pay for electricity than those in Doornkop, with 74 % of the households in KwaGuqa using electricity for cooking while in Doornkop it was only 43 %. Moreover, for space heating, only 33 % of households in KwaGuqa and 16 % in Doornkop could afford to use electricity. Although more people are employed in Doornkop (52 %) than in KwaGuqa (41 %), according to the results of this study, fewer people use electricity for cooking in Doornkop. This implies that more people could afford to cook using electricity in KwaGuqa than in Doornkop despite a higher unemployment rate in KwaGuqa. The exact reason for the differential payment across the two study sites is not known but it could be that although more people are employed in Doornkop, they have informal jobs while in KwaGuqa most people have formal jobs because they work in the adjacent coal mines.

In most households, the fuel used for cooking was the same as that used for heating water. A few electrified households that did not use electricity for cooking heated their water in electric kettles. Contrary to Hoets's (1994) study in the township of Evaton, which indicated that township households do not have electric appliances, observations in this study revealed that township households do have electric appliances. Most electrified houses did, however, continue to burn coal "to save electricity" and the few that did not burn coal either did not have coal stoves

(5.5 %) or their stoves were broken (1 %) otherwise they would have burnt coal. A small percentage (0.5 %), of the households stopped using coal because they were allergic to coal smoke. Only 1 % did not burn coal because they disliked coal as it made their houses dirty so they had to spend additional time on cleaning chores.

Most township households used paraffin for cooking. In the un-electrified homes, paraffin was used mainly for cooking, especially in summer, as the residents did not make coal fires during the summer months. The reason for this is that they made coal fires mainly for space heating, so in summer when it is warm there was no need to make coal fires. In the electrified households, where electricity was not used for cooking, paraffin was used despite the numerous complaints about the disadvantages of using paraffin. They disliked paraffin because it smokes and the smoke stings their eyes and makes them choke. Yet they used paraffin, despite disliking it, because it was available and cheaper and it served the purpose of cooking, especially when there was no need for space heating. Moreover, residents raised concerns that paraffin burnt down shacks in the townships which led to the loss of life and property of the affected. Wood was not predominantly used due to its scarcity, the perceived inconvenience of going to collect wood and the said lack of time to do so. LPG was also unpopular because it was perceived to be expensive and dangerous as inhaling it may lead to death.

4.1.2 Coal Burning

Amount of Coal Burnt

The township households that burnt coal did so mainly in winter, primarily for space heating, but also for cooking. Winter coal burning occurred in 60 % and 58 % of the households in Doornkop and KwaGuqa, respectively. These numbers declined significantly during summer (Table 4.3) with most summer coal burning being associated with cooking.

Table 4.3: The percentage of township households in Doornkop and KwaGuqa showing seasonal coal consumption patterns

Average Number of Bags/Month (1 bag = 70 kg)	Doornkop		KwaGuqa	
	Summer %	Winter %	Summer %	Winter %
2	8	34	13	12
5	4	22	6	21
8		4		7
11				8
14				1
Van (~500kg)				9
Total	12	60	19	58

As expected, households in KwaGuqa burnt more coal than those in Doornkop on a monthly basis as shown in Table 4.3. There are several reasons for this. Firstly, KwaGuqa Township is close to the coal mines and, as a result, the people from KwaGuqa Township can afford to buy coal directly from coal yards at the mines (where coal merchants also buy their coal) as they can buy a van-load at a time. This finding is in accordance with that of Qase *et al* (2000) that township households within a distance of 150 km from coal mines burn more coal than those located further away. Secondly, the price of coal could be another factor contributing to the difference in the amount of coal used between the two townships as, during the winter of 2004, a bag of coal cost R27 in KwaGuqa and R35 in Doornkop. It would be expected, therefore, that people would buy more coal where it is cheaper. Thirdly, average ambient temperatures were lower in KwaGuqa (16 °C) than they were in Doornkop (17.5 °C) in the winter of 2004, which is in line with other studies that, when it is cold, township households usually burn more coal (Mathee and von Schirnding, 2003).

The results showed that during winter 46 % of township coal-burning households burn 140 kg of coal per month; 43 % burn 350 kg of coal per month; 11 % burn 560 kg of coal per month; 8 % burn 770 kg of coal per month; 1 % burn 980 kg of coal per month, and 9 % burn ~500 kg of coal per month. On average each coal-burning township household burns about 170 kg of coal per month during winter. That is, 55 % of households in Doornkop burn an average of 170 kg of coal per month and 57 % of households in KwaGuqa burn an average of 170 kg of coal per month during winter.

Availability of Coal

A key societal dimension explaining the persistent use of coal is the role of coal supply networks. As a consequence of burning coal in township households for decades, several coal-supply networks were established. The coal-supply networks still function well today (2005) and are one of the reasons it has been difficult to phase out coal. It was observed during the questionnaire survey phase of this study that coal merchants sell bags of coal door-to-door in the townships and their coal yards are situated within the townships. A similar observation was made by Qase *et al* (2000), which was that coal merchants sell bags of coal door-to-door in the townships. This makes it easy for township households to buy coal in large quantities, even for those in townships located far away from coal fields (like Doornkop), as it eliminates the burden of carrying heavy bags of coal over long distances. Coal merchants also made life easier for coal-burning households by agreeing to sell coal in 20-litre buckets to those that cannot afford to buy bags of coal, which is another incentive for burning coal. This finding attests to that of Energy Research Centre (ERC) (ERC, 2004) which found that, among poorer households, the most important criteria affecting people's choices of fuel use are the affordability and availability of different energy options. People have found it easier to use coal because it is affordable and available.

Social Acceptability of Coal

Coal has been used for decades in South African township households, therefore, they have learnt and adapted to a 'coal lifestyle' where they use coal to supply their

energy needs for cooking and space heating. They employ coping strategies to deal with the problems of burning coal. It is difficult for them, therefore, to switch entirely away from coal use, as coal is what they have known over the years as an energy source. It would, therefore, require a possible change in attitude before the residents switch from coal to an alternative energy source. This would still be hard to achieve, however, because people have a good experience with coal, which is that, whenever they make a coal fire, they get the results that they expect – warmth – and they can also cook on their coal stoves. Furthermore, coal users have failed to believe reports which state that coal smoke affects their health because they use coal and cannot see any direct effect from it. This mistrust of reports about the negative impacts of domestic coal combustion is another reason that people have continued to burn coal.

It was found in this study that first-hand environmental experiences are a significant influence of people's perceptions and behaviour as stated by Rogan *et al* (2005). The respondents generally spoke about coal based on their coal-using experience. They preferred making household coal fires for heating and cooking in winter to using any other energy source – including electricity. This occurred despite reports that health impacts of household fuels caused by exposure to pollution are significant problems for poor communities in South Africa (Spalding-Fecher, 2005). It would be difficult, therefore, to convince coal users that coal combustion affects people's health adversely as they said they use coal and have not seen any adverse health effects. For instance, a resident of KwaGuqa stated:

“I have worked in coal mines and burnt coal in my house all my life. Now I am a pensioner and I still burn coal in my house. I have never had health problems because of coal combustion so it cannot be true that coal combustion affects people's health.”

Although some respondents had previously observed that respiratory ailments increased in winter, they could not link those increases to coal smoke. One woman said:

“The frequency of my son’s asthma increases in winter because of the low temperature and because all sicknesses are prevalent in winter, which is normal.”

This failure to link the prevalence of respiratory ailments in winter to coal smoke presents a problem. This could mean that the health impacts of domestic coal combustion may not be recognised by the people living in the townships. How then does one go about convincing such people that coal smoke affects people’s health adversely? The answer to this question is the key solution required for people to switch from coal burning in their homes. The biggest challenge, though, remains providing a competitively priced alternative fuel with the same heating properties as coal and one that offers less pollution.

The results, thus far, show that coal remains the prominent and preferred source of energy for thermal purposes in many township households. The disadvantage of using an electric heater was said to be that:

“One has to sit next to the heater to feel the warmth but still the electric heater warms the feet only, unlike coal that warms the whole house. When the electric heater is switched off, everyone is cold again.”

According to Scorgie *et al* (2003b), various electrified households continue to use coal for space-heating purposes, particularly due to its multi-functional nature that supports cooking and heating purposes. The results of this study support the findings of Scorgie *et al* (2003b). However, it was found that the main reason for coal burning is that coal is what the people have known over the years to burn when it is cold in order to keep warm. As some respondents remarked:

“Amalahle sikhule ngawo [we have used coal since we were small children] and our parents have always used coal. We have never had problems... electricity just came.”

When it is cold, the first thought the people had was to make coal fires as several respondents stated:

“Coal is best when it is cold.”

Consequently, people will not give up coal burning because it is logical to make a coal fire when it is cold.

Moreover, the role played by coal in township households goes beyond just heating and cooking. Indirectly, coal also seems to support educational goals in the lives of its users by enabling children to perform better at school. For instance, one woman said:

“I have to make a coal fire in the house when it is cold. My children cannot do homework when it is cold in the house... it must at least be warm.”

Despite these attributes, the use of coal remains costly to the users because of the potential adverse impacts on health which impacts on the quality of life, productivity and incomes since people have to spend a significant portion of their incomes on medical bills. However, people’s perceptions play a major role in the domestic use of coal as the people believe that “coal is best”. Findings here appear to concur with those in other cases – in China and India, for instance. Despite a reported inefficiency of coal stoves, 71 % of Chinese households continued to burn coal in 1990 (Bach and Fiebig, 1998). In India, where 81 % of all households rely on unprocessed solid fuels, 3 % use coal and 78 % use biomass fuels. Respiratory ailments due to the use of these polluting fuels are believed to increase the national burden of disease in the country (Smith, 2000).

4.1.3 Alternative Energy Sources

During the questionnaire survey, the respondents were asked if they would use an alternative fuel to coal if it was available. Most coal users said they would not buy low-smoke fuels because they do not think that there is anything wrong with coal. This was particularly the case in KwaGuqa where some respondents were unwilling to discuss any alternative fuel to coal. This finding could be attributed to the ready availability of coal in the area. At least a quarter (28 %) of all 200 households under

study said they would buy low-smoke fuel if it burnt longer than coal, produced less smoke than coal and produced the same amount of warmth that coal produces. Households that do not burn coal because they dislike it said they would not buy low-smoke fuel as they do not use solid fuel. However, according to some households, talking about whether or not they would buy low-smoke fuel was pointless as they “had not ‘seen’ this low-smoke fuel”. They would need to “see and test” low-smoke fuel first before they could discuss whether they would buy it. This concurs with findings obtained from a study conducted by the Energy and Research Institute (TERI) (TERI, 2000b) in India that the introduction of a technology or fuel needs first to be seen before it is accepted by a community. In their study (TERI, 2000b) new technologies to reduce emissions from domestic fuel use were well received after the villagers had seen a pilot study in nearby houses in their villages and had seen the advantages of using those new technologies.

In terms of the health impacts of low-smoke fuel, people perceived that the suffocation associated with smoke when making a coal fire would be eliminated if they used low-smoke fuel. This presents an opportunity to replace coal if the low-smoke fuel can meet the demands of society. However, aggressive campaigns would be needed to show people that the alternative fuels are at least as good as, or better than, coal. The biggest condition though was whether low-smoke fuel would be “warmer” than coal and could burn as long as coal does. Any alternative fuels would need to be affordable and easily accessible. It was concluded, therefore, that affordability is an important determinant of the types of fuels that people utilise.

4.1.4 Affordability

Studies have shown that above all it is poverty that condemns 2.4 billion people (more than a third of the world’s population) to cook and heat using dirty solid fuels (WHO, 2004). They cannot afford to cook and heat with cleaner fuels (such as gas and electricity) hence they burn what they can find. In South Africa, studies have revealed that poor households cannot afford to use electricity for cooking but only for lighting and media (ERC, 2004). Terblanche (1994) stated that poverty and rapid urbanisation have an impact on choice and affordability of energy sources.

This was true for this study as well as respondents stated that they could not afford to cook and heat with electricity. They could not afford because they form part of the low-income groups with an average household monthly income amounting to approximately R3 721.00 in 2001 in Kwaguqa (IDP, 2007) and approximately R1 000.00 in Doornkop (Roux and Vahle, 2002). They further complained that coal was also too expensive. One woman from KwaGuqa said:

“Coal is expensive... it should be cheap here because it is mined here. It should be R15 a bag.”

Another said:

“My husband does not want us to burn coal because it is expensive, it costs R27 a bag. LPG is better.”

These quotes clearly show that some people in the township cannot afford to use coal despite it being the cheapest energy source. Tables 4.4 and 4.5 show the number of electrified households, their employment status and the amount of money spent on electricity.

Table 4.4: Electrified households, their employment status and money spent on electricity units in Doornkop

Electricity Units per Month (R)	Total No. of Households (n=100)	Employment Status			
		Employed	Unemployed	Pensioner	Self-Employed
0-50	32	13	14	1	4
51-100	27	19	6	2	0
101-150	7	5	1	0	1
151-200	4	4	0	0	0
201-250	2	2	0	0	0
>250	3	0	1	0	2

Table 4.5: Electrified households, their employment status and money spent on electricity units in KwaGuqa

Electricity Units per Month (R)	Total No. of Households (n=100)	Employment Status			
		Employed	Unemployed	Pensioner	Self-Employed
0-50	4	1	2	1	0
51-100	13	0	6	6	1
101-150	14	6	3	4	1
151-200	11	2	5	4	0
201-250	4	2	1	1	0
>250	41	21	12	8	0

In Doornkop most people (32) could only pay for electricity units in the range of R0 - R50, whereas in KwaGuqa the majority of people (41) could afford to buy electricity units for more than R250 per month. The number of people buying electricity units in the said categories does not seem to be affected by employment status as it is true for employed and unemployed people. The possible reason again is the difference in the general economic status of people in the different townships, with KwaGuqa having a better economic status than Doornkop (SuperCROSS, 1993-2006). A summary of the employment status and the amount of money that households spend in buying electricity units is presented in Table 4.6.

Table 4.6: Summary of electrified households, their employment status and money spent on electricity units in Doornkop and KwaGuqa

Electricity Units per Month (R)	Total No. of Households (n=200)	Employment Status			
		Employed	Unemployed	Pensioner	Self-Employed
0-50	36	15.1%	23.5%	7.1%	36.4%
51-100	40	20.4%	17.6%	28.6%	9.1%
101-150	21	11.8%	5.9%	14.3%	18.2%
151-200	15	6.5%	7.4%	14.3%	0%
201-250	6	4.3%	1.5%	3.6%	0%
>250	44	22.6%	19.1%	28.6%	18.2%

In South Africa, poverty is directly linked to unemployment (UNDP, 2000). It was expected, therefore, that unemployed people would not be able to afford to pay for electricity. However, the fact that 19.1 % of unemployed respondents could afford to buy electricity units of more than R250 per month indicates that even unemployed people could buy more electricity units. This is in line with theories of the energy ladder, that energy expenditure occupies a prominent place in poor households' economies (Eberhard and van Horen, 1995). It was a matter of setting priorities as the households that spent R250 on electricity would rather pay for electricity first and let other issues come after that. It seemed that even if people indicated electricity was expensive they could still afford to pay for it, at least for lighting and entertainment purposes. Electricity received a general preference in terms of lighting.

4.2 PEOPLE'S PERCEPTIONS PERTAINING TO DOMESTIC FUELS

4.2.1 Electricity versus Coal Burning

Coal burning is a strong cultural attribute in township households and has several social and familial attributes. Coal burning has become a common practice and the social organisation in the house has also become prevalent. According to 83 % of the respondents in both study areas, coal burning brings their families together. Township households value sitting together in coal-fire warmed houses (Hoets,

1994). In the study conducted by Hoets (1994) in the township of Evaton, also in South Africa, it was found that families valued sitting together in their coal-fire warmed houses.

Despite the 'social' benefits of coal burning, electricity was seen to offer a better life. Electricity was preferred for lighting, fridges, ironing and entertainment (television and radio) but not for cooking and space heating. As one respondent said:

“Coal is for space heating and electricity is for ironing and lighting.”

A similar finding was made by Scorgie *et al* (2001) in the townships of eMbalenhle and Qalabotjha in South Africa. Scorgie *et al* (2001) stated that according to the respondents, electricity was cheaper and, therefore, households used electricity for lighting and entertainment. The households also stated that electricity was very expensive when compared to coal for cooking, heating water, ironing and particularly for space heating. Consequently, Hoets (1994) concluded that electrifying households may not solve the problem of township pollution since township households use electricity only for activities that draw low amounts of power like lighting and entertainment (television and radio) but still burn coal for cooking and space heating. This finding was particularly true for the communities in this study.

Perceptions of Economic Impacts of Coal Burning

Another societal dimension of coal versus electricity is the economic costs and trade-offs between energy sources. Respondents said it was cheaper to burn coal than to use electricity because they saved money by burning coal. Residents said coal burns for a long period of time and it keeps the whole house warm, unlike an electric heater that keeps only the feet warm and, once switched off, the house is cold again. The burning of coal for space heating is perceived as a positive economic impact against using electricity for space heating. According to the respondents, electricity is expensive. One respondent stated:

“Every January the price of electricity units increases and the number of units in the cards decreases... electricity is becoming more expensive.”

This was seen as a negative economic impact and the biggest disadvantage of electrification. Township households expect that Eskom would charge them less for the use of electricity because they have ‘an economically disadvantaged’ background.

According to Eskom pricing documents (Eskom, 2006), pricing structures differ between large and small customers’ supplies and also in terms of what specific service is required. Township households fall under the “home light tariff”, which is a cash payment only tariff and is the cheapest available. On the contrary, Bond and Hallows (2002) stated that low-income households pay higher electricity prices than large bulk consumers (like mines and mineral smelters) due to the higher cost of supplying electricity to households, implying that the home light tariff is not the cheapest available. According to Eskom, however, the home light tariff is applicable to single-phase supplies in areas designated by Eskom as urban or high-density areas (such as townships). The home light tariff has different energy rates based on the supply capacity required and it provides for a subsidy to low-usage customers. One would expect, therefore, that township households would be able to afford to use electricity for all their energy needs. However, the opposite is true as stated by Fiil-Flynn and Greenberg (2002), that the per-unit price of electricity is too high for low-income households compared to disposable income. As a result, township households tend to consume less electricity than anticipated (Fiil-Flynn and Greenberg, 2002; Spalding-Fecher, 2005) and continue to burn coal for space heating or utilise paraffin for cooking.

One of the Eskom stakeholders interviewed believed that township households that continue to burn coal do not understand that the amount of heat energy released per kilowatt hour by electricity is higher than that released by coal. It was stated that in parts of the townships that have been electrified for more than 10 years, households no longer burn coal because they have understood the full benefits of using

electricity. That is, using electricity is cheaper than using coal in terms of the amount of heat energy released.

Saying that township households burn coal because they do not understand the full benefits of using electricity is, however, not true. This statement underestimates the social value of a coal fire in township homes and other reasons for coal burning. The statement also indicates that Eskom stakeholders do not fully understand and appreciate the social values of their customers – households. Moreover, it indicates that township households may not know the environmental costs of burning coal, yet interviews with them revealed that they do. This lack of common understanding between Eskom and households has been demonstrated in the past and it was reported by ERC (2004) and Spalding-Fecher (2005). For example, electricity consumption in newly electrified township areas was lower than expected by Eskom. As a result, electrification has been said to be unsustainable because of the low consumption in many areas that does not cover operation costs (Fiil-Flynn and Greenberg, 2002; ERC, 2004). Electricity is generally seen as an important step in socio-economic development (ERC, 2004) and township households want their houses to be electrified, however, they cannot afford to use electricity for cooking and heating.

Eskom: Perceptions and Goals Pertaining to Domestic Coal Combustion

Eskom stakeholders that were interviewed acknowledged that one of the worst air pollution problems in South Africa is indoor air pollution resulting from domestic coal combustion in the townships. They said if township households stopped burning coal and switched completely to electricity it would help to reduce air pollution. Electricity production, however, does not eliminate the environmental cost of air pollution. It transfers the cost of pollution from stacks in power stations to somewhere else and to somebody else. Although the pollution from stacks can be transported to other places by air transport patterns (Tyson and Preston-Whyte, 2000), such pollution is better controlled than indoor pollution from domestic coal combustion and it has less of an effect on people's health (Spalding-Fecher, 2000) because of the high elevation at which the emissions are released and it can be

measured. Reducing domestic coal combustion in the townships would solve the problem of air pollution more than cutting air pollution from stacks. Consequently, there is a huge drive by the DME and Eskom at present (2005) to electrify households.

Electrification has been funded by the DME and not Eskom since April 2001. The mass electrification programme was initiated to relieve backlogs in the townships and rural areas that resulted from the inequitable distribution of modern energy sources which occurred during apartheid governance in South Africa. Nevertheless, the Eskom Distribution Division still carries out the actual work in non Metro-serviced areas. During the interviews, stakeholders stated that over 200 000 households a year are being connected to the national electricity grid with over 70 % of homes now on the grid.

It is one thing to supply electricity and it is another for people to actually use the electricity provided. Eskom provides electricity but cannot make people use it. Eskom officials stated:

“Another big problem is the lack of understanding of the use of electricity. Electricity releases more heat energy per kilowatt hour than coal, which makes coal more expensive to use as a fuel for heating than electricity.”

According to Eskom stakeholders, if township households understood this, the households would rather use electricity.

Results of this study have shown that the township people respond to the heat output of coal burning and affordability and they do not care about the kilowatt hour output which seems not to heat their rooms fast and well enough. Eskom officials believe that the township households that continue to burn coal have been provided with electricity only recently, indicating that households that have had electricity for a long time (>5 years) no longer burn coal. This assumption seems to be contrary to actual practices, as the results of this study have revealed that township households continue to burn coal no matter how long they have had electricity. Fiil-Flynn and

Greenberg (2002) stated that this makes electrification in South Africa unsustainable since households do not utilise the electricity supplied.

4.2.2 Perception of Coal

The questionnaire administered attempted to evaluate the perception that people have about the health effects of burning coal in their homes. Results showed that the reason for the ongoing usage of coal in households is largely influenced by people's perceptions about the advantages and impacts of coal combustion and the compelling need to keep warm given their present economic means.

Nearly half (47 %), of respondents (Figure 4.1) said inhalation of smoke from coal – particularly during the ignition of the fire – affects people's health by causing suffocation and headaches. They were referring to the immediate effects of inhaling coal smoke just after lighting a coal fire. Only 2 % in Doornkop and 3 % in KwaGuqa said coal smoke could have chronic effects on human health. This could possibly suggest that the people are uninformed about the probable chronic effects of burning coal in enclosed environments or that they did not fully understand the question. This finding is unlike that found in a study conducted by Luginnah *et al* (2002) in Oakville, Ontario, where respondents' concerns for long-term health impacts of air pollution outweighed more immediate ones (such as visible smoke emissions). The failure of coal users to link long-term health impacts to coal smoke make it difficult to phase out or to regulate the use of coal. People would need to be convinced of the benefits of phasing out the burning of coal that could improve their health prospects. The biggest challenge, however, would remain providing an alternative fuel at an affordable price.

