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Power, Policy and Pricing: an analysis of Free Basic Electricity in Khayelitsha.

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Abstract

This study focuses on the economic rationale for increased electrification in Khayelitsha and for enhanced Free Basic Electricity (FBE) policies. Air quality readings in Khayelitsha have shown high readings of pollution and a particularly high incidence of coarse particulate matter (PM10). These are on average 25 per cent higher than Goodwood and 70 per cent higher than in central Cape Town. PM10s are particularly harmful pollutants and impose an increasing marginal external cost; the health implications of exposure varying directly with exposure levels. Open fires, traditional and paraffin stoves, and flame based lighting are major contributors to respiratory disease and altered lung function. Low birth-weight, nutritional deficiency, tuberculosis, cardiovascular disease and cataracts have also been associated with the prevalence of PM10. It was found in this dissertation that PM10 readings are significantly higher than allowed by national standards and that a 100 per cent increase in Free Basic Electricity, from 50kWh per month to 100kWh, would be appreciably beneficial to health outcomes. Dose-response functions were used to evaluate the effect of a 10 per cubic metre$\mu g//\text{m}^3$ decrease in PM10 for lung diseases, Lower Respiratory Illness in children, Chronic Obstructive Pulmonary Disease (COPD), cardiovascular and respiratory mortality and other related symptoms. It was seen that all of these adverse health episodes would decrease to varying extents, for example between 13 and 14 lives could be saved from COPD, cardiovascular mortality could decrease by around 468 deaths and respiratory deaths could decrease by about 2 491. Added to this, between 721 665 and 1 237 140 annual sick days would be saved annually and ambient pollution readings would drop, although the extent to which this would happen is unknown.

Note

Some of the information presented in this dissertation date far back as 2001 (as in the case of the 2001 Census data). It should be noted that the relevant data from the 2011 Census will only be released after this dissertation has been submitted. Unfortunately I could not wait for this since it would require registration for another year at the University.

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Chapter 1

Introduction

One of the key motivations for undertaking this study is the lack of literature on the costs and benefits of the further electrification of Khayelitsha or of increases in the electricity subsidy. While tests have been done on the use of alternative fuels in Khayelitsha, no local literature has dealt with the implications of these different fuels for indoor pollution and how electrification in the region may decrease the prevalence of PM10. There is also little information on the costs and benefits of the existing electrification of Khayelitsha.

The primary aim of this dissertation is to assess the social benefits of electricity in Khayelitsha using a cost-effectiveness analysis of an increase in the monthly provision of Free Basic Electricity (FBE) from the current 50kWh to 100kWh. FBE has existed in South Africa since July 2000. There have been no reforms to the policy since its inception despite continually increasing electricity prices and increasing domestic (indoor) pollution. Air pollution, whether domestic or ambient, is a significant problem in the Western Cape and is strongly correlated with a range of health problems including chronic obstructive pulmonary disease, lower respiratory infection in children, tuberculosis, low birth weights and a range of ophthalmic conditions. Such fuel-related health externalities are a major focus of this study. Due to the fact that very little research has been done in South Africa regarding PM10 prevalence and health problems, local adaptations of international dose-response functions are used to assess the value of increased FBE in alleviating PM10-related illnesses. Dose-response functions depict the health outcomes associated with a $10\mu g/m^3$ increase in PM10. Once these are established the health benefits that arise from using electricity for domestic use instead of ‘dirty’ fuels can be estimated.

Chapter 2

Literature review

2. 1. Opening comments

In 1997 the City appointed the University of Cape Town to investigate the 'brown haze' phenomenon normally experienced in Cape Town between May and September. The brown haze strongly degrades visibility and is typically characterised by strong temperature inversions and windless conditions (Wicking-Baird *et al*, 1997). It has been speculated that the haze is the result of two dominant factors: vehicle emissions and pollution arising from informal settlements such as Khayelitsha (ibid).

The report mentioned air quality readings in Khayelitsha that showed high readings of pollution in general, with a particularly high incidence of PM10 (coarse particulate matter) i.e. particles with a diameter equal to or less than 10 micrometres. Such particulates are not well filtered and therefore settle in the lungs. The functioning of vital organs can be affected if exposure is sustained over an extended period.

PM10 concentrations can be general (as in the case of the 'brown haze') or localised (as in the case of domestic air pollution). The domestic combustion of fuels, fuels on open fires and traditional stoves, wood burning and refuse burning are major contributors to PM10 concentrations and have adverse effects on health in the form of respiratory disease and altered lung function (ibid).

A plausible solution to this problem is the further electrification of Khayelitsha, however there is no indication that its costs and benefits have been adequately considered. An evaluation would need to address the negative health externalities of alternative fuels such as wood and paraffin as well as the social impacts of alternative electricity pricing policies. It would also need to address the negative health externalities of illegal electricity connections.. With Electricity prices rising faster than inflation each year the cost of governmental policies already in place, such as the Free Basic Electricity (FBE) grant, is changing. Increases in ESKOM's nominal tariffs were 24.8 per cent between 2010 and 2011, 16 per cent between 2011 and 2012 and are projected to be around 25.9 per cent between 2012 and 2013 (NERSA, 2010). This has obvious economic as well as welfare implications for the prospect of electrification in Khayelitsha.

2. 2. Physical and socio-economic background to the problem

Khayelitsha, is a township situated approximately 35km east of Cape Town between Table Bay and False Bay (Figure 1). Its population is youthful, with two-thirds being younger than 30 years old and with the largest age cohort between 20 and 24 years old (City of Cape Town, 2006). Households are small and relatively impoverished, the average comprising about four members with a mean monthly revenue of R1600 per employed person. Just over half (52 per cent) of the population is 'economically active' with 25 per cent currently employed and 27 per cent unemployed but actively looking for work (ibid). The high unemployment rate in Khayelitsha is ascribed to a lack of employment opportunities rather than lack of educational training (ibid). Basic demographic indicators taken from the 2001 census are as follows (Statistics South Africa, 2003):

Population: 329206

Population groups:

- Black: 99.5 per cent