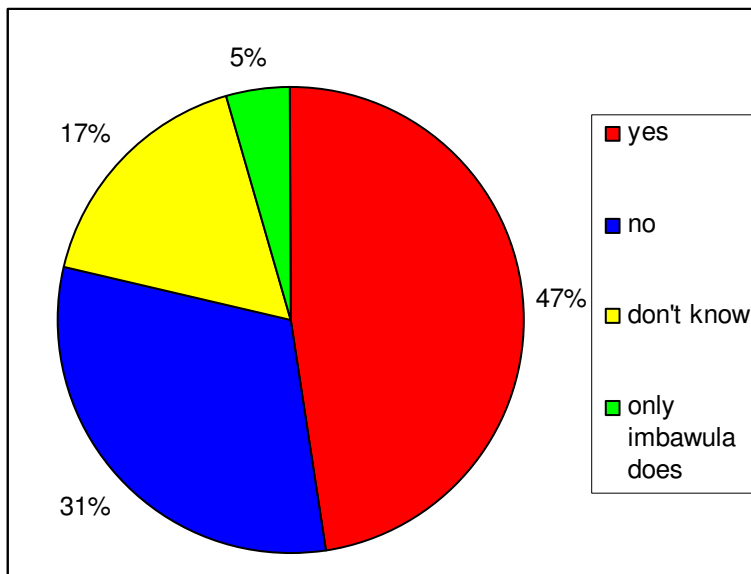


Figure 4.1: Responses given by respondents in Doornkop and KwaGuqa when asked if coal smoke from domestic coal combustion affects people's health

Almost half (46 %) of the respondents (Figure 4.2) that said coal smoke causes suffocation were referring to their first-hand experiences with coal as they themselves burn coal. They said coal smoke is suffocating during ignition (if one inhales the smoke) and causes headaches and coughing. Despite suffocation during ignition of coal fires, township dwellers continue to burn coal. It would seem that township dwellers have developed a tolerance for coal smoke. Interestingly, 34 % of respondents that burn coal said coal smoke did not affect people's health and 14 % said they did not know that coal smoke affected people's health. This finding shows that township dwellers are uninformed about the health impacts of domestic coal combustion. More households (50 %) that do not burn coal said coal smoke affects people's health but they were also referring to coughing and choking at ignition. Some of households gave this as the reason they stopped utilising coal. Some did not use coal because they dislike it as it makes their houses dirty. Some said they would burn coal if they had coal stoves, while others covered themselves with blankets for warmth when it was cold.

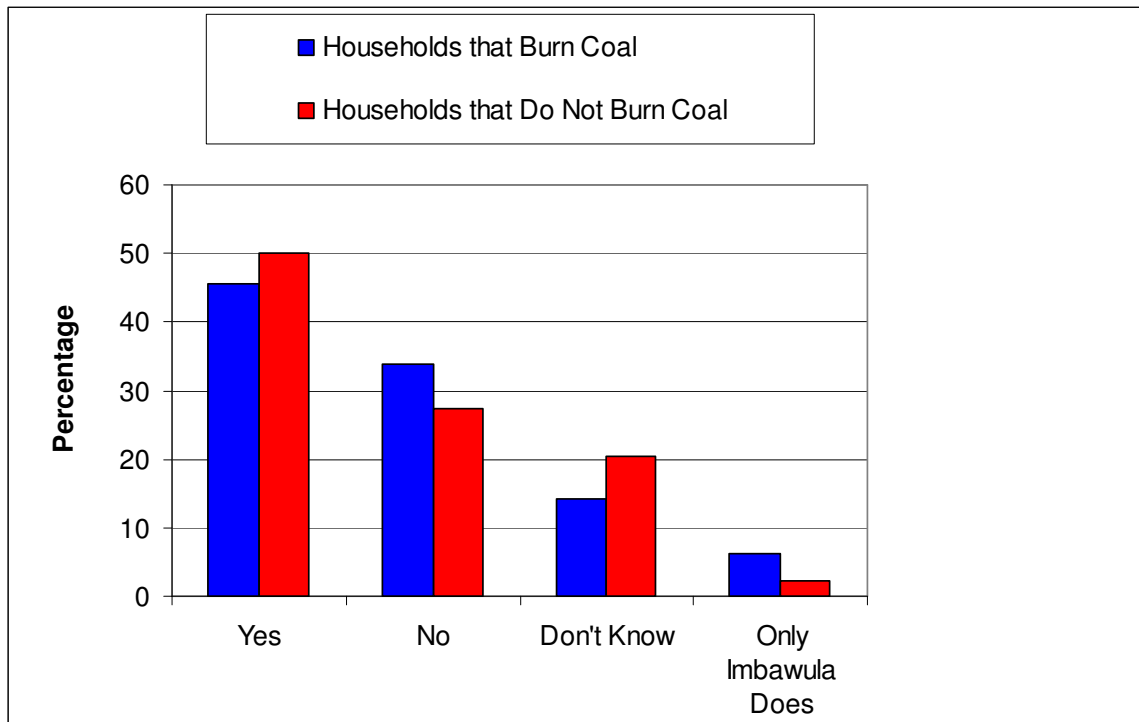


Figure 4.2: Responses of township households when asked if coal smoke affects people's health

According to Scorgie *et al* (2003a) it is evident that interventions which target domestic fuel combustion are likely to be associated with the most significant reductions in respiratory-related hospital admissions and premature mortality. However, based on the findings of this study, there is little evidence that domestic coal combustion causes respiratory-related hospital admissions as there were very few reports of hospital admissions due to respiratory illnesses. More so, in 69 % of the households (Figure 4.3) no people were identified as having respiratory ailments. It is understandable therefore, why township dwellers do not think that coal smoke affects their health. One woman said:

“In our house, no one gets sick from coal”.

The difficulty in determining immediate versus lagged health impacts is not an easy one to resolve. In a study conducted by Oosthuizen *et al* (2004), for example, it was revealed that air pollution concentrations that are detrimental to human health affected the population under study about 13 years after they lived in an air-polluted

area. It is well known (Dockery *et al*, 1993; Annegarn and Sithole, 1997; Annegarn *et al*, 1998; Finkelman, 2000; Scorgie *et al*, 2001) that domestic coal combustion releases significant air pollution that is detrimental to human health. This could mean, therefore, that the human health impacts of domestic coal combustion are lagged in some of those township dwellers with no respiratory ailments.

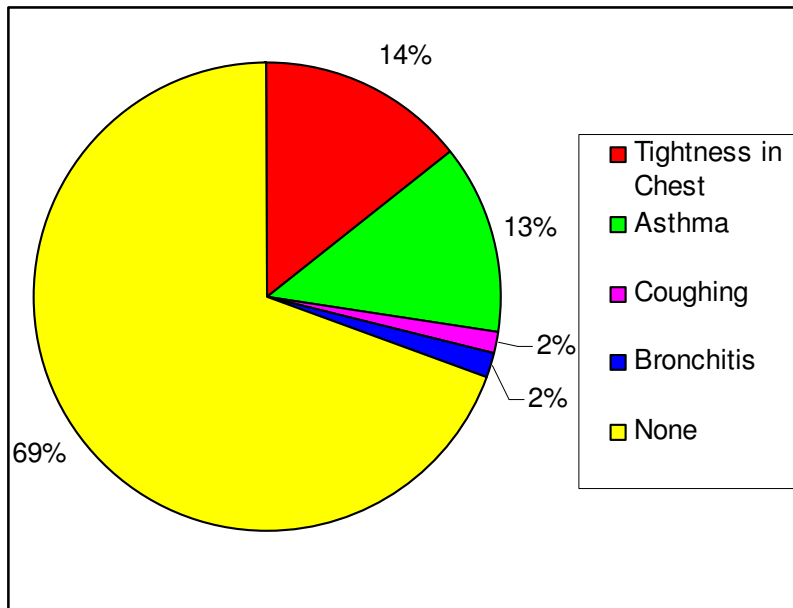


Figure 4.3: Percentage of households with respiratory ailments in Doornkop and KwaGuqa

Untangling the reasons for persistent coal burning in township households is complex. As indicated in Figure 4.2, almost half of the respondents perceive a coal-related health risk. The perceived health risk, however, is short-term. Coughing and choking, for example, were cited problems linked to coal-smoke inhalation during the ignition stage of a coal fire. The respondents said once the coal fire was lit and the initial smoking phase was over there was no health risk, and, when probed further, many cited other contributing factors that also aggravated their health. As seen in Figure 4.4, unemployment, livelihood occupation and poverty also emerge as key factors determining the health of households (Oosthuizen *et al*, 2004).

Although a significant percentage of the households had heard either from radio, television or from their children (who are told at school) that coal smoke has chronic effects on people's health, they still did not believe those reports as they have not 'seen' or experienced health problems. They failed to link their 'illnesses' to coal smoke, yet previous studies have revealed that there is a link (Terblanche *et al*, 1993; WRI, 1999b; Smith, 2002; Scorgie *et al*, 2003a; WHO, 2004; Spalding-Fecher, 2005). For instance, 14 % had family members suffering from tightness in their chests (Figure 4.3), yet they still did not think that it was because of the coal smoke. Of households that actually had people suffering from respiratory ailments, 75 % had observed that the frequency of their ailments increased in winter. They said, however, the frequency increased in winter because of the cold in the winter months (June to August) and did not implicate coal smoke. One respondent said:

“Asthma is his disease and it has got nothing to do with coal smoke.”

Only 8 % of the respondents in Doornkop said the occupants of their houses who had respiratory ailments could be affected by both coal smoke and low temperatures, whilst 2 % from KwaGuqa said the occupants of their households got sick because they were affected by emissions from the neighbouring industries. Some of the occupants of the selected households who had respiratory ailments had not observed any differences with varying seasons. Figure 4.4 shows the percentage of people who had respiratory ailments and their different age groups. The highest (40 %) were children (age 0 to 10 years), which is in agreement with the report of Matooane *et al* (2004) and WHO (2005) that respiratory illnesses resulting from inhaling coal smoke in domestic environments are high amongst children because they spend most of their time at the domestic hearth. The elderly (age >50 years) also had a high percentage (12 %) of members with respiratory ailments because they also spend most of their time at the domestic hearth (WHO, 2005).

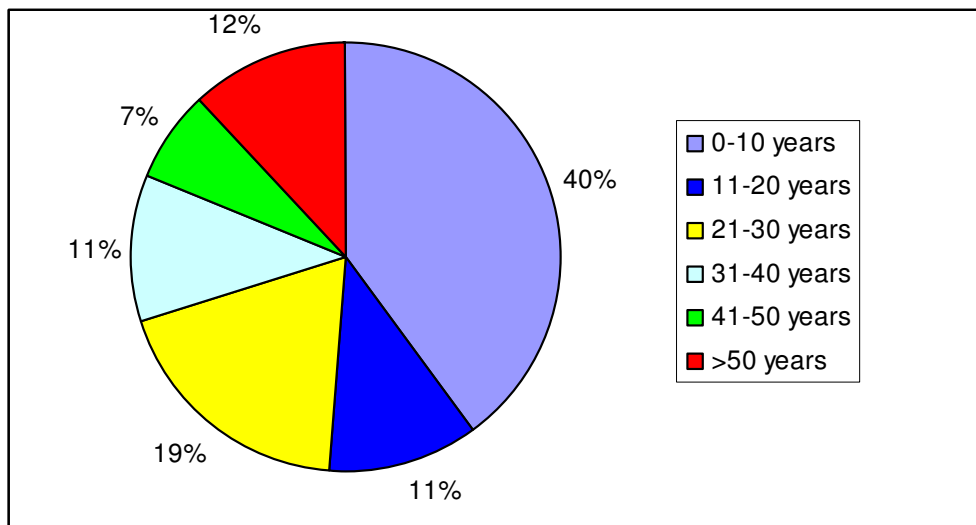


Figure 4.4: Ages of people suffering from respiratory ailments in the townships

Results also showed (Figure 4.4) that the age group with the second highest percentage (19 %) of members with respiratory ailments was the age group 21 to 30 years. Most people in the age group 21 to 30 years are unemployed; this finding could mean that they spend a lot of time at the domestic hearth: as much as the infants and the elderly. Moreover, in a study conducted by Oosthuizen *et al* (2004) it was indicated that young adults (age 23 years) showed an increase in lower respiratory ailments (such as bronchitis, pneumonia and asthma) due to factors such as lifestyle and the fact that they had previously lived in the Vaal Triangle (until they were 10 years old). This also showed that domestic coal smoke does not affect people immediately – a number of years passed before the people demonstrated obvious health effects. A similar observation could be made in this study by assuming that people in the age group 21 to 30 years had spent their developing years in the townships.

4.3 THE MULTI-FACETED SOCIETAL DIMENSIONS OF DOMESTIC COAL COMBUSTION

4.3.1 Emerging Patterns

Patterns of fuel use were observed in this study to test the concept of the energy ladder. Two main patterns of fuel use were observed. The first pattern, outlined below, is used by all township households (Figure 4.5) and it can be used to explain the pathway that an energy source would follow when made available for use in the townships. The main factors of this pattern that determine whether the introduction of a fuel will be successful are user-satisfaction and affordability. User satisfaction determines whether or not the people are going to continue to use that fuel. If the fuel satisfies their needs, they accept it and, if not, they stop using it. After accepting a fuel, affordability then influences ongoing usage of that fuel. This observation is in line with the concept of the energy ladder, described in Chapter 2 of this thesis, that affordability determines whether a population group would use an energy source or not (Bruce, 2002). If the people cannot afford to use a fuel they stop using it and if they can afford it they use it fully. In some cases, one finds that they can afford to use the fuel sometimes or for certain energy needs and fail to do so when there is a lack of financial resources. This then leads to partial use of the fuel in question (Figure, 4.5). An example of a partially-used fuel in township households would be electricity. As reported earlier in this chapter, many township electrified households cannot afford to use electricity for all their energy needs; hence they use it for lighting and entertainment and use either coal or paraffin for cooking. This trend, however, contradicts the concept of the energy ladder which depicts a linear move up the ladder and not multiple or partial fuel-use.

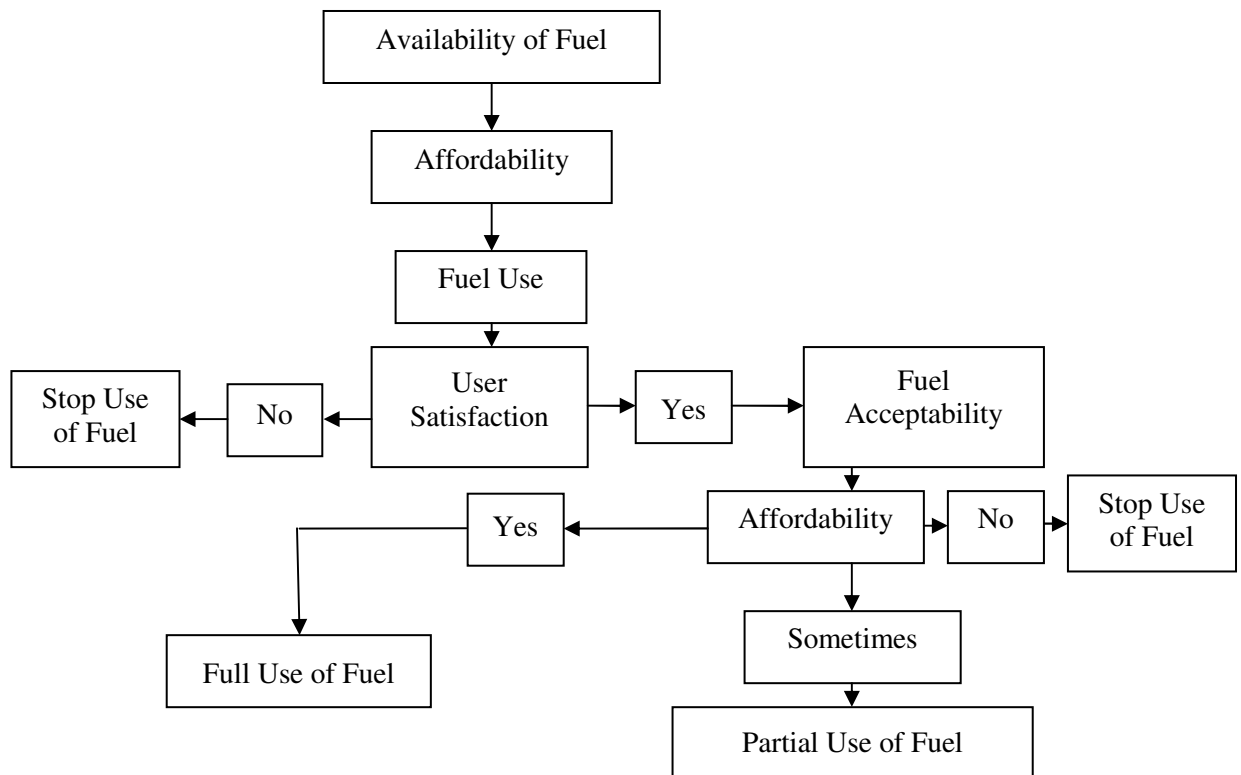


Figure 4.5: A pattern of fuel use that was observed to be followed by township households in this study

The second pattern observed, that confirms earlier research (e.g. Terblanche *et al*, 1993b; Hoets, 1994) was that of coal use as coal was the predominant source of energy for heating and all other fuels were used around coal. Actual coal use, however, was observed to follow a different pattern (Figure 4.6). This is due to the historical reasons for coal usage in the townships as outlined earlier in this thesis. As a consequence of the historical lack of fuel choice in townships, the first step in the coal-use pattern became the availability of coal. That is, respondents would start with coal before they could consider any other energy source. For instance, the disadvantages of using electricity, wood or LPG for heating were viewed against the advantages of burning coal. The use of coal, due mainly to its availability, is in line with WHO (2005) findings that poor people burn any fuel that they can find.

In the coal-use pattern identified in Figure 4.6, the main features are the availability of coal and the demand of society to keep warm or to cook. The next step is the use of coal followed by user satisfaction. If the community is satisfied by the services that coal offers they then accept coal and continue to use it. According to the respondents, however, there have been awareness campaigns in recent times in the media to educate the people about the long-term adverse impacts of domestic coal combustion (shaded grey in Figure 4.6). These campaigns, however, fed into the perceptions of the coal users. This has led to the ongoing use of coal where the people did not believe that coal burning could affect their health in the long term. It may also lead to a desire to switch to 'cleaner' alternative fuels. A summary diagram putting together a fuel-use pattern followed after the people desire to switch from coal to alternative fuels has been suggested (Figure 4.7).

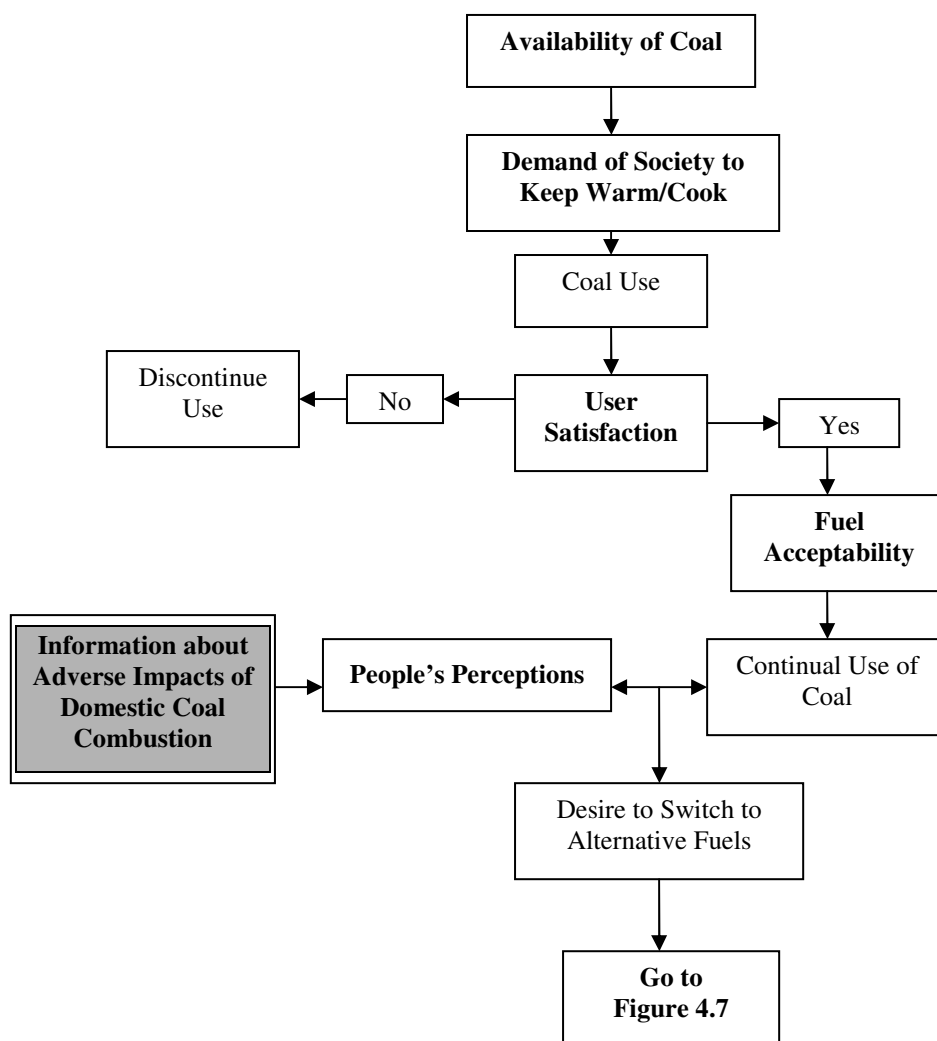


Figure 4.6: A pattern of coal use that was observed to be followed by township households in this study

In Figure 4.7, the main features are the availability of alternative fuels, the actual use of the alternative fuels and affordability. Once the people have desired to switch from coal, it is pertinent that the alternative energy sources be readily available. If these alternative energy sources were supplied to the communities, possibly by government as a pilot project, the next step would be their use. If, however, the alternative energy sources were available to be purchased by the communities, affordability would be the determining factor as to whether or not they would use the alternative energy sources. The affordability of coal would then influence the use of alternative energy sources. Depending on affordability of the alternative energy sources, a pattern similar to that outlined in Figure 4.6 is suggested. Where

the communities could use the fuels, they would be in a better position to test whether or not the energy sources satisfy their needs, and thus it is suggested the pattern would follow as outlined in Figure 4.5.

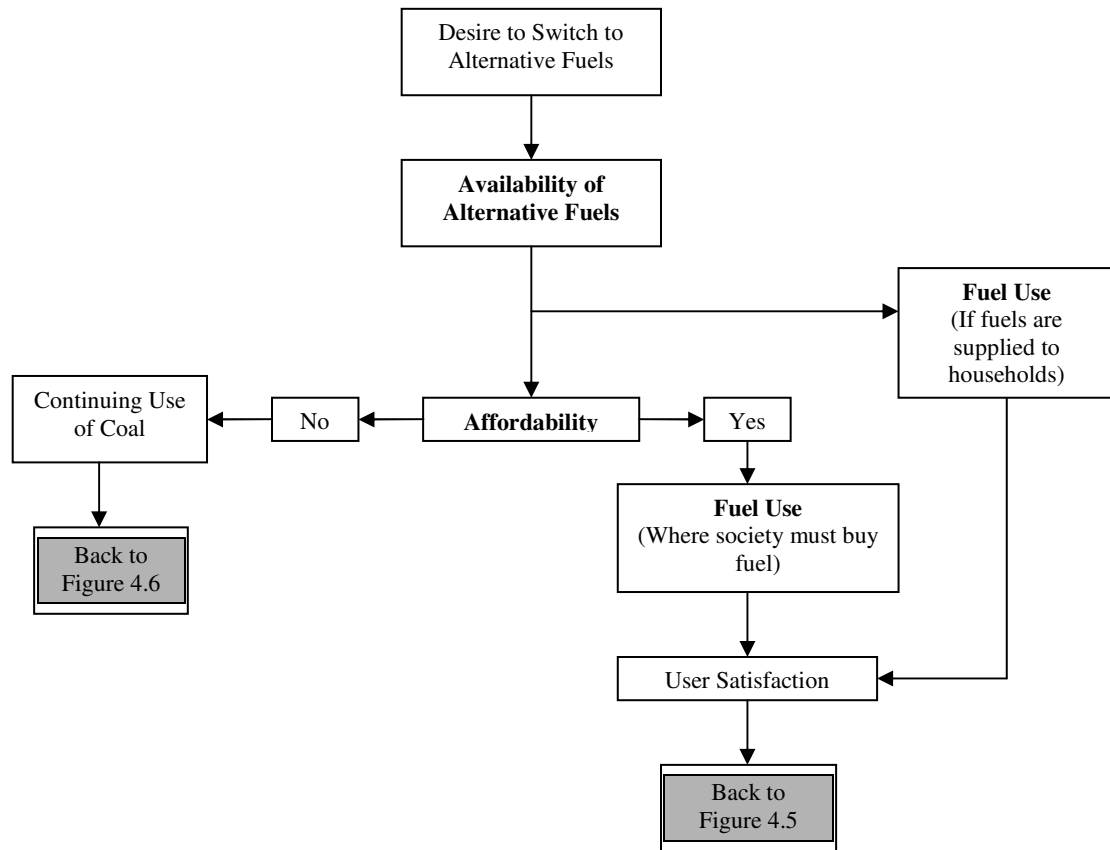


Figure 4.7: A summary diagram of possible future fuel-use patterns derived from observations in township households in this study

4.3.2 Conclusion and Linkage to the Energy Ladder

Energy sources of choice are not always accessible either because they are unavailable or people cannot afford them (Mehlwana and Qase, 1996). Electricity can, therefore, be said to be inaccessible to township households who cannot afford to use it and to those that are not yet electrified. In this study, electricity was found to be underutilised in many township households because it is too expensive for people to enjoy its benefits since townships are regarded as low-income or poor

areas (Hoets, 1994; Mehlwana and Qase 1996; Scorgie *et al*, 2001; Spalding-Fecher, 2005).

In earlier assessments there was no electricity supply (Terblanche, *et al*, 1993b; 1994). During the course of this study, however, most households already had electric appliances. This is contrary to the conclusion by Hoets (1994), who asserted that the township households did not use electricity because they did not have electric appliances. Township households, however, did not use the appliances because of low incomes and inability to pay for services (Figures 4.5, 4.6 and 4.7). Mehlwana and Qase (1996) stated that people's use of appliances depends on whether they can afford to buy them, or at least to buy the fuels they require. Most households could afford to buy the appliances but could not afford to purchase the electricity units to be able to use them. Some un-electrified households had purchased electric appliances in anticipation of receiving electricity in their houses. Nevertheless, Mehlwana and Qase (1996) highlight that it is accessibility of fuels that is a major influence on appliance use. Un-electrified households, therefore, could not use their electric appliances. The availability of electric appliances (even in un-electrified households) shows that the lack of electric appliances is not the reason people do not use electricity and that there are other reasons for this.

The findings of this study concur with the concept of the energy ladder that energy provides little or no utility in its own right, but is used by people to fulfil a number of different needs or to provide services such as lighting, space heating and cooking (Eberhard and van Horen, 1995). Consequently, the people were attached more to what the energy sources provided rather than to the energy sources themselves. The importance of an energy source was, therefore, linked to the perceived greatness of the energy need. That is, if the population perceived the need to keep warm as highly essential, the fuel that they would utilise to keep warm became the most important requirement at that given time. Finally, it was poverty and overall livelihoods that determined the type of fuels used and whether there can be movement up the energy ladder.

* * * * *

In Chapter 4, a discussion and analyses of findings from Doornkop and KwaGuqa have been presented. The main findings were that:

- Multiple fuel use is a common pattern in township households,
- Coal-burning is mainly conducted for space heating but also for cooking in both electrified and un-electrified households,
- The availability of coal led to the social acceptability of coal and the establishment of coal supply networks that are still functioning and supporting domestic coal combustion. These coal supply networks are part of the reason it has been difficult to phase out domestic coal combustion in township homes as they increase the convenience of burning coal in township homes,
- Affordability is the main factor determining the types of fuels used and the ability to switch to alternative energy sources,
- People believed that coal is good for space heating, electricity is good for lighting and that coal burning does not have chronic health effects – that it has only short-term health effects.
- Chapter 4 has also provided an overview of the patterns of fuel use in the townships. Finally, the findings of the study mirror those of the energy ladder. In Chapter 5, the results and discussion obtained by aerosol monitoring at KwaGuqa in August 2004, as well as an estimate of population exposure to aerosol pollution, are presented.

CHAPTER 5:

RESULTS: INDOOR AEROSOL MONITORING IN KWAGUQA

This chapter presents the results and discussion of the indoor aerosol monitoring that took place in KwaGuqa during August 2004. Comparisons with PM₁₀ standards are made, as well as analyses of the relationship between aerosol concentrations and ambient temperature. The elemental analysis of PM₇ in the township is also presented. Finally, an estimate of population exposure to PM₇ pollution is provided.

5.1 DIURNAL PATTERN OF INDOOR AEROSOL CONCENTRATIONS

Aerosol concentrations (PM₇ respirable dust) were monitored continually in three households during August 2004. Of the four (4) selected households, one (1) was un-electrified and burning coal, two (2) were electrified and burning coal and the last one (1) was electrified with no coal burning. The results presented here, however, are from three (3) households as the aerosol monitor installed in the second electrified and coal-burning household was destroyed by a power surge after a power failure on 11 August 2004. Despite the fact that not all the households used coal directly, the PM₇ concentrations followed the same trends (Figure 5.1). The household that used coal as the only energy source generally had the highest PM₇ concentrations. The electrified coal-burning household, however, showed only a slight reduction in PM₇. These results agree with those of Rollin *et al* (2004) who found un-electrified houses to have significantly higher PM₁₀ concentrations than electrified houses; however, they found that dwellings that used mixed fuels (electricity and solid fuels) had the greatest proportion of respirable particulate matter. These results are important as they show that unless a significant change in coal combustion is encouraged throughout the townships, the impact of

electrification on air quality might be limited or even insignificant – a sentiment that is backed by Terblanche *et al* (1995) and Matooane *et al* (2004).

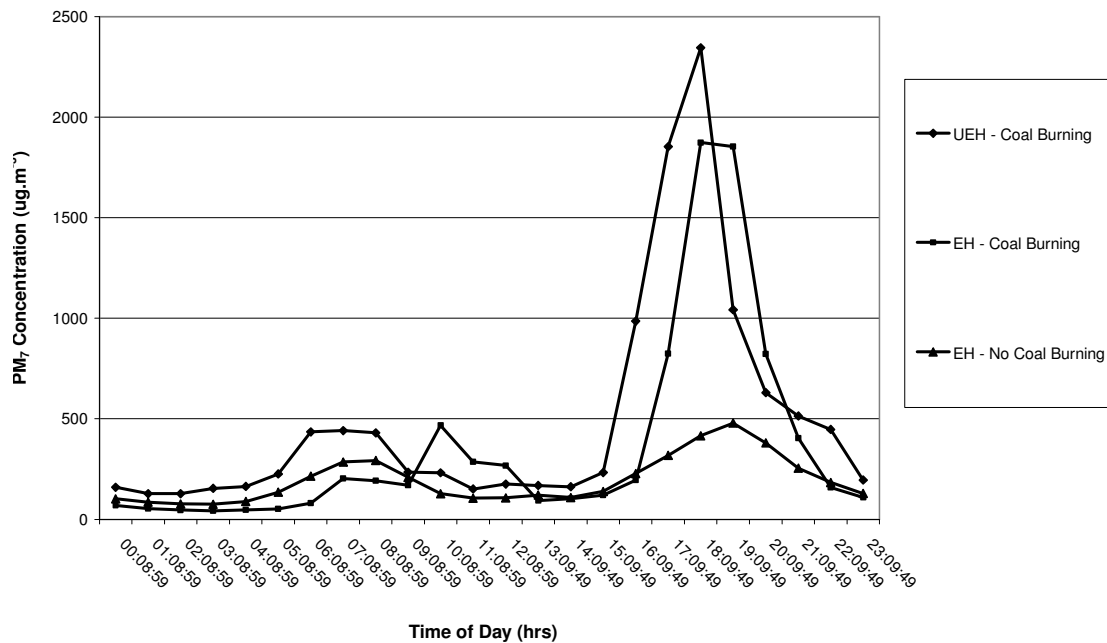


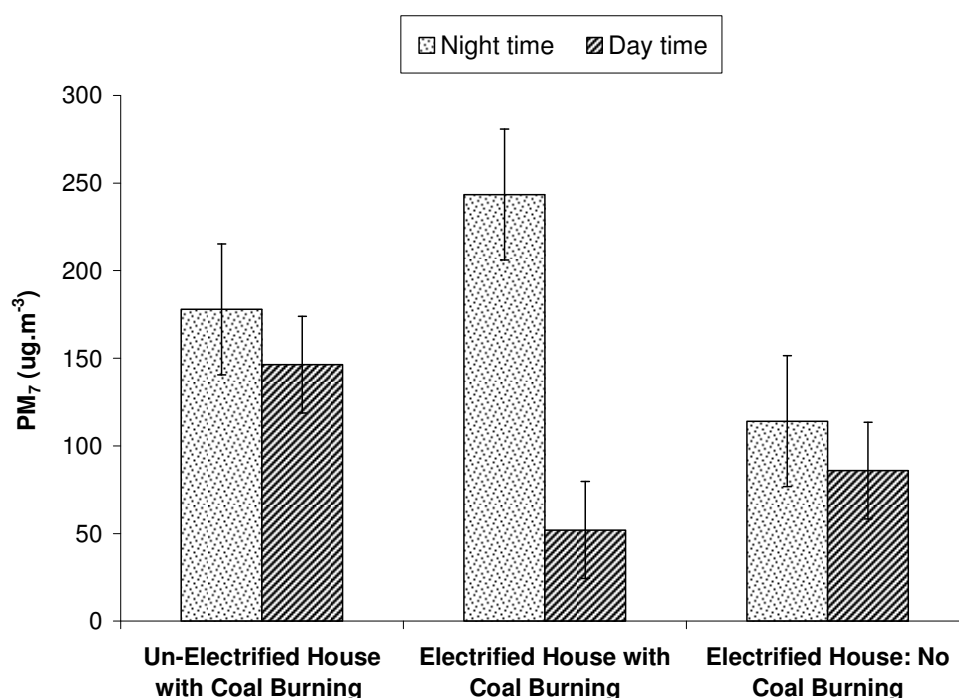
Figure 5.1: Average diurnal pattern of PM₇ in KwaGuqa (August 2004) in the four (4) different households, where “EH” is an Electrified House and UEH is an Un-Electrified House

PM₇ concentrations in the non coal-burning electrified house were regarded as representing ambient levels in the township as there is no significant direct source of PM₇ inside the non coal-burning electrified house but only a contribution from adjacent coal-burning households. Several studies in urban slums have shown that indoor air is affected by ambient air contamination (Smith *et al*, 1994; WHO, 2000) and townships are no exception. Notably, ambient aerosol concentration trends were similar to the other households during the night and early morning (Figure 5.1). This shows that ambient aerosol levels in the township rise and decrease with rising and decreasing indoor concentrations in coal-burning households.

During the afternoon and early evening, as PM₇ levels increased dramatically in the coal-burning households (reaching 2344.89 $\mu\text{g.m}^{-3}$ in the un-electrified house and

1854.07 $\mu\text{g.m}^{-3}$ in the electrified house), ambient concentrations were much lower (with a maximum of 478.74 $\mu\text{g.m}^{-3}$). This clearly shows the major contribution that coal-burning households have in the township in general. Although ambient PM_{10} levels are lower than indoor PM_{10} levels in this study, they are still significant as WHO (2005) stated that aerosol concentrations affect human health even below 100 $\mu\text{g.m}^{-3}$. It can be concluded, therefore, that township residents were all at a high risk of contracting respiratory illnesses associated with exposure to particulate matter during this study, whether or not they burnt coal in their houses.

A mass distribution of aerosol concentration shows that higher concentrations of aerosols occur at night-time compared to daytime in all the households, although there were differences between the households (Figure 5.2). This was due to the higher aerosol concentrations recorded during night-time. The highest night-time mass distribution aerosol concentration occurred in the electrified household that burns coal, whereas the un-electrified coal-burning household showed the highest daytime values.



Error bars on the graph represent the standard error.

Figure 5.2: Mean daytime and night-time aerosol concentration in electrified and un-electrified township houses

Differences exist in the detailed pattern of PM₇ loading on a daily basis. A few days (5 August 2004 (Figure 5.3), 19 August 2004 (Figure 5.4), and 24 August 2004 (Figure 5.5)) have been selected for more detailed analysis. On 5 August 2004 the PM₇ concentrations were high in all coal-burning households (both electrified and un-electrified). The concentrations increased in the morning between 04:00 and 10:00 and again in the evening between 16:00 and 21:00. These two peaks are related to space heating and cooking for breakfast and dinner. In general, the morning peak is shorter and smaller than the evening peak because people need to go out to work or school soon after getting up. In the evening people return from their daily activities and spend several hours in their houses, cooking and heating the houses before going to bed – thus the longer peak of PM₇ levels.

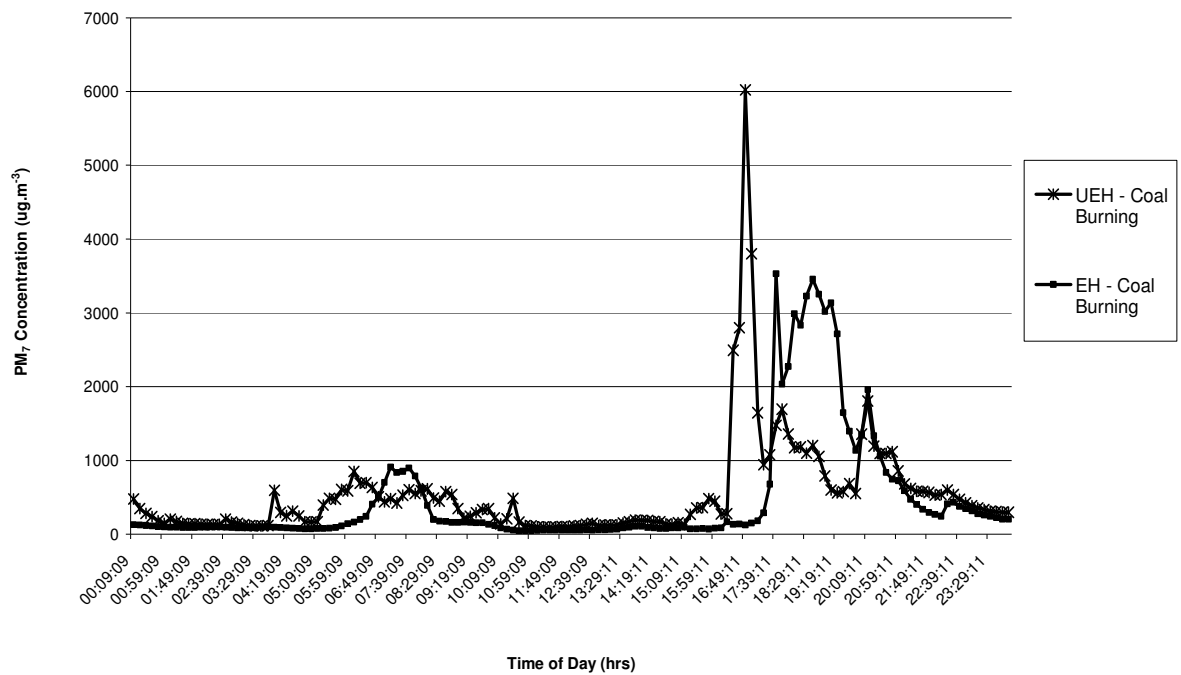


Figure 5.3: Indoor PM₇ concentration in coal-burning households – 05 August 2004, where “EH” is an Electrified House and “UEH” is an Un-Electrified House

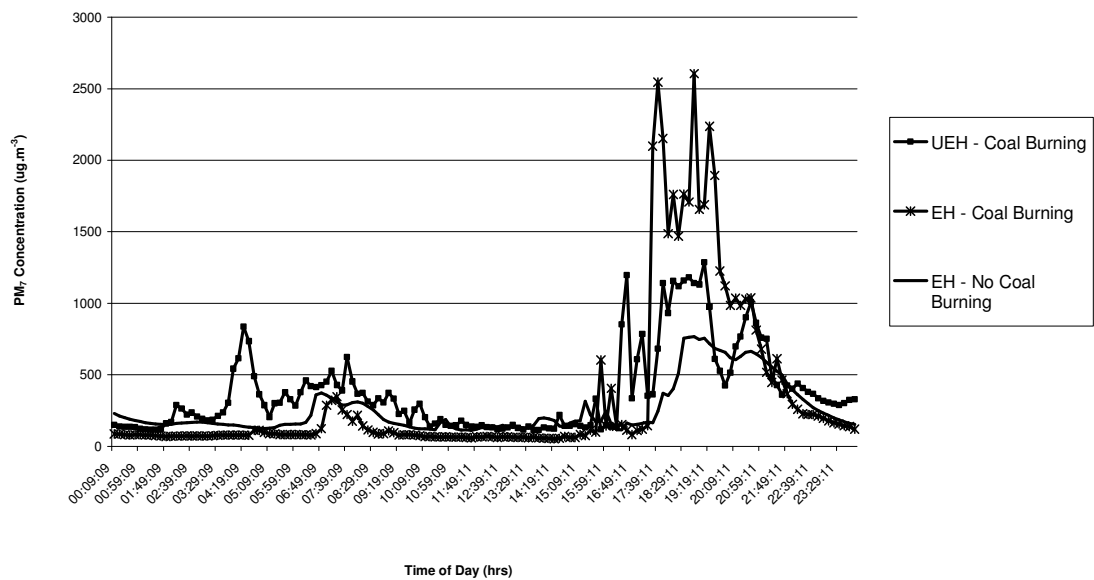


Figure 5.4: Indoor PM₇ concentration – 24 August 2004, where “EH” is an Electrified House and “UEH” is an Un-Electrified House

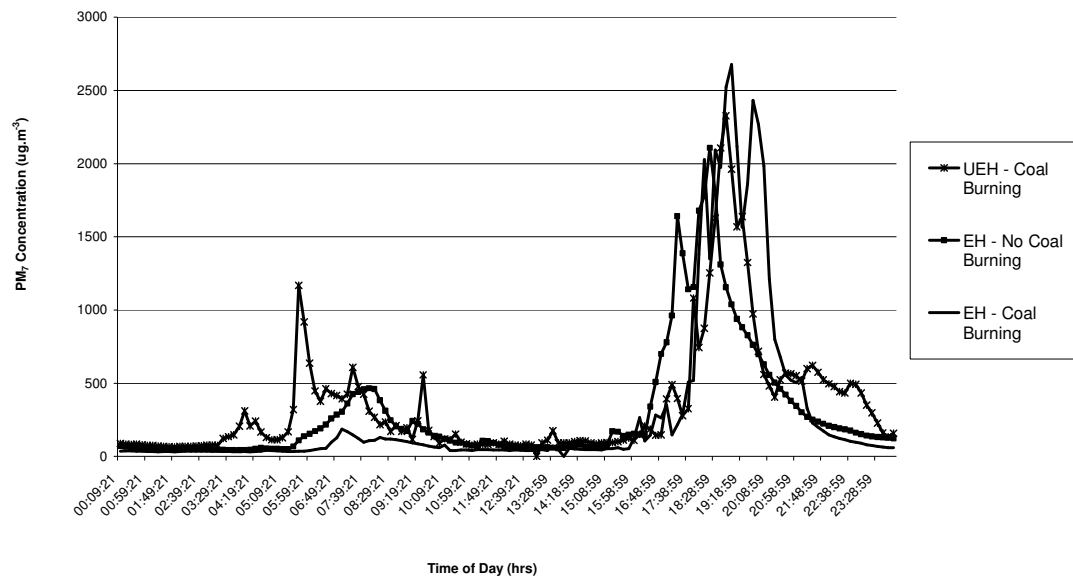


Figure 5.5: Indoor PM₇ concentration – 19 August 2004, where “EH” is an Electrified House and “UEH” is an Un-Electrified House

Measurements recorded on 24 August 2004 showed that PM₇ concentrations were higher in the electrified coal-burning household than they were in the un-electrified coal-burning household (Figure 5.3). This shows that indoor particulate pollution was high in coal-burning households irrespective of whether or not the household in question was electrified. The insignificance of electrification in reducing indoor particulate pollution in coal-burning households in the township is thus demonstrated. Ambient PM₇ concentrations (reflected by the concentrations of the non coal-burning electrified household) increased about two (2) hours after indoor PM₇ concentrations increase (Figures 5.3 and 5.4), which shows that it takes about two (2) hours for individual households to affect the overall PM₇ concentrations of ambient air.

PM₇ concentrations in all households were high on 19 August 2004 (Figure 5.5). Ambient concentrations normally increased approximately two (2) hours after that of coal-burning households (Figures 5.4 and 5.5). However, on 19 August 2004 ambient concentrations in the evening increased at about the same time as the concentrations in the coal-burning households. This shows that there is a general

contribution of indoor PM₇ concentration to ambient PM₇ concentration from coal-burning households in the township and it could mean that other households that had not been selected for the study had already lit their coal fires. The differences between the coal-burning households in the time at which concentrations increased may have to do with the habits of the people in the house, which are differences in the times at which coal fires are made.

Short, sharp peaks of PM₇ are identifiable in all the houses that burn coal, as opposed to the smoother curve of the electrified house that does not burn coal (Figures 5.4 and 5.5). These short peaks are associated with the initial lighting of the fire and then subsequently the adding of additional fuel to the fire to keep it burning. Evidence of these peak emissions after adding fuel or disturbing domestic fires has been well documented by Ludwig *et al* (2003). It is disturbing to note that on 5 August 2004 the peak concentrations reached 6 000 µg.m⁻³ as such levels have glaring health implications (WHO, 2004). Daily averages were 469.72 µg.m⁻³ for the coal-burning, electrified house and 735.38 µg.m⁻³ for the un-electrified coal-burning house. These values are higher than the DEAT PM₁₀ standard of 180 µg.m⁻³ (Government Gazette, 2005) and the US EPA (Scorgie *et al*, 2003b) standard of 150 µg.m⁻³ for a 24-hour averaging time. This finding concurs with the statement by WHO (2005) that indoor smoke can exceed acceptable levels for small particles in outdoor air by two orders of magnitude.

Indoor PM₇ concentrations have not been studied before; however, there have been some studies on ambient aerosol concentrations in other townships and rural areas in South Africa and internationally that also show a dual peak during a 24-hour period. Engelbrecht *et al* (2000) showed a dual-peak diurnal variation of PM₁₀ concentrations in winter was recorded in the township of Qalabotjha, South Africa. Similarly, McKendry *et al* (2004) found that PM₁₀ concentrations increase when domestic burning occurs and decrease significantly as home fires are extinguished in Christchurch, New Zealand. In their study, a shorter morning peak of PM₁₀ concentrations between 07:00 and 10:00 and a major evening peak between 22:00 and 01:00 were also observed as a result of increased emissions from domestic fires at these times. However, the evening peak in their study was also a result of a strong

temperature inversion and low wind speeds and the morning peak was affected by morning traffic. Also, in a study conducted by Funasaka *et al* (1999), the mixing layer played a major role in particulate concentrations as they increased with time during the early morning and decreased with an increase of the mixing layer height. In this study, temperature inversions, wind speed and other meteorological factors affected PM₇ concentrations to a lesser extent because measurements were taken inside the households where the sources (coal stoves) were located. The overwhelming impact on the concentrations came from the indoor source – coal combustion.

5.2 AEROSOL GENERATION AND DISPERSION RATES

Aerosol concentration rate is a change of aerosol concentration over time. Generation rate is the rate at which aerosol levels increase until they reach the maximum. Dispersion rate is the rate at which aerosol levels disperse from the peak concentrations. Observations of the time-dependent trend of daytime indoor aerosol generation (starting from 05:00) and reduction (starting from 10:00) in the various houses were made (Figures 5.6a and 5.6b). It was during these times that aerosol generation and dispersion occurred during the daytime.

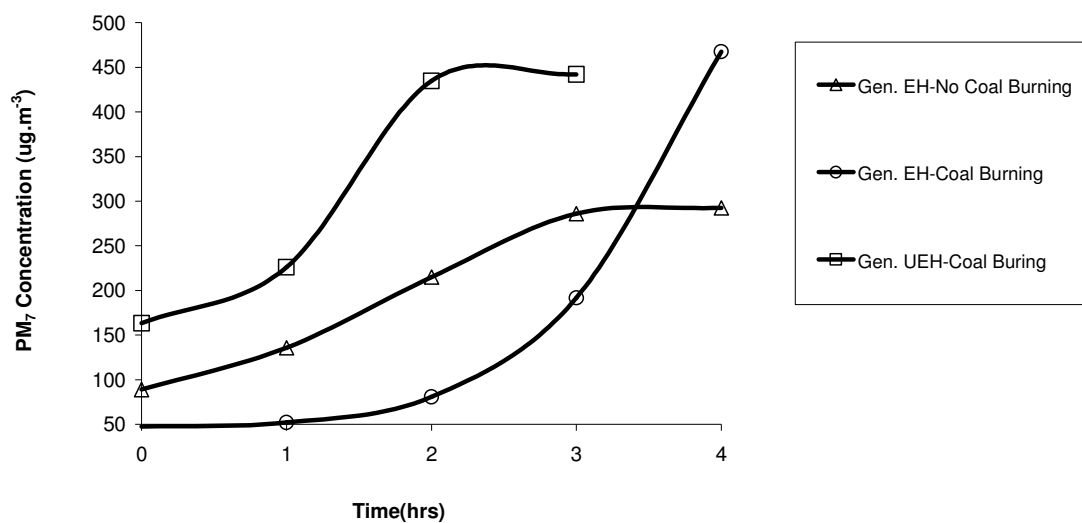


Figure 5.6a: Time-dependent generation of aerosols from coal burning in both Electrified Houses (EH) and Un-Electrified Houses (UEH) in the daytime

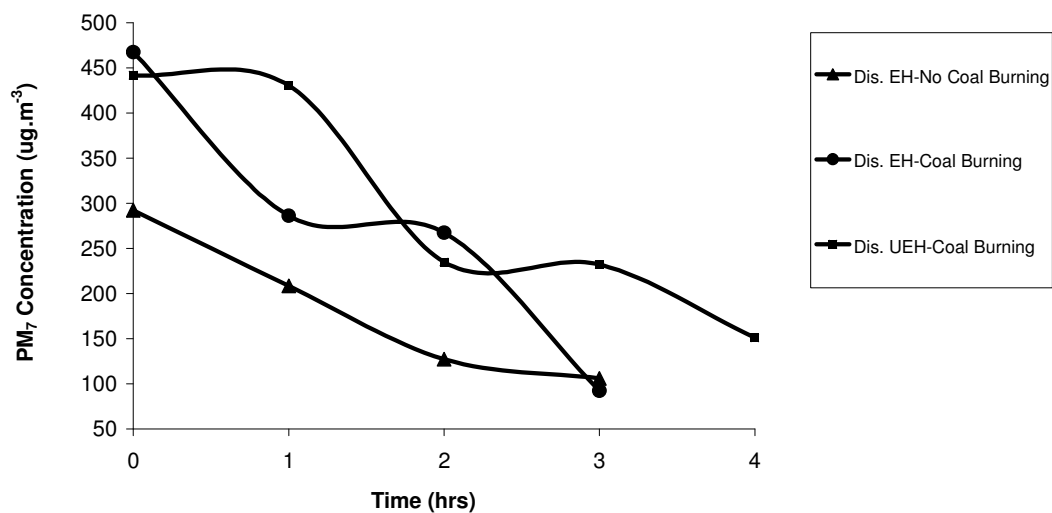


Figure 5.6b: Time-dependent dispersion of aerosols from coal-burning in both Electrified Houses (EH) and Un-Electrified Houses (UEH) in the daytime

It was observed that aerosol generation in coal-burning houses (both electrified and un-electrified), had higher build-up rates than in electrified houses with no coal burning during the daytime. Specifically, aerosol generation in the un-electrified house that burnt coal approached the maximum faster than that in the electrified house that burnt coal, with the exponential growth rate being higher in the former. This could imply that more coal was burnt in the un-electrified house than in the electrified house. Aerosol generation in the electrified household with no coal burning had a linear growth rate and the reduction rate, too, was linear, which was because there was no immediate aerosol source in that house. Aerosol dispersion in the coal-burning households (both electrified and un-electrified) fluctuated. It was assumed that the fluctuations were caused by disturbances to the fires as a result of the addition of fuel (Ludwig *et al*, 2003).

Aerosol generation (starting from 16:00) and dispersion (starting from 21:00) rates during the night-time are shown in Figures 5.7a and 5.7b. During the night-time, the generation rates of aerosols in coal-burning houses (both electrified and un-electrified) were exponential, reaching a maximum within an average of four (4) hours. Unlike during daytime, aerosol generation during night-time had an exponential growth rate in the non coal-burning electrified house. This could be attributed to the quick-peaking higher aerosol concentrations during night-time than during daytime in coal-burning households as they are the major contributors to aerosol concentrations in the said house. However, aerosol dispersion rates were still smoother in the night-time – like they were during the daytime. Again, aerosol reduction in the coal-burning households (both electrified and un-electrified) fluctuated due to disturbances of the domestic fires.

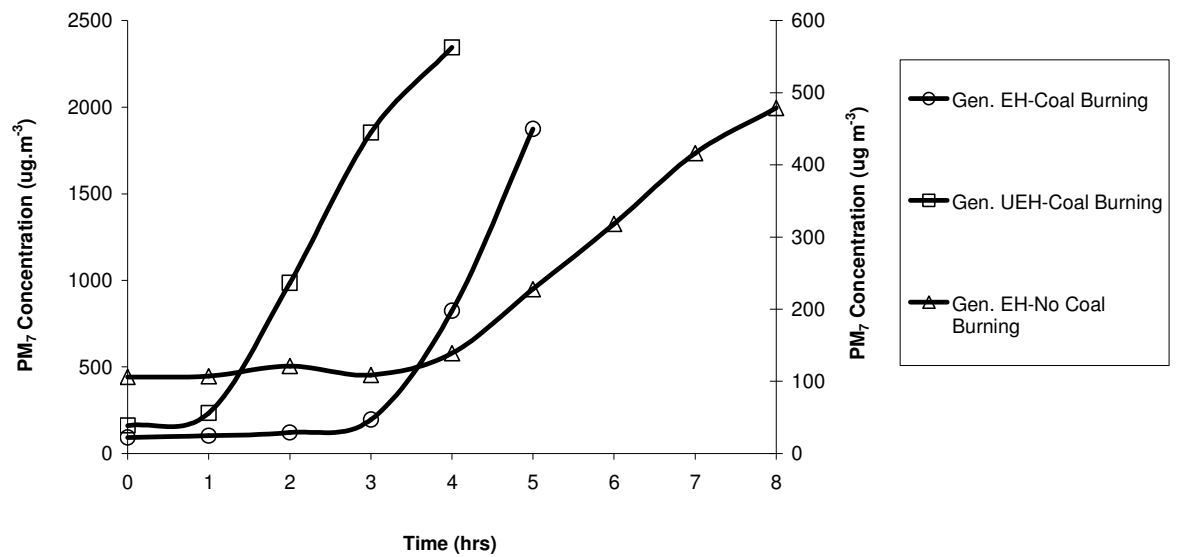


Figure 5.7a: Time-dependent generation of aerosols in both Electrified Houses (EH) and Un-Electrified Houses (UEH) at night-time

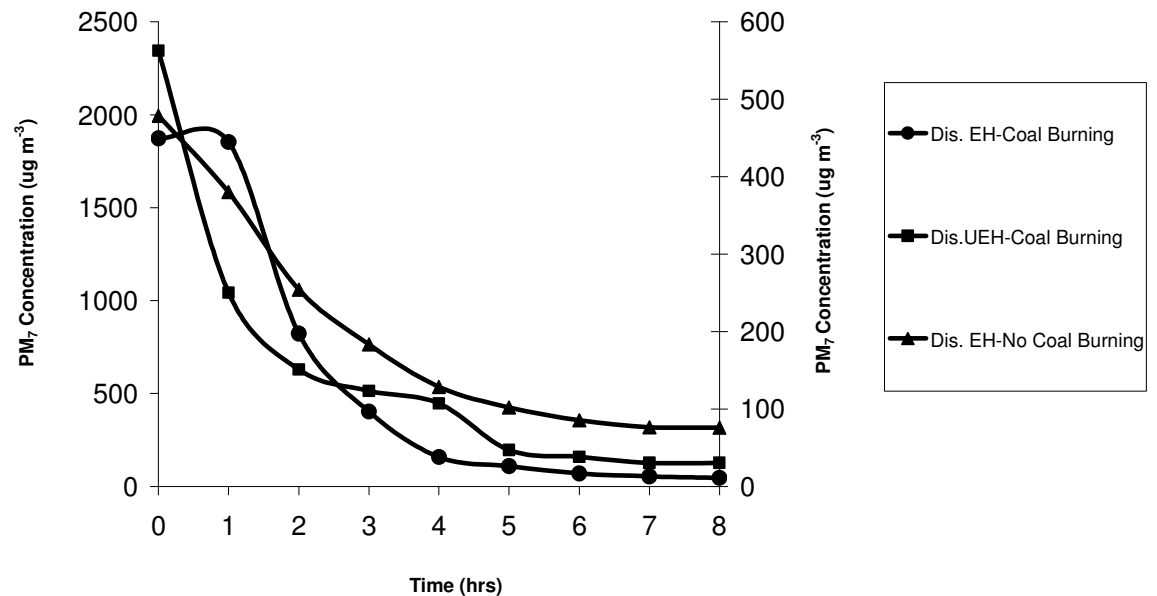


Figure 5.7b: Time-dependent dispersion of aerosols from in both Electrified Houses (EH) and Un-Electrified Houses (UEH) at night-time

5.3 EXCEEDANCES OF DEAT PM₁₀ STANDARD

PM₁₀ includes a wider range of particles than PM₇. Where both PM₇ and PM₁₀ are measured, PM₇ concentrations are expected to be less than the PM₁₀ concentrations as fewer particles fall under PM₇. However, this was not the case in this study, where PM₇ concentrations were frequently above the DEAT PM₁₀ standard of 180 $\mu\text{g.m}^{-3}$ (Government Gazette, 2005), even reaching as much as eight times higher than the PM₁₀ standard (Figure 5.8). A similar finding was noted by Mathee and von Schirnding (2003) who stated that during the cold winter months indoor air pollution levels as well as ambient air pollution levels may exceed health standards. In this study, the concentrations in the electrified household that does not burn coal can be regarded as representing the ambient concentrations in the township. It is essential, therefore, to note that 43 % of the time (during August 2004) ambient concentrations were above the DEAT PM₁₀ daily limit standard of 180 $\mu\text{g.m}^{-3}$. Yet the Government Gazette (2005) states that the daily limit (180 $\mu\text{g.m}^{-3}$) may not be exceeded more than three (3) times in one (1) year. This implies that 47 % of the time (in August 2004) the township residents were exposed to particulate matter that is above the daily limit placing them at a high risk of contracting respiratory illnesses. Hence the high mortality rate in the townships and informal settlements where coal is used for cooking and heating (Doppegieter *et al*, 1998; BNM, 2003).

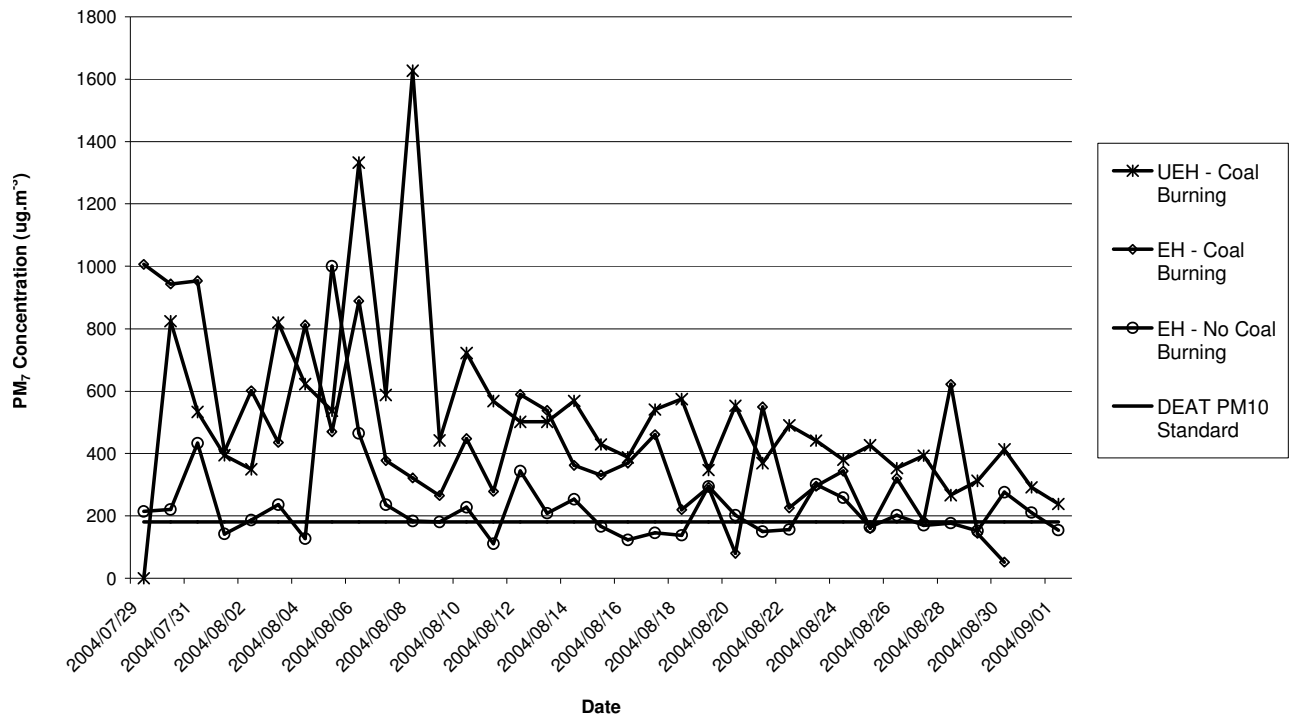


Figure 5.8: Diurnal exceedances of the DEAT PM₁₀ standard, where “EH” is an Electrified House and “UEH” is an Un-Electrified House

Moreover, daily average aerosol concentrations regarded to represent ambient levels exceeded the DEAT PM₁₀ standard by a factor of 10 on 6 August 2004. This finding is in agreement with that of (Doppegieter *et al*, 1998) that daily averages often exceed guidelines by a factor of 10 or more in developing countries. Doppegieter *et al* (1998) stated that such data suggest that tens of millions of people in developing countries are routinely exposed to high levels of pollution leading to a huge estimated toll in disease and premature death. This is true for South Africans living in the townships where these data were collected.

5.4 RELATIONSHIP BETWEEN AEROSOL CONCENTRATION AND AMBIENT TEMPERATURE

During the questionnaire survey, respondents stated that coal burning in the township occurs during winter (May to August) mainly for space heating. It is then

that people cook on their coal stoves. It was expected, therefore, that mean daily PM₇ concentrations would be high when the mean daily temperature was low. Results showed a significant change in aerosol concentration with changes in ambient temperature (Figure 5.9). The daily averages of aerosol generation indicate that aerosol concentration increases with a decrease in ambient temperature as there is an increased demand for indoor heating. In the early part of August 2004, when the ambient temperature was as low as ~8 °C, the amount of aerosols generated was higher compared to aerosols formed towards the end of the month when ambient temperatures rose to ~18 °C.

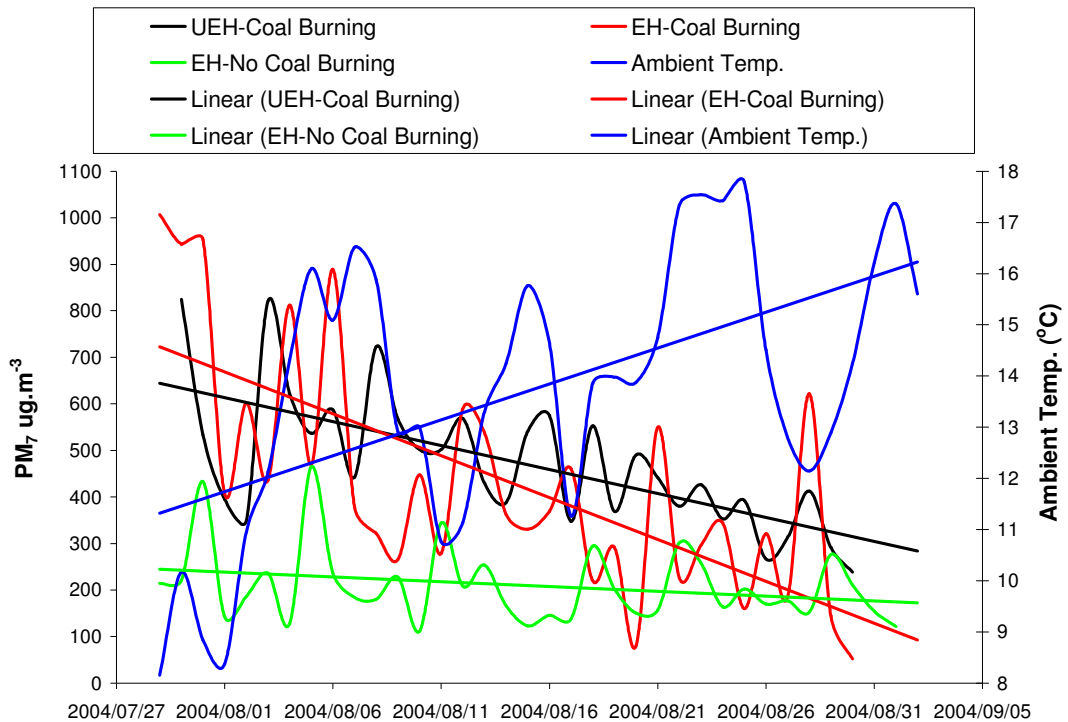


Figure 5.9: A time-series trend of aerosols in relation to changes in ambient temperature obtained from daily mean values (August 2004) in the un-electrified house with coal burning

Although the results showed a significant decrease in aerosol concentration with increases in ambient temperature in all the houses (Figure 5.9), differences exist in correlation analysis results. Spearman's correlation analyses between aerosol concentrations and ambient temperature, showed significant differences between

the households. There was no correlation between aerosol concentration and ambient temperature in the un-electrified house with coal burning ($r^2 = 0.0000$) and the electrified house ($r^2 = 0.0064$); however, there was a negative correlation in the electrified house with coal burning ($r^2 = -0.2421$) (Figures 5.10; 5.11 and 5.12). These results seem to indicate that the households with a single energy source use this energy source for all activities and not just for space heating; therefore, there is no correlation with ambient temperature. In contrast, the coal-burning households that have electricity use coal burning mainly for space heating, as the questionnaires indicate, thus the correlation with ambient temperature. Electrification has, therefore, enabled the household to burn coal only when it is cold – hence less coal is burnt.

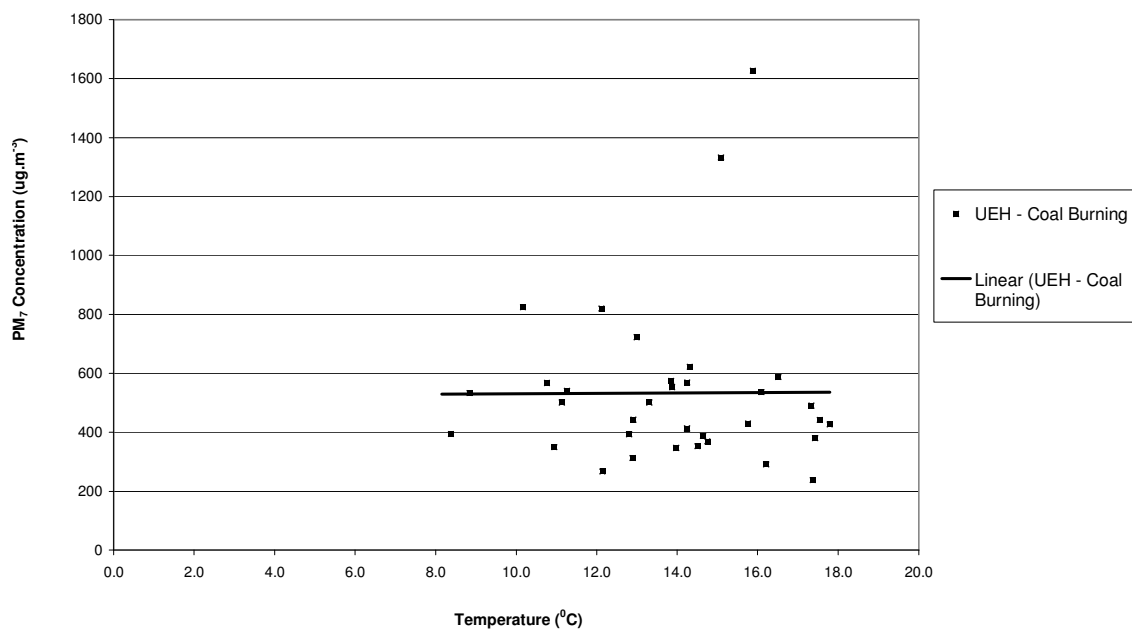


Figure 5.10: A correlation between aerosol concentration and ambient temperature in the un-electrified house with coal burning

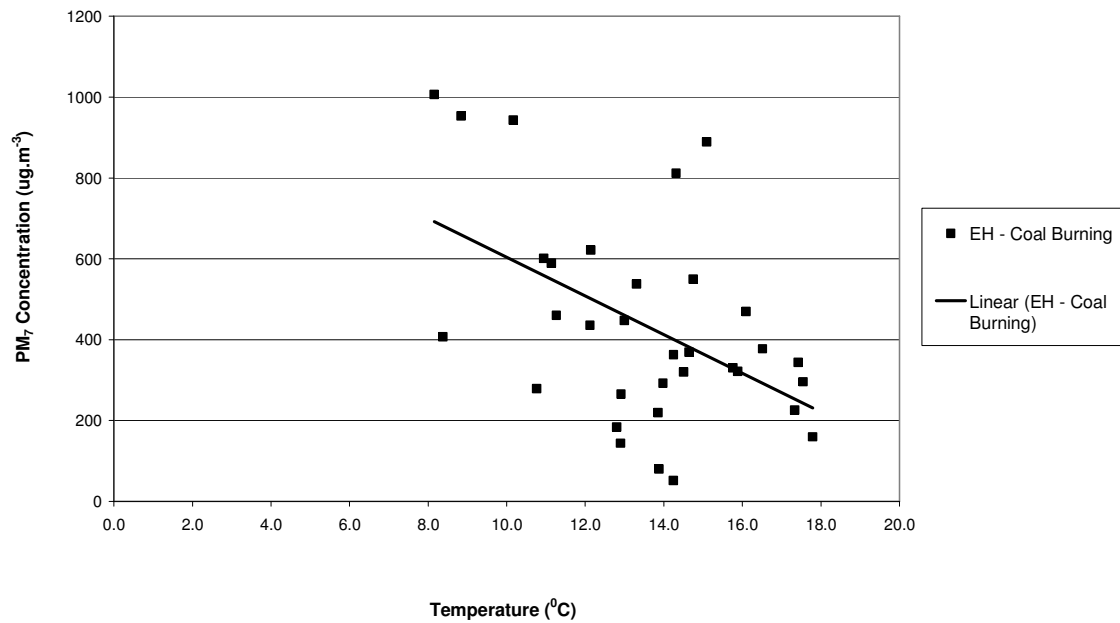


Figure 5.11: A correlation between aerosol concentration and ambient temperature in the electrified house with coal burning

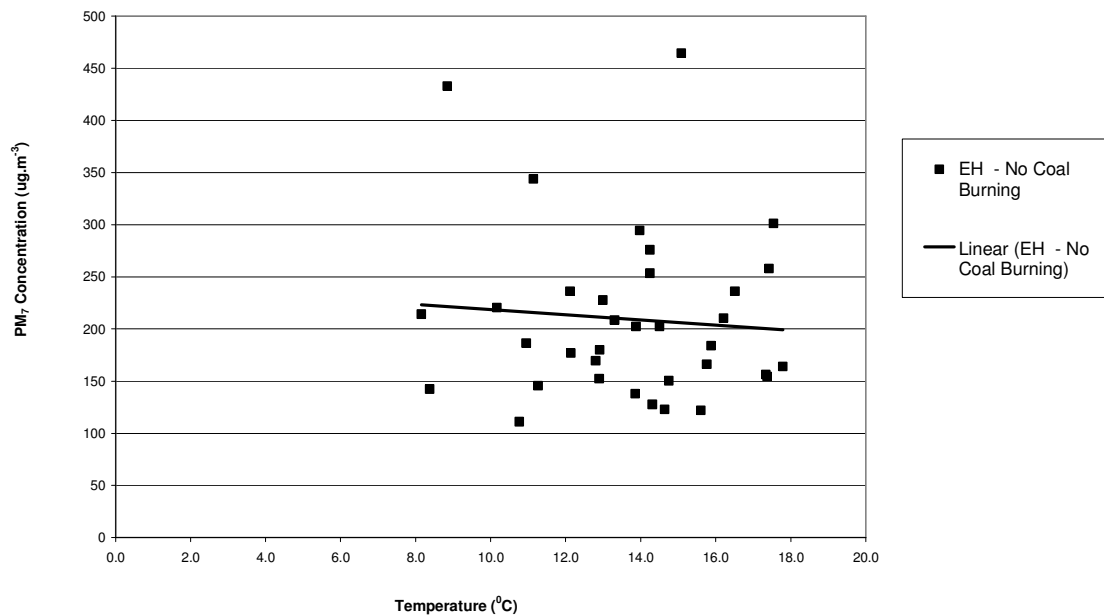


Figure 5.12: A correlation between aerosol concentration and ambient temperature in the electrified house with no coal burning

Indoor PM₇ values should be recorded in a similar study conducted in summer. Indoor PM₇ levels would be expected to be lower in summer but the wider range of

temperatures would enable a detailed analysis of the correlation between aerosol concentration and temperature. However, it is important to note that such a study would have less relevance in summer as it was revealed during the questionnaire survey that township households generally do not burn coal in summer (except for 12 % of the respondents) because there is no need for space heating when ambient temperatures are comfortable. For example, in a study conducted by Terblanche *et al* (1992; 1993a) where seasonal differences in personal exposure to Total Suspended Particulates (TSP) were compared, significantly higher exposures were recorded during winter periods compared to summer. This was attributed to the increased use of coal for space heating during winter and the severe temperature inversions in winter that reduce the dilution and dispersion capability of the atmosphere (Terblanche *et al*, 1993a).

5.5 ELEMENTAL ANALYSIS OF RESPIRABLE PARTICULATE MATTER

5.5.1 Elemental Composition and Source Contributions

The elemental composition of the PM₇ filters collected by personal samplers was determined using PIXE analysis. Spectra were fitted for 10 elements: Al, Si, S, K, Ca, Mn, Fe, Cu, Zn and Pb. Correlation calculations are a convenient and tested tool for source delineation of particulate aerosols (Pandey *et al*, 1998). Therefore, correlation calculations for the identified elements were performed (Table 5.1). Five possible anthropogenic sources of these elements have been identified. These sources are: soil dust, coal combustion, steel smelters, and traffic and wood-smoke emissions. Steel smelters were also considered to be a possible source because there was a steel industry within a distance of 1 km from the township under study.

Table 5.1: Spearman correlation coefficients between elemental concentrations measured by PIXE (correlation coefficients between 0.80 and 1.0 are highlighted in grey, n=19)

Si	1.000								
S	0.581	1.000							
K	0.936	0.637	1.000						
Ca	0.913	0.481	0.821	1.000					
Mn	0.913	0.481	0.821	1.000	1.000				
Fe	0.997	0.576	0.938	0.904	0.904	1.000			
Cu	0.444	0.350	0.488	0.321	0.321	0.437	1.000		
Zn	0.928	0.670	0.937	0.805	0.805	0.931	0.534	1.000	
Pb	0.445	0.638	0.580	0.294	0.294	0.436	0.685	0.591	1.000
	Si	S	K	Ca	Mn	Fe	Cu	Zn	Pb

Silicon (Si) is the main tracer for soil dust (Prati *et al*, 2000; Cyrys *et al*, 2003; D'Alessandro *et al*, 2003; Ho *et al*, 2003). All other elements that strongly correlated ($r^2 > 0.8$) with Si were regarded to be from the same source and they were called “soil elements”. These soil elements are believed to be contained mostly in the aluminosilicate components in natural dust (Cyrus *et al*, 2003). The soil elements were potassium (K), calcium (Ca) and manganese (Mn). The correlation analysis suggests that iron (Fe) and zinc (Zn) were from the same source as Si. Copper (Cu), sulphur (S) and lead (Pb) were not correlated with the soil elements, a finding which suggests that these elements had independent sources. Enrichment factor values, however, suggest that Cu originated from the soil.

Sulphur (S) is the main tracer for coal combustion and lead (Pb) is the tracer for traffic emissions (Saitoh *et al*, 2002; Cyrys *et al*, 2003; Vallius *et al*, 2003). In this

study coal combustion would be a result of both domestic use and use by the adjacent smelter. Cu was assumed to originate from the neighbouring steel smelters, however, its close correlation with Pb suggested that it came from traffic emissions. Prati *et al* (2000) stated that Fe is the typical tracer for steel smelter emissions. It was expected, therefore, that Fe would also be correlated with Cu to show that they were both from the neighbouring steel smelter industries. However, this was not the case suggesting that the main source contributor of Fe in the township is soil dust and not the steel smelters. A similar observation that soil dust was the main source for Fe was made by Cyrus *et al* (2003) and Ho *et al* (2003). This preliminary result means that there was no evidence suggesting a contribution of steel smelters to the overall elemental concentration of PM₇ in the township. Detailed analysis in the form of enrichment factors revealed, however, that Fe had an anthropogenic source, possibly the steel smelter industries located close to the township, as it had an average enrichment factor value of 2.10 (Table 5.2).

Table 5.2: Enrichment factors of PM₇

Individual	Si	S	K	Ca	Fe	Cu	Zn	Pb
UEH** - CB^ (Elderly Female)	1.00	1008.81	18.13	0.00	2.40	409.68	203.74	625.69
EH* - CB (Age 20 Male)	1.00	874.98	4.21	0.00	2.27	189.16	79.95	140.51
EH - CB2 (Age 35 Female)	1.00	512.28	5.71	0.01	1.79	438.15	49.76	208.95
EH – NCB^^ (Age 35 Female)	1.00	921.69	9.38	0.00	1.95	690.26	246.13	530.34
Average Enrichment Factor	1.00	829.44	9.36	0.00	2.10	431.81	144.89	376.37
*EH = Electrified House **UEH = Un-Electrified House ^CB = Coal Burning ^^NCB = Non-Coal Burning								

Elements with an enrichment factor value near 1.0 show a strong influence of the soil component, whereas a high value for the enrichment factor indicates anthropogenic origin (Table 5.2). Elements such as S, Cu, Zn and Pb showed higher enrichment values >10 (highlighted grey). This implies that they had a source that is

not associated with soil dust. According to the enrichment factor values, the elements Si, and Ca originated from a natural source, soil dust.

In a study conducted by Cyrys *et al* (2003), Zn, Pb and Cu were found to be highly correlated and were considered to be indicators for traffic emissions. Wear of tyres and brakes were reported to contribute to the Zn and Cu load in street dust (Cyrus *et al*, 2003). In this study, Cu and Pb were found to be well correlated (coefficient 0.685), an observation suggesting that these elements originate from a common source but Zn did not correlate with either of the two. A similar observation was made by Prati *et al* (2000). There is little evidence; therefore, according to the correlation analysis that Zn originated from traffic emissions, it probably came from soil dust. The enrichment factors suggest that Zn had a secondary source which is probably the smelter industries (Cyrus *et al*, 2003).

Elemental K accounted for much weight relative to the other elements but was not highly enriched in the enrichment factor calculation relative to Si, suggesting that it had an anthropogenic source. The main source of anthropogenic K could be wood burning (Vallius *et al*, 2003). There was no evidence, however, of wood burning in the township except that households use a few pieces of wood when starting a coal fire. Those pieces of wood could have been the possible source of fine K. Source contribution calculations also revealed that about 87 % of the measured K had anthropogenic origin (Table 5.3) and only 13 % originated from the soil.

5.5.2 Source Contributions to Individuals under Study

It is important to note that aerosol loading in the filters was representative of both ambient and indoor PM₇ measurements. The personal samplers were collecting PM₇ wherever the individuals were at any given time. The description of the households as given in Table 5.3 and Figure 5.12, thus, is only useful in identifying the type of household that the individuals came from. It is the activities of the individuals that significantly affect elemental composition of the air they breathe. That is, the amount of time that an individual spends indoors or outdoors is what determines the aerosol loading and hence the corresponding elemental concentrations.

Source contribution calculations revealed that 36 % of the Fe measured originated from the soil and the remaining 64 % had an anthropogenic origin, which would be the steel industries (Table 5.3). Only 0.01 % of the S originated from soil and 99.99 % had an anthropogenic origin, coal combustion. Similarly, Cu originated mainly from traffic emissions (99.95 %) as only 0.05 % originated from soil dust.

Table 5.3: Source apportionment of PM₇ in the township

Individual*	Si soil μg.m ⁻³	Ca soil μg.m ⁻³	Zn smelter μg.m ⁻³	Pb traffic μg.m ⁻³	Fe soil μg.m ⁻³	Fe smelter μg.m ⁻³	S soil μg.m ⁻³	S coal μg.m ⁻³	K soil μg.m ⁻³	K wood μg.m ⁻³	Cu soil μg.m ⁻³	Cu traffic μg.m ⁻³
1	183.02	0.10	21.60	40.17	60.82	108.74	0.022	204.27	54.43	363.94	0.014	30.85
2	895.98	0.56	43.74	29.72	553.2	989.03	0.031	289.64	84.18	562.85	0.015	34.15
3	174.23	0.20	4.55	13.59	41.91	74.93	0.008	77.72	17.19	114.91	0.015	32.58
4	200.56	0.05	29.38	45.29	53.8	96.19	0.022	203.58	35.94	240.29	0.027	61.03
* Individual 1 is UEH - CB (Elderly Female) Individual 3 is EH - CB2 (Age 35 Female) EH = Electrified House CB = Coal Burning Individual 2 is EH - CB (Age 20 Male) Individual 4 is EH - NCB (Age 35 Female) UEH = Un-Electrified House NCB = Non Coal Burning												

Overall, PM₇ samples measured were composed mostly of soil elements (Table 5.4). This was so because there was a high fraction of bare ground sites in the township as compared to built-up and vegetated areas. Evidence of this was given by Ho *et al* (2003) that particulate matter measured in areas with bare ground sites has a high proportion of soil elements. As expected, elemental concentrations of soil elements were the highest for the 20 year-old male, reaching 1533.96 µg.m⁻³. This occurred because the said individual spent a higher fraction of his time outdoors than any other individual in this study. The lowest concentrations of soil elements were recorded for the 35 year-old living in an electrified house with coal burning (233.55 µg.m⁻³). This individual spent most of her time indoors as she had newborn twins. Concentrations were almost identical for the elderly woman and the 35 year-old female that lived in the electrified household with no coal burning.

Table 5.4: Total elemental contributions to respirable air

Individual	Soil Dust µg.m ⁻³	Smelter Emissions µg.m ⁻³	Traffic Emissions µg.m ⁻³	Wood Emissions µg.m ⁻³	Coal Combustion µg.m ⁻³
UEH – CB (Elderly Female)	298.41	130.34	71.02	363.94	204.27
EH – CB (Age 20 Male)	1533.96	1032.77	63.87	562.85	289.64
EH – CB2 (Age 35 Female)	233.55	79.48	46.17	114.91	77.72
EH – NCB (Age 35 Female)	290.39	125.57	106.32	240.29	203.58
EH = Electrified House CB = Coal Burning UEH = Un-Electrified House NCB = Non Coal Burning 					

Coal combustion elemental concentrations seemed not to be affected by the amount of time that individuals spent indoors. The lowest concentrations (77.72 µg.m⁻³) were recorded for the age 35 female with newborn twins, whilst 203.58 µg.m⁻³ was recorded for the age 35 female living in the electrified household without coal burning. This implies that coal combustion emissions were high in the township –

both indoors and outdoors. Similarly, traffic emissions were almost identical for all individuals with the 35 year-old female from the electrified household recording the highest ($106.32 \mu\text{g.m}^{-3}$) and the 35 year-old female from the electrified household with coal burning recording the lowest ($46.17 \mu\text{g.m}^{-3}$). Smelter emissions were the highest for the age 20 male as a result of moving around more than the others. Traffic emissions were the lowest recorded for all the individuals, ranging from $46.17 \mu\text{g.m}^{-3}$ to $106.32 \mu\text{g.m}^{-3}$.

5.6 ESTIMATING POPULATION EXPOSURE TO AEROSOL POLLUTION

Previous studies have stated that domestic coal combustion releases air pollution in coal-burning households (Hoets 1994;1998; Qase *et al*, 2000; Scorgie *et al*, 2003a; 2003b). Studies conducted by Terblanche *et al* (1993b) in Sebokeng (Vaal Triangle, South Africa) and Marble Hall District (north-eastern Transvaal, South Africa) indicated that human exposures to air pollution caused by household use of wood and coal exceeds health standards by factors of 2-10. In this study, actual indoor aerosol monitoring was conducted in coal-burning households in the townships to determine whether aerosol released from domestic coal combustion reached levels that potentially could affect people's health. The results as shown in the previous sections of this chapter indicate that aerosol concentrations in coal-burning households are high and are likely to have implications for people's health. It is important to note though that monitoring alone does not address the social part of the problem. Monitoring and the social aspects (explained in Chapter 4), when combined, enable one to estimate population exposure to air pollution in order to better understand the multi-dimensional context in which energy use is played out.

5.6.1 Estimating Indirect Population Exposure to PM₇ Elements

Time-activity patterns were estimated in this study by observing people's behaviours similarly to a study conducted by Tsai *et al* (2000) in Bangkok, Thailand. Based on results from indoor PM₇ monitoring in township households and the approximated time-activity patterns (Table 5.5), indirect indoor population exposure (Table 5.6) and indirect outdoor population exposure (Table 5.7) to

aerosol pollution has been estimated. Direct population exposure to PM₇ elements has also been estimated (Figure 5.13) based on results from PIXE analysis of respirable air.

Table 5.5: Estimated daily time-activity data of the different population groups in the township based on personal observations during the questionnaire survey

Population Group	Time Assigned (hours)		
	Activity		
	Indoors	Outdoors within the township	Away from the township
Infants and the Elderly	22	2	0
School Children	16	8	0
Employed Adults	12	2	10
Unemployed Adults	16	8	0

It is believed that infants and the elderly spend most of their time indoors and much less time outdoors but still within the township (Table 5.5). As a result, pollution exposure is expected to be the highest among these population groups (Smith, 2002; WHO, 2005). Unemployed adults spend a significant fraction of their time (8 h daily) outdoors within the township and 16 h daily indoors, similar to school-going children. It is important to note though that some school children attend school outside the township and that their exposure could be less for that time or similar to that of employed adults. For employed adults that reside in the township it was estimated that daily they spend 12 h indoors and 2 h indoors within the township (Table 5.5). The remaining 10 h of the day was divided into working hours (8 h daily) and 2 h daily travelling to and from work places that are outside the township. Exposure was not approximated for the time spent outside the township. The less the amount of time a population group spends indoors in township households, the less the exposure to indoor respirable aerosols or particulates.

Table 5.6: Average indirect daily exposure to indoor respirable aerosols (PM₇) in coal-burning households

Population Group	Time Assigned Indoors (hrs)	Exposure $\mu\text{g.m}^{-3}$ (EH)	Exposure $\mu\text{g.m}^{-3}$ (UEH)
Average Daily Concentration	-	355.70	484.81
Infants	22	326.06	444.41
School Children	16	237.13	323.21
Employed Adults	12	177.85	242.41
Unemployed Adults	16	237.13	323.21
Elderly	22	326.06	444.41
EH = Electrified Household UEH = Un-Electrified Household			

Indirect indoor exposure was the highest in the un-electrified coal-burning household (Table 5.6). The estimates of indoor population exposure in coal-burning households show that infants and the elderly were exposed to 326.06 $\mu\text{g.m}^{-3}$ in electrified households and 444.41 $\mu\text{g.m}^{-3}$ of PM₇ in un-electrified households on a daily basis in the townships (Table 5.6). This finding concurs with that of Barnes (2005) that children living in homes that burn coal for heating were 9.9 times more likely to develop lower respiratory infections than those homes using electricity. School children and unemployed adults were exposed to 237.13 $\mu\text{g.m}^{-3}$ in electrified households and 323.21 $\mu\text{g.m}^{-3}$ of PM₇ in un-electrified households daily. Although the DEAT PM₁₀ daily standard of 180 $\mu\text{g.m}^{-3}$ is for ambient air and these exceeding concentrations are for indoor air, they are still significant as infants, women and the elderly spend most of their time indoors (BNM, 2003).

Unemployed adults and school children were the second most highly exposed members of the township population. Bearing in mind that 34 % of the township population was not employed at the time that this study was conducted (winter

2004), exposure was significantly high. All exposure is regarded significant in this study because it is thought that there is no threshold for PM₁₀ below which no health effect occurs (WHO, 2000). Moreover, recent studies have suggested that short-term variations in particulate matter exposure are associated with health effects, even at low levels of exposure - <100 µg.m⁻³ - (WHO, 2000).

Ambient exposure to respirable aerosols was estimated using data from the electrified household that does not burn coal as discussed earlier in this chapter as concentrations in that house represent ambient (Table 5.7). Outdoor exposure is also significant, especially for people who spend a high fraction of their time within the townships. Such people include unemployed adults and school-going children if their schools are within the township. Employed adults who leave the township during their working hours are the least exposed as they only spend the evenings, nights and early mornings in the township, but that is when not considering the air quality at their work places.

Table 5.7: Average indirect daily exposure to outdoor respirable aerosols (PM₇)

Population Group	Time Assigned Outdoors (hrs)	Exposure µg.m⁻³ (EH - non coal burning)
Average Daily Concentration	-	194.32
Infants	2	16.19
School Children	8	64.77
Employed Adults	2	16.19
Unemployed Adults	8	64.77
Elderly	2	16.19
EH = Electrified Household.		

Overall calculated daily indirect exposure was in the range of 16 to 444 $\mu\text{g.m}^{-3}$ during winter 2004 (Figure 5.13), contrary to the finding of Doppegieter *et al* (1998) that township children are exposed to continuous daily pollution levels of between 1 000 $\mu\text{g.m}^{-3}$ and 3 200 $\mu\text{g.m}^{-3}$ in winter and 600 $\mu\text{g.m}^{-3}$ in summer. This shows that much less but significant exposure was obtained in this study. However, Doppegieter *et al* (1998) did not state whether their measurements of exposure were direct or indirect. Higher levels of direct exposure are expected when compared with indirect exposure.

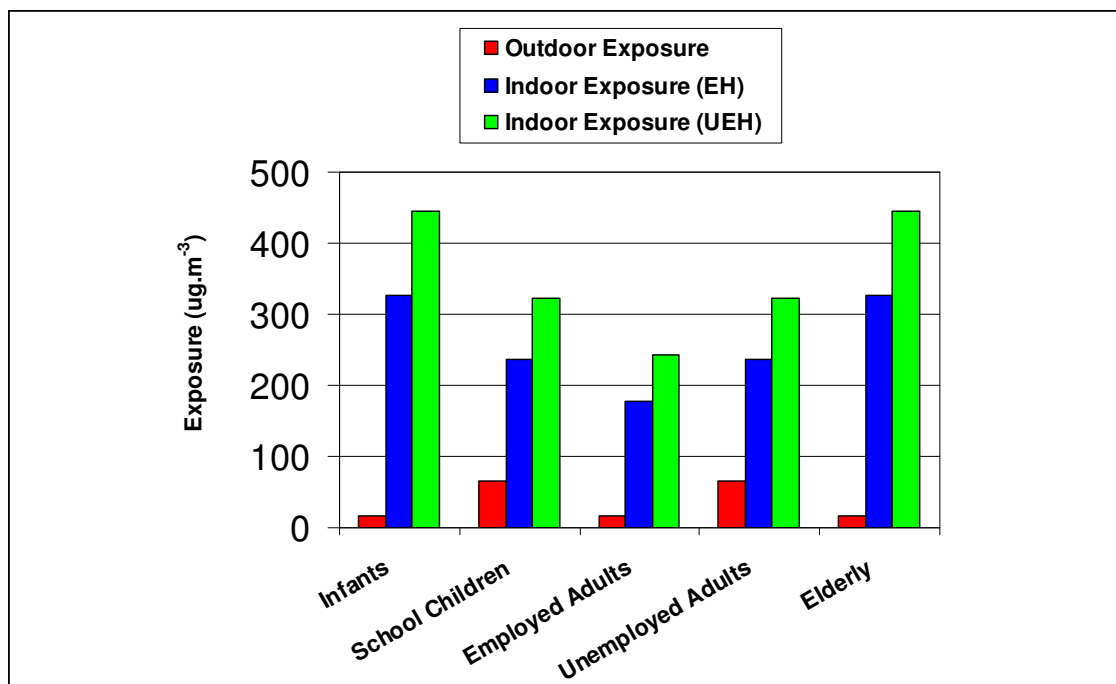


Figure 5.13: Estimated overall indirect population exposure in the townships, where “EH” is an Electrified House and “UEH” is an Un-Electrified House

5.6.2 Estimating Direct Population Exposure to PM₇ Elements

Direct population exposure to respirable elements has been estimated based on measurements from personal samplers (Figure 5.14). It is important to note that exposure estimated in this study is that of selected individuals who were living in the households where aerosol monitoring was conducted. It is from both indoor and ambient air that was inhaled. The main sources of the elements are believed to have

been soil dust (Si, K, Ca and Cu), coal combustion (S), traffic emissions (Pb and Zn) and steel industries (Fe) (Prati *et al*, 2000; Ho *et al*, 2003; Reuer *et al*, 2003; Cyrus *et al*; 2003). Exposure, particularly outdoor, was the highest for the male aged 20 living in the electrified coal-burning household. This is so because he moved around the township more than any other individual under study. The second highest exposed individual was the elderly woman, followed by the female aged 35 from the electrified and coal-burning household. Lastly, the 35 year-old female from the second electrified coal-burning household was the least exposed. This is so because she spent almost all her time indoors as she had newborn twins.

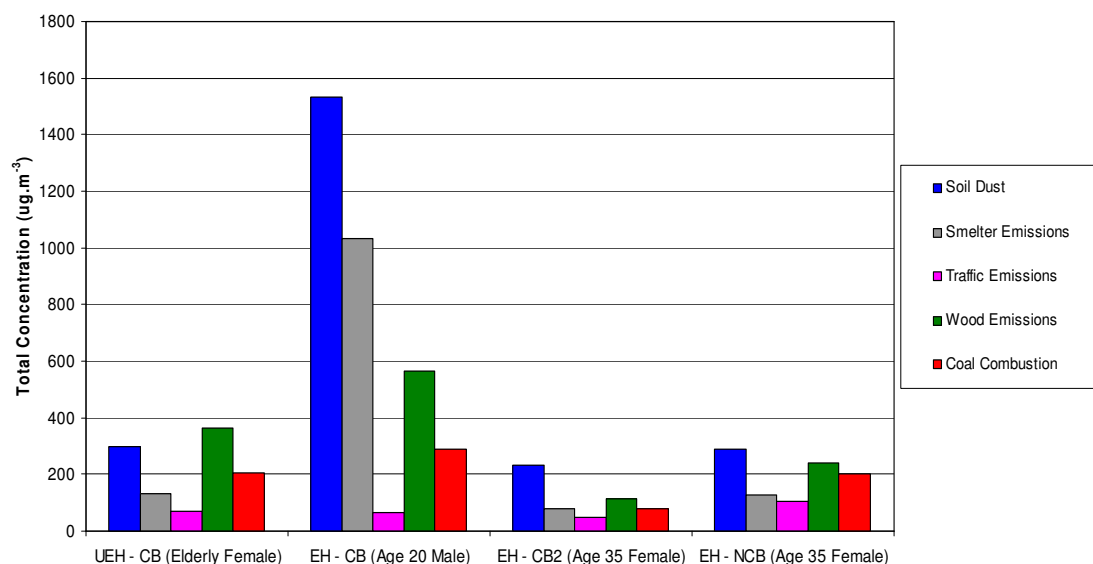


Figure 5.14: Source contributions to direct exposure to PM7 elements, where “EH” is an Electrified House and “UEH” is an Un-Electrified House; “CB” is Coal Burning and “NCB” is Non Coal Burning

The result shows that the main source for aerosols was soil dust and the steel industries. Coal and wood combustion were also significant sources of respirable aerosols in the township. Traffic emissions appear not to be a major source of respirable aerosols in the township; however, traffic emissions are still very important in terms of lead concentrations. Lead has major health implications as, if it is inhaled, it can cause damage to the nervous system, particularly that of small children. An average adult person at rest breathes in about 11 m³ of air per day

(HSW, 2006) and the average concentration of lead was $38.4 \mu\text{g.m}^{-3}$. This means that an adult person at rest breathes in about $422.4 \mu\text{g.m}^{-3}$ of lead per day. Exposure should be even higher for small children as their breathing rate is higher than that of adults, which then places exposed children at a higher risk of nervous system damage than those children not exposed to lead or traffic emissions. All population groups living in the township are at a higher risk of exposure than populations living away from the area.

* * * * *

In Chapter 5 the results and discussion obtained by aerosol monitoring at KwaGuqa in August 2004 have been provided. In summary, the results revealed that:

- PM_{10} concentrations followed the same trend in both electrified and un-electrified households with morning and evening peaks that are directly related to the making of coal fires.
- Higher PM_{10} levels were recorded in the night-time as people kept their coal fires burning longer than in the daytime.
- Despite following the same trend, PM_{10} aerosols were generated faster in the un-electrified coal-burning household than they were in the electrified households.
- PM_{10} levels are frequently above the DEAT standard of $180 \mu\text{g.m}^{-3}$.

Further, elemental analysis of respirable particulate matter showed that, on average, soil dust in the biggest contributor, followed by coal combustion and to a lesser extent are smelter, wood and traffic emissions. Estimates of population exposure to PM_{10} revealed that infants and the elderly are the most exposed, followed by school children and unemployed adults. Employed adults working outside the township are the least exposed. The next chapter is the concluding chapter and it presents the conclusions drawn from the results of this study.

CHAPTER 6:

CONCLUSIONS

This chapter presents the conclusions drawn from the results of this study.

6.1 SUMMARY

Energy resources and energy usage in South Africa are becoming key policy and development concerns. Previous research in this domain has focused on households who did not have access to electricity. Notwithstanding some major changes in energy provision, this thesis shows how energy usage patterns have persisted over time, or in other cases either changed over time. This thesis highlights the complex drivers, socio-economic and biophysical, and consequences shaping coal as an energy resource in South Africa. Firstly, aerosol monitoring shows that domestic coal usage releases high levels that exceed the country's daily limit 43% of the time and such concentrations are detrimental to the health of exposed populations. Secondly, complex behavioural and social factors are also shown to underpin and determine patterns and types of domestic energy sources used.

The literature review conducted in this study explored the role of aerosols as an important atmospheric pollutant that impacts on climate, human health and the socio-economic status of human beings (Swietlicki *et al*, 1996b; Kim *et al*, 2003; Zheng *et al*, 2004). The domestic use of energy (biomass and coal in particular) contributes significantly to the amount of aerosols in the atmosphere and it causes significant indoor air pollution that has glaring health implications (Lindesay, 1992; Annegarn *et al*, 1998; Eck *et al*, 1999; WHO, 2005). Unlike other African countries, whose low-income populations use biomass as the main energy source (Marufu *et al*, 1997; Ludwig *et al*, 2003), low-income communities – particularly in urban areas – use coal in South Africa (Spalding-Fecher and Matibe, 2003). Domestic coal

combustion is, nevertheless, a major source of air pollution in South African townships and it has a great impact on the human health of exposed populations (Terblanche *et al*, 1992; 1993a; van Nierop, 1995; Spalding-Fecher and Matibe, 2003).

In light of the above, alternative energy sources to coal have been proposed and researched to reduce emissions from domestic coal combustion in South Africa. These alternatives include low-smoke fuels and electrification (Terblanche *et al*; 1993b; Scorgie *et al*, 2001; Surridge *et al*, 2004; Spalding-Fecher, 2005). Domestic coal combustion has, however, persisted after electrification (Hoets, 1994; Scorgie *et al*, 2003a; Spalding-Fecher *et al*, 2002).

Energy use is, however, a very complicated phenomenon that is influenced by a range of factors including perceptions, lifestyle and livelihoods and other factors. In an attempt to better understand and ‘map’ out energy use and behaviour, a conceptual framework of energy use at household level, the energy ladder, and the importance of people’s perceptions in using different energy sources (Eberhard and van Horen, 1995; Mehlwana and Qase 1996; Bruce, 2002; Barnes, 2005) are outlined in Chapter 2. This thesis has explored the reasons for the persistence of domestic coal combustion, applied the concept of the energy ladder and measured the amount of indoor aerosol pollution that domestic coal combustion releases. The conclusions drawn from this work are presented in the next sections of this chapter.

6.2 DOMESTIC COAL COMBUSTION: A PERSISTING REALITY

Despite electrification and the provision of free basic electricity in South Africa, township households have continued to burn coal inside their houses. Although there appears to be a reduction in the amount of coal burnt in electrified households, the pollution released is still higher than acceptable levels. Terblanche *et al* (1992; 1993a) in earlier assessments, showed that coal usage continued due to the lack of resources to create an infrastructure for complete transition to electricity and the lack of money to maintain the system. This study conducted 12 years later and with

most township coal-burning houses having access to electricity shows that users *still*, in most cases, prefer to use coal as a source of energy. The findings indicate that there are indeed a range of reasons that explain why township households continue to burn coal, which require further research; namely, the social role of domestic coal combustion, poverty and the unreliability of the electricity supply.

6.2.1 The Social Role of Domestic Coal Combustion

This study found, in Chapter 4, that there are deeply entrenched social networks and behavioural patterns to support the “culture” of coal usage in the townships. This is partly due to the historical inequitable distribution of energy sources of the apartheid era in South Africa. Coal as a cheap source of energy was perceived as, and became, the predominant energy source in the townships to meet household energy needs. As a result, a “culture” of coal usage was developed whereby it became a common household custom to make a coal fire. One of the findings of this study is that township households still continue that culture of sustained domestic coal combustion.

Coal-trading infrastructures (e.g. coal merchants) were also developed as a result of prolonged coal usage in the apartheid era of the country. For instance, the large infrastructure to utilise coal in the townships that was reported by Qase *et al* (2000) and BNM (2003) still exists and is functioning well. These coal utilisation infrastructures make it easy for township households to buy coal even in large quantities. Coal merchants also sell coal at affordable rates to coal users, which is another incentive for burning coal. The convenience of coal utilisation is, therefore, one of the reasons it has been difficult to phase out coal.

Furthermore, township homes have already made the prerequisite investment for burning coal – buying a coal stove. According to Hoets (1994), the coal stove is the biggest single investment for most homes. If township households were to switch from domestic coal combustion completely they would be abandoning their coal stoves. Asking them to abandon their stoves abruptly might be asking for more than they can bear. Moreover, beyond heating and cooking, a coal fire is a social focal

point for the family (Hoets, 1994). Most respondents stated that they like sitting together in the house while keeping warm. Such a social event would be lost if domestic coal combustion were to cease completely which would be regrettable because the people treasure it. Consequently, stopping coal usage, which would be a benefit to all, must be a gradual and considerate process.

Additionally, the multi-functional ability of coal (cooking while heating the house) has made coal usage even more convenient and preferable and so people continue to use it (Scorgie *et al*, 2003a). One would expect, therefore, that domestic coal users have a profound knowledge of domestic coal combustion practices, which could be used as a reliable source of information as stated by Lykke (2000). Any endeavours to make coal users switch from burning coal must recognise and utilise local knowledge in interventions. That is, the endeavours must not give the impression that local knowledge is insignificant or based on ignorance. Moreover, bearing in mind that people resist imposed change (Rogan *et al*, 2005), a possible ‘switching’ from domestic coal combustion would need to be carefully explained to, and undertaken with, the coal-burning communities and phased in over time.

6.2.2 Perceived Health Effects of Domestic Coal Combustion

A significant percentage of the selected households had heightened awareness through the media that inhaling coal smoke has chronic adverse effects on people’s health. These households, however, did not believe such reports as they had not observed chronic adverse health effects. A large number of households (75 %) (Figure 4.3) that had occupants suffering from respiratory ailments had observed that the frequency of their ailments increased in winter but they said it was because of cold temperatures in winter (June to August) and not coal smoke. Although the respondents perceived a coal-related health risk, they indicated that this risk is predominantly an issue in the short term. Short-term health risks perceived were coughing and choking that occurs when one inhales coal smoke at the ignition stage of a coal fire. When probed further, many respondents cited other contributing factors that also aggravated their health (Figure 4.2). Other factors that were cited as

contributing to health problems in the township were unemployment, livelihood, occupation and poverty (Oosthuizen *et al*, 2004).

6.2.3 Poverty Issues

Poverty is an important ‘driver’ possibly explaining domestic coal combustion and it is the major obstacle preventing a shift from domestic coal combustion. This finding concurs with that of Terblanche (1994) who states that poverty has an impact on choice and affordability of energy sources. The results of this study showed that 34 % of the interviewed households were unemployed. Unemployment usually parallels poverty very closely in South Africa (UNDP, 2000). Consequently, interventions to reduce indoor air pollution seem to be hindered by poverty because residents could not afford to use electricity. A similar finding was made by Barnes (2005) who noted that it is unlikely that poor households will progress towards the exclusive use of cleaner fuels like electricity. Income levels as well as price changes affect demand for electricity (Bond and Hallows, 2002; Spalding-Fecher, 2005). In this study, township households could not meet the expense of using electricity for all their energy needs. Although they were ‘happy’ with electricity, they still wanted to burn coal for space heating.

Respondents also complained that the price of electricity rose every year, making it increasingly difficult to use electricity. This has led to low consumption of electricity as noted by Fiil-Flyn and Greenberg (2002) and ERC (2004) which has made electrification to be unsustainable as it does not cover the operation costs. This finding is in line with Bond and Hallows (2002) who stated that low-income households pay higher electricity prices than large, bulk consumers due to the higher cost of supplying electricity to individual households. These low-income households then tend to use electricity only for lighting (Bond and Hallows, 2002) and entertainment as was shown in this study. Electrification, therefore, cannot solve the problem of domestic coal combustion because people cannot afford to use it for warmth and cooking. Spalding-Fecher (2005) indicated that a reduction in coal use reflects a socio-economic transition beyond simply a change in availability of electricity or electric appliances. This was found to be true in this study as well,

since households had electric appliances but could not use them owing to high electrical costs. This is, however, contrary to Hoets (1994) and Barnes (2005) who stated that the cost of purchasing electric appliances is prohibitive to electricity usage by households. This study, therefore, mirrors the concept of household energy use which posits that as people's economies improve there is a general transition up the energy ladder to cleaner and more expensive fuels (Bruce, 2002; Smith, 2002).

6.2.4 The Unreliability of the Electricity Supply

The respondents indicated that the electricity supply in the townships was unreliable and they said they could not depend on electricity entirely as they could not ensure its availability when they needed it. A similar finding was reported by BNM (2003). The unreliability of the electricity supply was observed to be particularly true in this study as DustTrak aerosol monitors were usually affected by the unreliability of the electricity supply. Although the monitors had standby batteries, the electricity supply would be cut without warning for long periods of time and sometimes the standby batteries ran out of power. Also, during the questionnaire survey, some households interviewed, particularly in Doornkop, had illegal electricity connections, which is an indication of the vandalism stated by BNM (2003). It is the vandalism that partly contributes to the unreliability of the electricity supply. The unreliability of the electricity supply also makes it challenging to be dependent on electricity.

6.3 ENVIRONMENTAL AND HEALTH BENEFITS OF ELECTRIFICATION

Reductions in air pollution from household energy sources promise significant benefits in terms of saving lives, improving the quality of life and boosting productivity (Terblanche *et al*, 1994). The results of this study concur with the finding of Spalding-Fecher (2000) and Spalding-Fecher and Matibe (2003) who noted that the introduction of electricity in township households has had significant environmental and health benefits. Aerosol monitoring, in Chapter 5, revealed that while electrified households continued to burn coal, the amount of coal burnt – hence the resultant aerosol concentration – was less than that burnt in un-electrified

houses. This study also concurs with that of Annegarn *et al* (1998) who reported a 15 % decline in the amount of PM₁₀ aerosol levels in Soweto from 1992 to 1998 due to electrification. Although the indoor PM₇ concentrations changed with different households, elemental concentrations of respirable aerosols did not change between different households. The elemental concentrations were determined significantly by people's activities, implying that the sources of respirable aerosols did not change between the households but only the levels released changed.

Moreover, this study has revealed that there will be long-term benefits of electrification contrary to the statement by Barnes (2005) that it is unlikely that many of the poorest households in developing countries will progress up the energy ladder towards the exclusive use of cleaner-burning fuels in the foreseeable future. Possible 'pathways' of energy use and adaptation have been traced (for example, Figures 4.5, 4.6 and 4.7). A key finding, however, is that a 'one-size-fits-all' approach will not be suitable and more research and analysis on energy usage and alternative energy sources needs to be undertaken. It was evident from the results of this study that if township households continue to use electricity, the amounts of coal burnt over time should decrease. Such a trend is linked to, however, not only the continuing usage of electricity but is also coupled to the betterment of the economic status of the people. Low-income households burn coal. If the economic status of the people were to improve, they may eventually stop burning coal. The biggest dilemma is that while giving the process of shifting from domestic coal combustion time and consideration, people's lives are being exposed to harmful levels of air pollution.

Some challenges were faced when conducting this study. For example, despite pre-testing the questionnaire, answers to some of the questions were not forthcoming during the field survey. Questions from section C about low-smoke fuels could not be readily answered by some of the respondents as they felt that they had not 'seen' these low-smoke fuels. Despite probing, some respondents refused to talk about a low-smoke fuel that they had not seen or used before, hence it was inappropriate to continue asking those questions. In order to obtain information in this regard, future studies must ensure that there is a basis for answering these questions. This can be

done by first providing low-smoke fuels and allowing the populations under study to use them prior to asking questions about the low-smoke fuels.

In terms of indoor aerosol monitoring, the biggest limitation was the unreliability of the electricity supply to the electrified households in the township. Although there were standby batteries in the DustTrak aerosol monitors, sometimes the electricity supply was cut off for so long that the batteries ran out of power. This was overcome by changing the batteries each time the data were downloaded but there were still some small gaps in the data recorded. The DustTrak aerosol monitor in the second coal-burning electrified household was destroyed by a power surge after a power failure. The DustTrak aerosol monitor had to be taken to the manufacturer to be fixed and recalibrated. Consequently, data recording ended on 11 August 2004 in the said household. With regard to the elemental analysis of respirable aerosols, improvements for future studies must stratify the population according to different age groups and people's activities as this study has revealed that the respective households did not make a difference in levels recorded.

6.4 IMPLICATIONS FOR POLICY MAKERS

Designing a strategy for reducing air pollution aimed at effectively protecting the public's health requires more information than knowledge of the locations where the adverse effects may occur and speculation on the amounts of air pollution released from sources. Information on the severity and magnitude of the effects, in terms of the type and expected number of cases attributable to the pollution, may be necessary to justify and support decisions that may be costly and require various efforts from society (WHO, 1999).

The links between air pollution and health are mediated by the perception of the exposure and other individual and contextual factors (Howells *et al*, 2005). This study has also shown, however, that a range of other factors mediate coal use. These are the availability of coal, affordability and the unreliability of the electricity supply. Moreover, this study has provided part of the required information –

population exposure to aerosol pollution – to gain the societal efforts to switch from domestic coal combustion to alternative energy sources. This information can be used to inform the coal users that such combustion is detrimental to their health to convince them to switch from coal burning. Potentially, this would work in South African coal-burning communities for phasing out domestic coal combustion since studies have shown that consumers behave differently if they have energy-source information than if they have energy-source-plus-emissions information (Johnson and Frank, 2004).

Creating awareness about burning coal more efficiently (e.g. Basa Njengo Magogo method of ignition described in section 2.1.7 of this thesis) is one alternative to reducing air pollution resulting from domestic coal combustion. Another alternative to reducing air pollution from domestic coal combustion and the resulting health impacts is to improve the coal burning devices – stoves. The government can subsidise the improvement of coal stoves and improved ventilation in coal burning households to reduce the amounts of pollution released, particularly where poverty is the main inhibiting factor to switching from domestic coal-use.

Although poverty is the major obstacle preventing a shift from domestic coal combustion in most cases, lack of knowledge about the adverse effects of using coal also contributes to the ‘coal-burning’ attitude. The perception that domestic coal combustion does not affect people’s health is prevalent in township coal-burning communities and is cited earlier in this thesis (section 6.2.2) as one of the contributing factors to the continued use of coal. Awareness campaigns can be conducted to spread the message, which is that domestic coal combustion has detrimental health effects to its users and to everyone in the township. When the coal-burning society realises how much air pollution they are exposed to, based on measurements taken inside their houses instead of speculation, there is a chance that they would desire to switch from domestic coal combustion, the knowledge of cheaper alternative sources would also be essential. The desire to switch from domestic coal combustion is a starting point to achieving the actual switch.

Awareness campaigns can also, inform coal-users of other sources of energy that may be cheaper than coal, for example solar cookers. Despite such efforts, this study of township households shows that because of the costs of electricity, uptake of such campaigns is generally very limited. Cheaper energy sources, however, have a better chance to be accepted by these communities as more money would be available in the households for other uses. Consequently, policies to guide the switch to alternative energy sources can be formulated.

Quantifying the impact of exposure to air pollution is one of many steps to providing information on the severity and magnitude of air pollution. It has become an increasingly critical component of the public's health in policy formation (WHO, 1999). Exposure to indoor PM₇ pollution has been quantified in this study. Further studies can be conducted to quantify the impact of the exposure in order to aid in policy formation. For instance, studies on health effects of long-term exposure to air pollution also need to be conducted in township populations to inform both policy makers and coal users about the nature of the pollution responsible for adverse health effects, as well as the characteristics of susceptible population groups. Calculating the number of hospital admissions on account of respiratory diseases attributable to domestic coal combustion also needs to be performed to help convince township dwellers to stop burning coal in their households.

REFERENCES

- ANC (African National Congress), 1994: *The reconstruction and development programme*. Umanyano Publications, Johannesburg.
- Anderson, B.E., Grant, W.B., Gregory, G.L., Browell, E.V., Collins Jnr, J.E., Sachse, G.W., Bagwell, D.R., Hudgins, C.H., Blake, D.R. and Blake, N.J., 1996: Aerosols from biomass burning over the tropical South Atlantic region: Distributions and impacts. *Journal of Geophysical Research*, 101 (D19), 24 (137): 117-124.
- Andreae, M.O., Atlas, E., Cachier, H., Cofer III, W.C., Harris, G.W., Helas, G., Koppmann, R., Lacau, J.P. and Ward, D.E., 1996: "Trace gas and aerosol emissions from savanna fires". In: J.S. Levine (ed.), *Biomass burning and global change*. MIT Press, Cambridge, 278-294.
- Annecke, W., 1999: *Assistance to NERL regarding non-economic determinants of energy use in rural areas of South Africa*. Unpublished manuscript, Energy and Development Research Centre, University of Cape Town, Cape Town.
- Annegarn, H.J. and Sithole, J., 1997: *Soweto Air Monitoring - Project SAM: Annual report for the period January-December 1996*. Report No. AER97.094_SAM. Department of Environment and Tourism, Pretoria.
- Annegarn, H.J., Grant, M.R., Kneen, M.A. and Scorgie, Y., 1998: *Direct source apportionment of particulate pollution within a township*. Low-Smoke Coal Programme: Draft of final report. Report No. AER98.117DME. Department of Minerals and Energy, Pretoria.
- Anyamba, A., Justice, C.O., Tucker, C.J. and Mohoney, R., 2003: Seasonal to Interannual Variability of Vegetation and Fires at SAFARI 2000 Sites Inferred from Advanced very High Resolution Radiometer Time Series Data. *Journal of Geophysical Research*, 108 (D13) 8507: doi: 10.1029/2002JD002464.

- Ausubel, J.H., 1989: "Regularities in technological development: An environmental view".
In: *Technology and environment*, J.H. Ausubel and H.E. Sladovich (eds),
National Academy Press, Washington, D.C.
- Ausubel, J.H. and Sladovich, H.E. (eds), 1989: *Technology and environment*. National
Academy Press, Washington, DC.
- Babu, S.S., Moorthy, K.K. and Satheesh, S.K., 2004: Aerosol black carbon over the Arabian
Sea during intermonsoon and summer monsoon seasons. *Geophysical Research
Letters*, 31 (L06104): doi: 10.1029/2003GL018716.
- Bach, W. and Fiebig, S., 1998: China's key role in climate protection. *Energy*,
23 (4): 253-270.
- Bailis, R., Pennise, D., Ezzati, M., Kammen, D.M and Kituyi, E., 2003: Impacts of
greenhouse gas and particulate emissions from woodfuel production and end-use
in Sub-Saharan Africa.
<http://www.rael.berkeley.edu/OA5.1.pdf>
Website accessed: 23 January 2006.
- Barnes, B.R., 2005: Interventions to reduce child exposure to indoor air pollution in
developing countries: Behavioural opportunities and research needs. *Children,
Youth and Environments*, 15 (1): 67-82.
- Bechtel, R.B., Marans, R.W. and Michelson, W., 1987: *Methods in environmental and
behavioral research*. Van Nostrand Reinold Company, New York.
- Billmark, K.A., Swap, R.B. and Macko, S.A., 2003: Characterisation of Sources for
Southern African Aerosols through Fatty Acid and Trajectory Analysis. *Journal
of Geophysical Research*, 108 (D13): doi: 10.1029/2002JD002762.
- BNM (Basa Njengo Magogo Project Team), 2003: *Basa njengo Magogo pilot study: Orange
Farm*. First progress report. Unpublished manuscript, Department of Minerals
and Energy, Pretoria.
- Bogo, H., Otero, M., Castro, P., Ozafran, A.K., Calvo, E.J. and Negri, R.M. 2003: Study of
atmospheric particulate matter in Buenos Aires city, *Atmospheric Environment*,
37: 1135-1147.

- Bond, P. and Hallows, D., 2002: "The environment of apartheid-capitalism: Discourses and issues". Chapter 1 in Bond, P., 2002: *Unsustainable South Africa: Environment, development and social protest*. University of Natal Press, Pietermaritzburg.
- Bond, P., 2002: *Unsustainable South Africa: Environment, Development and Social Protest*. University of Natal Press, Pietermaritzburg.
- Bowser, B.A., 2004: *Tracking pollution*.
http://www.pbs.org/newshour/bb/environment/july-dec04/pollution_09-07.html:
 Website accessed: 07 September, 2004.
- Braga, C.F., Teixeira, E.C., Yoneama, M.L. and Dias, J.F., 2004: Study of the elemental composition of aerosols in the Candiota region of Brazil using the PIXE technique. *Nuclear Instruments and Methods in Physics Research*, B (225): 561-571.
- Britton, M.S.T., 1998: *Low-Smoke Fuel Programme: Laboratory technical tests: Determination of emission factors*. Report No. ES9606. Department of Minerals and Energy, Pretoria.
- Bruce, N.G., 2002: *Household energy and health: An introduction*.
<http://www.sparknet.info>
 Website accessed: 11 May, 2006.
- Burnett, R.T. 1997: Critical Review Discussion. *Journal of Air and Waste Management Association*. 47: 995-1008.
- Burton, D. (ed.), 2000, *Research and training for social scientists*. Sage Publications, London.
- CEG (Clean Energy Group), 2004: *South Africa: Energy and Environmental Issues*,
<http://www.eia.doe.gov/cabs/safrenv.html>
 Website accessed: 15 November 2006.
- Charlson, R.J., Schwartz, S.E., Hales, J.M., Cess, R.D., Coakley Jr, J.A., Hansen, J.E. and Hofman, D.J., 1992: Climate forcing of anthropogenic aerosols. *Science*, 255: 423-430.
- Cumbane, J.J., 2002: *PIXE based study of air quality over Mozambique*. Unpublished MSc dissertation, University of the Witwatersrand, Johannesburg.

- Cyrus, J., Stolzel, M., Heinrich, W.G., Menzel, N., Wittmaack, K., Tuch, T. and Wichmann, H.E., 2003: Elemental composition and sources of fine and ultrafine ambient particles in Erfurt, Germany. *The Science of the Total Environment*, 305: 143-156.
- D'Alessandro, A., Lucarelli, F., Mando, P.A. Marcazzan, G., Nava, S., Prati, P., Valli, G., Vecchi, R. and Zucchiatti, A. 2003: Hourly elemental composition and sources: Identification of fine and coarse PM₁₀ particulate matter in four Italian towns. *Aerosol Science*, 34:243-259.
- DANCED (Danish Co-operation for Environment and Development), 2000: *Background study to provide input into the development of an air quality management strategy for the Province of Gauteng, South Africa*. Unpublished manuscript. Johannesburg.
- Dennis, A., Fraser, M., Anderson, S. and Allen, D., 2002: Air pollutant emissions associated with forest, grassland and agricultural burning in Texas. *Atmospheric Environment* 36: 3779-3792.
- DME (Department of Minerals and Energy), 1998: *White paper on energy policy for South Africa*. Department of Minerals and Energy, Pretoria.
- Dockery, D.W. and Pope, C.A., 1994: Acute respiratory effects of particulate air pollution. *Annual Review of Public Health*, 15: 107-132.
- Dockery, D.W., Pope, C.A., Xu, X., Spengler, J.D., Ware, J.H., Fay, M.E., Ferris, B.G. and Speizer, F.E., 1993: An association between air pollution and mortality in six U.S. cities. *The New England Journal of Medicine*, 329 (24): 1753-1759.
- Doppegieter, J.J., du Toit, J. and Liebenberg, J., 1998: *Energy Futures 1998/99*. Institute for Futures Research. FR645. DAR/1998/DOP/ENE.
- Eberhard, A. and van Horen, C., 1995: *Poverty and power: Energy and the South African state*. UCT Press, Cape Town.
- Eck, T.F., Holben, B.N., Reid, J.S., Dubovik, O., Smirnov, A., O'Neill, N.T., Slutsker, L. and Kinne, S., 1999: Wavelength Dependence of the Optical Depth of Biomass Burning, Urban and Desert Dust Aerosols. *Journal of Geophysical Research*, 104 (D24): 31333-31349.

- Elsom, D., 1987: *Atmospheric Pollution*. Basil Blackwell, Oxford.
- Engelbrecht, J., Reddy, V., Swanepoel, L. and Mostert, J., 1998: *Aerosol Monitoring and Source Apportionment in the Vaal Triangle*. Mintek Special Publication No. 17.
- Engelbrecht, J.P., Swanepoel, L., Chow, J.C., Watson, J.G. and Egami, R.T., 2001: PM_{2.5} and PM₁₀ concentrations from the Qalabotjha low-smoke fuels macro-scale experiment in South Africa. *Environmental Monitoring and Assessment*, 69: 1-15.
- Engelbrecht, J.P., Swanepoel, L., Chow, J.C., Watson, J.G. and Egami, R.T., 2002: The comparison of source contributions from residential coal and low-smoke fuels, using CMB modelling, in South Africa. *Environmental Science and Policy*, 5: 157-167.
- Engelbrecht, J.P., Swanepoel, L., Zunckel, M., Chow, J.C., Watson, J.G. and Egami, R.T., 2000: Modelling PM₁₀ aerosol data from the Qalabotjha low-smoke fuels macro-scale experiment in South Africa. *Ecological Modelling*, 127: 235-244.
- EPRI (Electric Power Research Institute), 2003: *Toxicological Evaluation of Realistic Emissions of Source Aerosols (TERESA). Assessment of air quality impacts on health and the Environment*.
<http://www.epri.com>
 Website accessed: 15 September 2003.
- ERC (Energy Research Centre), 2004: *Energy for sustainable development: South African profile*. Unpublished manuscript, Energy and Development Research Centre, University of Cape Town, Cape Town.
- Eskom (Energy Supply Commission), 2006: *Internal pricing documents*. Unpublished manuscript, Eskom, Johannesburg.
- Fiil-Flynn, M. and Greenberg, S., 2002: "Power to the powerful: Energy, electricity, equity and environment". Chapter 6 in Bond, P., 2002: *Unsustainable South Africa: Environment, development and social protest*. University of Natal Press, Pietermaritzburg.

- Finkelman, R., 2000: *Health impacts of coal combustion: United States Geological Survey*.
<http://www.pubs.usgs.gov/fs/fs94-00/fs094-00.pdf>
 Website accessed: 10 July 2003.
- Funasaka, K., Miyazaki, T., Kawayara, T., Tsuruho, K., Mizuno, T., Nakajima, H., Yamamoto, T. and Hara, H., 1999: A case study for wintertime observation of atmospheric particulates by an eye-safe laser radar. *Environmental Pollution*, 106: 47-53.
- Gao, S., Hegg, D.A., Hobbs, P.V., Kirchstetter, W., Magi, B.I. and Sadilek, M., 2003: Water-Soluble Organic Components in Aerosols Associated with Savanna Fires in Southern Africa: Identification, Evolution and Distribution. *Journal of Geophysical Research*, 108 (D13): 1-16: doi: 10.1029/2002JD002324.
- Government Gazette, 2005: Republic of South Africa; Government Gazette; Vol: 476, No: 27318. No. 39 of 2004: National Environment Management: Air Quality Act, 2004.
- Guazzotti, S.A., Suess, D.T., Coffee, K.R., Quinn, P.K., Bates, T.S., Wisthaler, A., Hansel, A., Ball, W.P., Dickerson, R.R., Neisub, C., Crutzen, P.J. and Prather, K.A., 2003: Characterization of Carbonaceous Aerosols Outflow from India and Arabia: Biomass/Biofuel Burning and Fossil Fuel Combustion. *Journal of Geophysical Research*, 108 (D15): 4485: doi: 10.1029/2002JD003277.
- Hallows, D. and Butler, M., 2002: "Power, poverty and marginalised environments: A conceptual". In: McDonald, D.A., 2002: *Environmental justice in South Africa*. UCT Press, Cape Town.
- Heltberg, R., 2004: Fuel switching: Evidence from eight developing countries. *Energy Economics*, 26: 869-887.
- Ho, K.F., Lee, S.C., Chow, J.C. and Watson, J.G., 2003: Characterization of PM₁₀ and PM_{2.5} source profiles for fugitive dust in Hong Kong. *Atmospheric Environment*, 37: 1023-1032.
- Hobbs, P.V., Reid, J.S., Kotchenruther, R.A., Ferek, R.J. and Weiss, R., 1997: Direct radiative forcing by smoke from biomass burning. *Science*, 275: 1776-1778.

- Hoets, P., 1994: *Acceptability of coal-base low smoke fuels – Phase 2*. Department of Minerals and Energy, Pretoria.
- Hoets, P., 1998: *Macro-scale experiment – Social acceptability of low smoke fuels*. Report No. ES9610. Department of Minerals and Energy, Pretoria.
- Hosier, R.H. and Dowd, J., 1987: Household fuel choice in Zimbabwe: An empirical test of the energy ladder hypothesis. *Resources and Energy*, 9 (4): 347-361.
- Howells, M., Victor, D.G., Gaunt, T., Elias, R.J. and Alfstad, T., 2005: Beyond free electricity: The costs of electric cooking in poor households and a market-friendly alternative. *Energy Policy*, Article in Press.
- HSW (HowStuffWorks), 2006: *How stuff works*.
<http://science.howstuffworks.com>
 Website accessed: 12 August 2006.
- IDP, 2007: Integrated Development Plan, March 2007. Emalahleni Local Municipality.
<http://www.emalahleni.gov.za>. Website accessed: 17 July 2007.
- Jack, D., 2004: *Income, household energy and health*.
<http://www.sparknet.info>
 Website accessed: 15 February 2005.
- Johansson, S.A.E. and Campbell, J.L., 1988: *PIXE: A novel technique for elemental analysis*. John Wiley and Sons, Great Britain.
- Johnson, B.B. and Frank, P.G., 2004: Public understanding of environmental impacts of electricity deregulation. *Energy Policy*, Article in press.
- Keil, A. and Haywood, J.M., 2003: Solar radiative forcing biomass burning aerosol particles during SAFARI 2000: A case study based on measured aerosol and cloud properties, *Journal of Geophysical Research*, 108 (D13): 8467:
 doi: 10.1029/2002JD002315, SAF 3:1-10.

- Kim, Y.J., Kim, K.W., Park, H.S., Park, J.S., Jung, H.R., Kim, S.D. and Han, J.S., 2003: *Physico-chemical characteristics of visibility impairing aerosol measured at two urban sites in Seoul and Incheon, Korea.*
<http://www.khist.ac.kr>
 Website accessed: 03 July 2005.
- Kitchin, R. and Tate, N.J., 2000: *Conducting research in human geography: Theory, methodology and practice.* Prentice Hall, United Kingdom.
- Levine, J.S. (ed.), 1996: *Biomass burning and global change.* MIT Press, Cambridge.
- Li, J., Posfai, M., Hobbs, P.V. and Buseck, P.R., 2003: Individual Aerosol Particles from Biomass Burning in Southern Africa: Compositions and Aging in Inorganic Particles, *Journal of Geophysical Research*, 108 (D13): 8484: doi: 10.1029/2002JD002310, 20-1 - 20-12.
- Lindesay, J.A., 1992: Biomass burning as a factor in atmospheric chemistry and terrestrial ecology. *Suid-Afrikaanse Tydskrif vir Wetenskap*, 88: 143-144.
- Liu, W., Wang, Y., Russell, A. and Edgerton, E.S., 2005: Atmospheric aerosol over two urban-rural pairs in the south-eastern United States: Chemical composition and possible sources. *Atmospheric Environment*, 39: 4453-4470.
- Ludwig J., Marufu L.T., Huber B., Andreae M.O., Helas G., 2003: Domestic combustion of biomass fuels in developing countries: A major source of atmospheric pollutants. *Journal of Atmospheric Chemistry*, 44 (1): 23-37.
- Luginaah, I.N., Taylor, S.M., Elliott, S.J. and Eyles, J.D., 2002: Community responses and coping strategies in the vicinity of a petroleum refinery in Oakville, Ontario. *Health and Place*, 8: 177-190.
- Lykke, A.M., 2000: Local perceptions of vegetation change and priorities for conservation of soody-savanna vegetation in Senegal. *Journal of Environmental Management*, 59: 107-120: doi: 10.1006/jema.2000.0336.
- Marufu, L., Ludwig, J., Andreae, M.O., Meixner, F.X. and Helas G., 1997: Domestic biomass burning in rural and urban Zimbabwe – Part A. *Biomass and Energy*, 12 (1): 53-68.

- Maryland Energy Administration, 2003: *Facts and issues: Conventional sources – Coal*.
<http://www.energy.state.md.us/facts/coal.html>
 Website accessed: 12 November 2003.
- Mason, B. and Moore, C.B., 1982: *Principles of Geochemistry*. 4th ed. John Wiley and Sons, New York.
- Mathee, A. and von Schirnding, Y.E.R., 2003: “Air quality and health in Greater Johannesburg”. In: G. McGranahan and F. Murray (eds), *Air pollution and health in developing countries*. Earthscan Publications, London, 206-219.
- McGranahan, G. and Murray, F. (eds), 2003: *Air pollution and health in developing countries*. Earthscan Publications, London.
- Matooane, M., Terblanche, P. and Tosen, G., 2004: *Health impacts of three electrification scenarios for urban areas in South Africa*. Paper presented at the Conference of the National Association for Clean Air (NACA), October 2004: Indaba Hotel, Johannesburg, South Africa.
- McCormick, R.A. and Baulch, D.M., 1962: The variation with height of the dust loading over a city determined from the atmospheric turbidity. *Journal of the Air Pollution Control Association*, 12: 492-496.
- McDonald, D.A., 2002: “What is environmental justice?” pages 1-14. In: McDonald, D.A., 2002: *Environmental Justice in South Africa*. UCT Press, Cape Town.
- McDonald, D.A., 2002: *Environmental Justice in South Africa*. UCT Press, Cape Town.
- McKendry, I.G., Sturman, A.P. and Vergeiner, J., 2004: Vertical profiles of particulate matter size distributions during winter domestic burning in Christchurch, New Zealand. *Atmospheric Environment*, 38: 4805-4813.
- Mdluli, T.N., Annegarn, H.J. and Scorgie, Y., 2003: *The potential socio-economic impacts of measures to reduce air pollution from domestic coal combustion and vehicles: The case of Soweto*. Poster presented at the International Young Scientists’ Global Change Conference (Trieste, Italy); 16-21 November 2003.

- Mehlwana, A. and Qase, N., 1996: *Social determinants of energy use in low-income metropolitan households in the Western Cape (Phase 1)*. Report No: EO9420. Department of Minerals and Energy, Pretoria.
- Metzner, J., 2003: Air pollution: Global problem.
<http://www.pulseplanet.com/archive/Jul03/2976.html>
 Website accessed: 28 July 2003.
- Monn, C., 2001: Exposure assessment of air pollutants: A review on spatial heterogeneity and indoor/outdoor/personal exposure to suspended particulate matter, nitrogen dioxide and ozone. *Atmospheric Environment*, 35: 1-32.
- Nachmias, D. and Nachmias, C., 1987: *Research methods in the social sciences*. St Martins Press, New York.
- NASA (National Aeronautical and Space Administration), 1996: *Atmospheric aerosols: What are they? and Why are they so important?* NASA facts on line.
<http://oea.larc.nasa.gov/PAIS/Aerosols.html>
 Website accessed: 25 May 2005.
- NRDC (National Research Defence Council), 2004: *Annual Report*.
<http://www.nrdc.org/international/default.asp>
 Website accessed: 25 May 2005.
- O'Connor, R.E., Bord, R.J. and Fisher, A., 1999: Risk perceptions, general environmental beliefs and willingness to address climate change. *Risk Analysis*, 19 (3): 461-471.
- Olszyna, K.J., Bairai, S.T. and Tanner, R.L., 2005: Effect of ambient NH₃ levels on PM_{2.5} composition in the Great Smoky Mountains National Park. *Atmospheric Environment*, 39: 4593-4606.
- Oosthuizen, M.A., Jinabhai, C., Terblanche, A.P.S. and Becker, P., 2004: *Prevalence of asthma in a group of young adults who spent their developing years in the Vaal Triangle, South Africa*. Paper presented at the Conference of the National Association for Clean Air (NACA), October 2004: Indaba Hotel, Johannesburg, South Africa.

- Pandey, P.K., Patel, K.S. and Subrt, P., 1998: Trace elemental composition of atmospheric particulates at Bhilai in central-east India. *The Science of the Total Environment*, 215: 123-134.
- Patterson, E.M., Kiang, C.S., Delany, A.C., Wartburg, A.F., Leslie, A.C.D. and Huebert, B.J., 1980: Global Measurements of Aerosols in Remote Continental and Marine Regions: Concentrations, Size Distributions and Optical Properties. *Journal of Geophysical Research*, 85 (C12): 7361-7376.
- Piketh, S.J., 2000: *Transport of Aerosols and Trace Gases over Southern Africa*. Unpublished PhD Thesis, University of the Witwatersrand, Johannesburg.
- Piketh, S.J., Annegarn, H.J. and Kneen, M.A., 1996: "Regional scale impacts of biomass burning emissions over southern Africa". In: J.S. Levine (ed), *Biomass burning and global change*. MIT Press, Cambridge, 320-326.
- Levine, J.S. (ed), 1996: *Biomass burning and global change*. MIT Press, Cambridge.
- Prati, P., Zucchiatti, A., Lucarelli, F. and Mando, P.A., 2000: Source apportionment near a steel plant in Genoa (Italy) by continuous aerosol sampling and PIXE analysis. *Atmospheric Environment*, 34: 3149-3157.
- Qase, N., Lloyd, P.J.D. and van Zyl, H., 2000: *Intervention potential for low-smoke fuels in the coal distribution chain*. Unpublished manuscript, Energy and Development Research Centre, University of Cape Town, Cape Town.
- Reid, J.S., Hobbs, P.V., Rango, A.L. and Hegg, D.A., 1999: Relationships between cloud droplet effective radius, liquid water content and droplet concentration for warm clouds in Brazil embedded in biomass smoke, *Journal of Geophysical Research*, 104 (D6): 6145-6153.
- Reuer, M.K., Boyle, E.A. and Grant, B.C., 2003: Lead isotope analysis of marine carbonates and sea water by multiple collector ICP-MS. *Chemical Geology*, 200: 137-153.
- Rogan, R., O'Connor, M. and Horwitz, P., 2005: Nowhere to hide: Awareness and perceptions of environmental change and their influence on relationships with place. *Journal of Environmental Psychology*, 25: 147-158.

- Rollin, H.B., Mathee, A., Bruce, N., Levin, J., von Schirnding, Y.E.R., 2004: Comparison of indoor air quality in electrified and un-electrified dwellings in rural South African villages. *Indoor Air*, 14: 280-216.
- Roux, T., and Vahle, R., 2002: *Electricity Rights in Soweto: An Analysis of Possible Legal Arguments*. Law & Transformation Programme Centre for Applied Legal Studies, University of the Witwatersrand. <http://www.law.wits.ac.za>. Website accessed: 17 July 2007.
- Russell, B.H., 2000: *Social research methods: Qualitative and quantitative approaches*. Sage Publications, London.
- Saitoh, K., Sera, K., Hirano, K. and Shirai, T. 2002: Chemical characterization of particles in winter-night smog in Tokyo. *Atmospheric Environment*, 36: 435-440.
- Scorgie, Y., Burger, L.W. and Sowden, M. 2001: *Analysis, synthesis and consolidation of the Qalabotjha and Embalenhle experiments, including other investigations*. Unpublished manuscript. Department of Minerals and Energy, Pretoria.
- Scorgie, Y., Burger, L.W. and Annegarn, H.J., 2003a: *Socio-economic impact of air pollution reduction measures – Task 2: Establishment of source inventories and Task 3: Identification and prioritization of technology options*. Report compiled on behalf of NEDLAC, 25 June 2003.
- Scorgie, Y., Kneen, M.A., Annegarn, H.J. and Burger, L.W., 2003b: *Air pollution in the Vaal Triangle – Quantifying source contributions and identifying cost-effective solutions*. Paper presented at the Conference of the National Association for Clean Air (NACA), October 2003: Vaal Park, South Africa.
- Smith, K.R., 2000: National burden of disease in India from indoor air pollution. *National Academy of Sciences*, USA 97 (24): 13286-13293.
- Smith, K.R., 2002: Indoor air pollution in developing countries: Recommendations for research. *Indoor Air*, 12: 198-207.
- Smith, K.R., Apte, M.G., Yuqing, M., Wongsekiarttirat, W. and Kulkarni, A., 1994: Air pollution and the energy ladder in Asian cities. *Energy*, 19: 587-600.

Soweto Project, 2001:

<http://www.sahistory.org.za/pages/town&c/villages/gauteng/soweto/links.htm>

Website accessed: 10 May 2006.

Spalding-Fecher, R. 2000: *Environmental benefits of electrification in developing countries: A quantitative assessment in South Africa*. Paper presented at the International Society of Ecological Economics 2000 Conference. 5-8 July, Canberra, Australia.

Spalding-Fecher, R. 2002: *Energy and sustainable development in South Africa*.

<http://www.helio-international.org/Helio/Reports/2002/English/SouthAfrica/SAtot.pdf>

Website accessed: 12 April 2003.

Spalding-Fecher, R. and Matibe, D.K., 2003: Electricity and Externalities in South Africa. *Energy Policy*, 31: 721-734.

Spalding-Fecher, R., 2005: Health benefits of electrification in developing countries: A quantitative assessment in South Africa. *Energy for Sustainable Development*, IX (1): 23-32.

Spalding-Fecher, R., Clark, A., Davis, M. and Simmonds, G., 2002: The economics of energy efficiency for the poor – A South African case study. *Energy*, 27: 1099-1117.

St Denis, M.J., Cicero-Fernandez, P., Winer, M., Butler, J.W. and Jesion, G., 1994: Effects on in-use driving conditions and vehicle/engine operating parameters on “off-cycle” events: Comparison with federal test procedure conditions. *Journal of Air and Waste Management Association*, 44: 31-38.

Stein, J., 2000: *Air pollution – Worse indoors for many*.

http://health-e.org.za/news/easy_print.php?uid=20000403

Website accessed: 10 November 2005.

Stroh, M., 2000: “Qualitative interviewing”. In: D. Burton (ed.), 2000, *Research and training for social scientists*. Sage Publications, London.

Sunyer, J. 2001: Urban air pollution and chronic obstructive pulmonary disease: A review. *European Respiratory Journal*, 17: 1024-1033.

- SuperCROSS, 1993-2006: *Space-Time Research 2001*. Space Time Research Pty Ltd.
<http://www.statssa.gov.za/extract.htm>
 Website accessed: 10 November 2005.
- Surridge, T., 2004: *Strategy to combat the negative impacts of domestic coal combustion*.
 Paper presented at the Conference of the National Association for Clean Air
 (NACA), October 2004: Indaba Hotel: Johannesburg, South Africa.
- Swap, R.J., Annegarn, H.J., Suttles, J.T., King, M.D., Platnick, S., Privette, J.L. and
 Scholes, R.J., 2003: Africa burning: A thematic analysis of the Southern African
 Regional Science Initiative (SAFARI), *Journal of Geophysical Research*,
 108 (D13): 8465: doi: 10.1029/2003JD003747.
- Swietlicki, E., Martinsson, B.G. and Kristiansson, P., 1996: The use of PIXE and
 complementary ion beam analytical techniques for studies of atmospheric
 aerosols. *Nuclear Instruments and Methods in Physics Research*,
 B (109/110): 385-394.
- Swietlicki, E., Puri, S. and Hansson, H.C., 1996b: Urban air pollution source apportionment
 using combination of aerosol and gas monitoring techniques. *Atmospheric
 Environment*, 30 (15): 2795-2809.
- Terblanche, A.P.S., Nel, R., Reinach, G., and Opperman, L., 1992: Personal exposures to total
 suspended particulates from domestic coal burning in South Africa. *The Clean Air
 Journal*, 8 (6): 15-17.
- Terblanche, A.P.S., Danford, I.R. and Nel R.M., 1993: *Health and safety aspects of
 household fuels – Phase 2*. Report to the Department of Minerals and Energy,
 Pretoria.
- Terblanche, A.P.S., Nel, C.M.E., Opperman, L., and Nyikos, H., 1993a: Exposure to air
 pollution from transitional household fuels in a South African Population. *Journal
 of Exposure Analysis and Environmental Epidemiology*, 3 (1): 15-22.
- Terblanche, A.P.S., Danford, I.R., and Nel, C.M.E., 1993b: Household Energy Use in South
 Africa, air pollution and human health. *Journal of Energy in Southern Africa* 4 (2):
 54-57.

- Terblanche, A.P.S., 1994: Energy and Health – The household energy ‘dilemma’ in South Africa. *World Energy Council Regional Forum: Southern and East Africa*. 3: 2-9.
- Terblanche, A.P.S., Nel, R., and Golding T., 1994: *Household Energy Sources in South Africa – An Overview of the Impact of Air Pollution on Human Health*. CSIR Environmental Services, Department of Minerals and Energy and EMSA (Pty) Ltd.
- Terblanche, A.P.S., Danford, I.R., and Pols, A.S., 1995: Comparative evaluation of human exposures to air pollution from low-smoke and conventional coal usage. *Journal of Energy in Southern Africa* 6 (3): 131-136.
- TERI (The Energy and Resources Institute), 2000a: *Improved cookstoves programme in North India*.
http://www.teriin.org/case_inside.php?id=17062
 Website accessed: 09 September 2006.
- TERI (The Energy and Resources Institute), 2000b: *Fuel substitution in the rural sector*.
http://www.teriin.org/case_inside.php?id=17069
 Website accessed: 09 September 2006.
- Trakolis, D., 2001: Local peoples’ perceptions of planning and management issues in Prespes Lakes National Park, Greece. *Journal of Environmental Management*, 61: 227-241: doi: 10.1006/jema.2000.0410.
- Tsai, F.C., Smith, K.R., Vichit-Vadakan, N., Ostro, B.D., Chestnut, L.G. and Kungskulniti, N., 2000: Indoor/outdoor PM₁₀ and PM_{2.5} in Bangkok, Thailand. *Journal of Exposure Analysis and Environmental Epidemiology*, (10): 15-26.
- Turco, R.P., Toon, O.B., Ackerman, T.P., Pollack, J.B. and Sagan, C., 1983: Nuclear winter: Global consequences of multiple nuclear explosions. *Science*, 222: 1283-1292.
- TWF (The World Factbook), 2005: *The world factbook*.
<http://www.cia.gov/cia/publications/factbook/geos/sf.html>
 Website accessed: 15 June 2006.
- Twomey, S., 1997: *Atmospheric Aerosols*. Elsevier Scientific, Amsterdam.

- Tyson, P.D. and Preston-Whyte, R.A., 2000: *The weather and climate of Southern Africa*. (2nd ed). Oxford University Press, Cape Town.
- UNDP, 2000: *Human development and transformation in South Africa*.
<http://www.undp.org.za/sahdr2000/balancesheet.pdf>
 Website accessed: 13 March 2004.
- Vallius, M., Lanki, T., Tiittanen, P., Koistinen, K., Ruuskanen, J. and Pekkanen, J., 2003: Source apportionment of urban ambient PM_{2.5} in two successive measurement campaigns in Helsinki, Finland. *Atmospheric Environment*, 37: 615-623.
- van Horen, C., Eberhard, A., Trollip, H. and Thorne, S., 1993: Energy, environment and urban poverty in South Africa. *Energy Policy*, 21 (5): 623-639.
- van Horen, C., 1996. *The cost of power: externalities in South Africa's energy sector*. Unpublished manuscript, Energy and Development Research Centre, University of Cape Town, Cape Town. In: Scorgie, Y., Burger, L.W. and Sowden, M. 2001: *Analysis, synthesis and consolidation of the Qalabotjha and Embalenhle experiments, including other investigations*. Unpublished manuscript. Department of Minerals and Energy, Pretoria.
- Van Horen C., Nel, R., and Terblanche, P., 1996: Indoor air pollution from coal and wood use in South Africa: an overview. *Energy for Sustainable Development*, 3 (1): 38-40.
- van Nierop, P.G., 1995: A source inventory of particulate air pollution in the Vaal Triangle. Unpublished MSc dissertation, University of the Witwatersrand, Johannesburg.
- Volkwein, J.C. and Thimons E.D., 2001: *New tools to monitor personal exposure to respirable coal mine dust*.
<http://www.cdc.gov/niosh/mining/pubs/pdfs/nttmp.pdf>
 Website accessed: 25 April 2005.
- Volkwein, J.C., Schoeneman, A.L. and Page, S.J., 1999: *Laboratory evaluation of pressure differential-based respirable dust detector tube*. Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, Pennsylvania.
<http://www.cdc.gov/niosh/mining/pubs/pdfs/leopd.pdf>
 Website accessed: 25 April 2005.

- von Klot, S., Wolke, G., Tuch, T., Heinrich, J., Dockery, D.W., Schwartz, J., Kreyling, W.G., Wichmann, H.E. and Peters, A. 2002: Increased asthma medication use in association with ambient fine and ultrafine particles. *European Respiratory Journal*, 20: 691-702.
- Wang, J.S.A, Xia, X., Wang, P. and Christopher, S.A., 2004: Diurnal variability of dust aerosols, optical thickness and Angstrom exponent over dust source regions in China. *Geophysical Research Letters*, 31 (L08107): doi: 1029/2004GL019580.
- WHO (World Health Organization), 1999: *Monitoring ambient air quality for health impact assessment*. WHO Regional Publications, European Series, No. 85.
<http://www.euro.who.int/document/e6702.pdf>
Website accessed: 21 July 2004.
- WHO (World Health Organization), 2000: Air quality guidelines for Europe. 2nd ed. WHO Regional Publications, European Series, No. 91.
<http://www.euro.who.int/document/e71922.pdf>
Website accessed: 12 May 2003.
- WHO (World Health Organization), 2004: WHO statement on indoor air pollution.
http://www.itdg.org/?id=iap_who
Website accessed: 16 June 2005.
- WHO (World Health Organization), 2005: *Indoor air pollution and health*. Fact sheet No. 292.
<http://www.who.int/mediacentre/factsheets/fs292/en/index.html>
Website accessed: 16 June 2005.
- Winkler, H., Spalding-Fecher, R., Tyani, L. and Matibe, K., 2000: Cost-benefit analysis of energy-efficiency in low-cost housing. Unpublished manuscript, Energy and Development Research Centre, University of Cape Town, Cape Town.
- WREC (World Renewable Energy Council), 1996: *Energy conservation and management: Role of women*. All India Women's Conference, Rural Energy Department; New Delhi.
- WRI (The World Resources Institute), 1998: *World resources: A guide to the global environment 1998-99*. Oxford University Press, Oxford.

WRI (The World Resources Institute), 1999a: *Rising energy use: Health effects of air pollution.*

<http://www.wri.org/wri/wr-98-99/airpoll.htm#outdoor>

Website accessed: 20 July 2003.

WRI (The World Resources Institute), 1999b: Health effects of air pollution: Urban air: Health effects of particulates, sulfur dioxide and ozone.

<http://www.wri.org/wri/wr-98-99/urbanair.htm>

Website accessed: 20 July 2003.

Yin, R.K., 1994: *Case study research design and methods*. 2nd ed. Sage, Thousand Oaks CA.

Zheng, J., Tan, M., Shibata, Y., Tanaka, A., Li, Y., Zhang, G., Zhang, Y. and Shan, Z., 2004: Characteristics of lead isotope ratios and elemental concentrations in PM₁₀ fraction of airborne particulate matter in Shanghai after the phase-out of leaded gasoline. *Atmospheric Environment*, 38: 1191-1200.

APPENDIX 1:

PILOT QUESTIONNAIRE

The questionnaire that was pre-tested in Soweto and KwaGuqa before the actual questionnaire surveys were conducted.

Preamble

I am a student at the University of the Witwatersrand and I am conducting research as a requirement for my degree. My area of research is air pollution and its impacts on human livelihoods. I am interested particularly in the combustion of coal and how replacing or improving it would affect you. I would like to ask you a series of questions relating on this topic.

SECTION A: FUEL-USE DATA

1. Which fuels do you use in summer?

.....

.....

.....

.....

.....

.....

2. Which fuels do you use in winter?

.....

.....

.....

.....

.....

.....

3. Which fuel do you use for lighting?

Electricity ☐ LPG ☐ Paraffin ☐ Candles ☐ Other

4. Which fuel do you use for cooking?

☐ Electricity ☐ LPG ☐ Paraffin ☐ Coal ☐ Wood

☐ Other

5. Which fuel do you use for space heating?

☐ Electricity ☐ LPG ☐ Paraffin ☐ Coal ☐ Wood

☐ Other

6. Which fuel do you use for heating water?

☐ Electricity ☐ LPG ☐ Paraffin ☐ Coal ☐ Wood

☐ Other

7. How many bags of coal do you buy per month?

☐ 1 -3 ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15

8. How many bags of coal do you buy per month in the winter season (May – August)?

☐ 1 -3 ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15

9. Which of the following electric appliances do you use?

☐ Stove ☐ Iron ☐ Kettle ☐ Geyse ☐ Other

SECTION B: SOCIO-ECONOMIC DATA

1. Head of household

☐ Male ☐ Female

2. Employed

☐ Yes ☐ No

3. Level of education of head of household

☐ Below Std 8 ☐ Matric ☐ Certificate ☐ Diploma ☐ Degree

☐ Other.....

.....

4. Number of people living in household

☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15

☐ >15

5. Monthly income (R)

☐ 0-300 ☐ 301-500 ☐ 501- 800 ☐ 801-1000

☐ 1001-1300 ☐ >1300

6. How much do you pay for a bag of coal (10kg)?

- ☐ <R30 ☐ R30 ☐ R31-R40 ☐ R41-R50
☐ >R50

7. Would you say that burning coal brings your family together?

- ☐ Yes ☐ No

8. How?

.....

.....

.....

.....

.....

.....

**SECTION C: HEALTH IMPACTS OF DOMESTIC COAL
COMBUSTION**

1. Does anyone in your household suffer from any of the following?

- | | |
|---|---------------------------------------|
| ☐ Acute Respiratory Infections (ARI) | ☐ Wheezing |
| ☐ Tightness in the Chest | ☐ Coughing |
| ☐ Asthma | ☐ Bronchitis |
| ☐ Lung Cancer | ☐ Lung Disease |
| ☐ Heart Disease | ☐ Stillbirths |

Underweight babies

2. How old is he/she?

- ☐ 0-24 months ☐ 3-5yrs ☐ 6-10yrs ☐ 11-15 yrs
☐ 16-20yrs ☐ >20yrs ☐ Elderly

3. How many times does he/she get sick per month?

- ☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ 10-12

4. Does the frequency increase in winter (May-August)?

- ☐ Yes ☐ No ☐ Not Observed

5. It increases to how many times per month?

- ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15 ☐ >15

6. Which clinic/hospital does he/she go for treatment?

.....
.....

7. How much do you pay for one visit to casualty?

- ☐ R13 ☐ R14-R20 ☐ R21-R40 ☐ >R41

8. Has he/she been admitted before?

- ☐ Yes ☐ No

9. How many times (admissions) per year?

.....
.....
.....

10. Is he/she admitted more frequently in winter?

.....
.....
.....

11. How frequently?

.....
.....

12. How much did you pay (admission) per day or for the duration of the admission?

.....
.....
.....

13. How would you say that this (whole thing about diseases) affects you financially and otherwise?

.....
.....
.....
.....
.....

SECTION D: LOW-SMOKE FUELS

1. If we would sell these low-smoke fuels as alternative fuels to you, would you be willing to buy them?

☐Yes ☐No

2. How much would you be willing to pay for an amount equal to that of coal (10kg)?

☐ <R30 ☐ R30 ☐ R31-R40 ☐ R41-R50 ☐ >R50

3. What price do you think you would afford for a 10 kg bag of low-smoke fuel?

☐ <R30 ☐ R30-R40 ☐ R41-R50 ☐ R51-R60 ☐ >R60

4. How do you think that this change in fuel would affect you?

.....

.....

.....

.....

.....

.....

SECTION E: COAL REGULATION OPTIONS

1. Basa njengo magogo

2. Stove maintenance programme

A brief explanation will be given before embarking on the discussions to be guided by the questions below.

1. Would you be willing to have the above-mentioned technologies in your house to regulate the use of coal?

☐ Yes ☐ No

2. How much would you be willing to pay for the stove maintenance programme?

☐ <R300 ☐ R300-R1 000 ☐ R1 001-R4 000

☐ R4 001-R5 000 ☐ >R5 000

3. Which price do you think you would afford for the stove maintenance programme?

- ☐ <R300 ☐ R301-R400 ☐ R401-R500
☐ R501-R600 ☐ >R600

4. How do you think this would affect you financially and in other ways?

.....

.....

.....

.....

.....

.....

.....

.....

APPENDIX 2:

FINAL QUESTIONNAIRE

A sample of the questionnaire that was used to interview householders in Soweto and KwaGuqa.

Preamble

My name is Thulie Mdluli and I am a student at the University of the Witwatersrand (my research assistants are). I am conducting a research as a requirement for my degree. My focus is air pollution and its impacts on human livelihoods. I am interested particularly in the combustion of coal and how replacing or improving it would affect you. I am kindly inviting you to sit with me in an interview where I will ask you a series of questions relating to this topic. You have a right to withdraw from this interview at any time. Your identity will not be disclosed and the information that you will provide will be used for research purposes only. If you need further information, you may contact Dr L Otter on 011 717 6533 or Prof C Vogel on 011 717 6510.

SECTION A: FUEL-USE DATA

1. Is your house electrified?

☐ ☐ Yes

☐ ☐ No

2. Do you burn coal at all? (If NO Skip 7-9)

☐ ☐ Yes

☐ ☐ No

3. Which fuel(s) do you use for lighting?

Electricity ☐ LPG ☐ Paraffin ☐ Candles ☐ Other

4. Which fuel(s) do you use for cooking?

☐ Electricity ☐ LPG ☐ Paraffin ☐ Coal ☐ Wood

☐ Other

5. Which fuel(s) do you use for space heating?

☐ Electricity ☐ LPG ☐ Paraffin ☐ Coal ☐ Wood

☐ Other

6. Which fuel(s) do you use for heating water?

☐ Electricity ☐ LPG ☐ Paraffin ☐ Coal ☐ Wood

☐ Other

7. Where do you burn your coal?

☐ Stove ☐ Brazier (Imbawula) ☐ Fire place

☐ Open flame

8. How many bags of coal do you buy per month?

☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15

van

9. How many bags of coal do you buy per month in the winter season (May – August)?

☐ 1 -3 ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15

van

SECTION B: SOCIO-ECONOMIC DATA

1. Head of household

☐ Male ☐ Female

2. Is the head of household employed?

☐ Yes ☐ No ☐ Self Employed ☐ Pensioner

3. Number of people living in household

☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ 10-12 ☐ 13-15

☐ >15

4. How much do you buy your electricity units for per month (R)?

☐ 0-50 ☐ 51-100 ☐ 101-150 ☐ 151-200

☐ 201-250 ☐ >250

5. How much do you pay for a bag of coal (70kg)?

☐ <R30 ☐ R31-R60 ☐ R61-R90 ☐ >R90

6. Would you say that burning coal brings your family together?

☐ Yes ☐ No

7. How?

.....

.....

.....

.....

.....

.....

SECTION C: LOW-SMOKE FUELS AND ELECTRICITY

Low-smoke fuels were developed as an alternative to coal in order to reduce smoke emissions and to reduce public health issues. (Engelbrecht *et al*, 2001). They can be used the same way as coal but they release less smoke hence they are believed to have less health impacts than coal. **(Give a description to the respondent and make sure he/she has an understanding of what these low-smoke fuels are and how they work).**

1. If you were to choose between low-smoke fuels and electricity, what would you choose and why?

☐ Low-Smoke Fuel ☐ Electricity ☐ Not comparable

.....

.....

.....

.....

2. If low-smoke fuels were sold to you or your house electrified, would you be willing buy them?

☐ Yes ☐ No

3. How much would you be willing to pay for an amount of low-smoke fuels equal to that of the coal (60 kg)?

☐ <R30 ☐ R31-R60 ☐ R61-R90 ☐ >R90

**4. How do you think that using low-smoke fuels would affect your health?
Probe.**

.....
.....
.....
.....

5. How do you think that electrification would affect your health? Probe.

.....
.....
.....
.....

6. If your house was electrified would you still burn coal? If yes, why?

.....
.....
.....
.....
.....
.....
.....
.....

SECTION D: HEALTH IMPACTS OF DOMESTIC COAL COMBUSTION

1. Has anyone in your household suffered from any of the following in the last one year?

- | | |
|---|---------------------------------------|
| ☐ Acute Respiratory Tract Infections | ☐ Wheezing |
| ☐ Tightness in the Chest | ☐ Coughing |
| ☐ Asthma | ☐ Bronchitis |
| ☐ Lung Cancer | ☐ Lung Disease |
| ☐ Heart Disease | ☐ Stillbirths |
| Underweight babies | Sinusitis |
| No illnesses | |

2. How old is he/she?

- | | | | |
|-----------------------------------|-----------------------------------|-----------------------------------|------------------------------------|
| ☐ 0-10 yrs | ☐ 11-20yrs | ☐ 21-30yrs | ☐ 31-40 yrs |
| ☐ 41-50yrs | ☐ >50 | | |

3. How many times does he/she get sick per month?

- | | | | | |
|------------------------------|------------------------------|------------------------------|--------------------------------|------------------------------|
| ☐ 1-3 | ☐ 4-6 | ☐ 7-9 | ☐ 10-12 | ☐ >12 |
|------------------------------|------------------------------|------------------------------|--------------------------------|------------------------------|

4. Does the frequency increase in winter: May-August? (If NO or not observed skip 6 - 7)

- | | | |
|------------------------------|-----------------------------|---------------------------------------|
| ☐ Yes | ☐ No | ☐ Not observed |
|------------------------------|-----------------------------|---------------------------------------|

5. It increases to how many times per month?

- | | | | | |
|------------------------------|------------------------------|--------------------------------|--------------------------------|------------------------------|
| ☐ 4-6 | ☐ 7-9 | ☐ 10-12 | ☐ 13-15 | ☐ >15 |
|------------------------------|------------------------------|--------------------------------|--------------------------------|------------------------------|

6. Why do you think that the frequency increases in winter? Is it because of the low temperatures or because of inhaling coal smoke?

.....

.....

.....

7. Has he/she been admitted in hospital before?

☐ Yes ☐ No

8. How many times (admissions) per year?

.....

.....

.....

9. Is he/she admitted more frequently in winter?

.....

.....

.....

10. How frequently?

.....

.....

.....

11. Do you think that coal smoke from domestic coal combustion affects people's health? Discuss.

.....

.....

.....

.....

.....

.....

APPENDIX 3:

ESKOM INTERVIEW OUTLINE

An outline of the interview that was used to interview government and Eskom officials.

Preamble

I am a student at Wits University and I am conducting a research as a requirement to finish my PhD. I am interested particularly in the air pollution resultant from domestic coal combustion and how electrification could possibly improve the problem. Would you mind answering a series of questions relating to this topic? Your identity will not be disclosed and the information that you provide will be used for research purposes only.

1. What are your pricing structures and are they the same for all consumers in the country?
2. What is the average electricity bill of a household in an electrified township?
3. In the electrified townships are people able or willing to pay for electricity consumption?
4. It has been noted that households in townships continue to burn coal even after their houses have been electrified. What are your views about this?
5. Given that domestic coal smoke is a constant threat to human health due to the low elevation at which emissions occur, what would you say about that? Do you think that this problem

could be solved by electrification? (**probe more and follow-up on ideas raised**)

6. What are your goals, if any, pertaining to this problem of domestic coal emissions and the use of alternative energy sources like electricity?

APPENDIX 4:

CLEARANCE CERTIFICATE FROM THE

NON-MEDICAL ETHICS COMMITTEE OF THE

UNIVERSITY OF THE WITWATERSRAND

APPENDIX 5:
CALIBRATION CERTIFICATES FOR DUSTTRAK
AEROSOL MONITORS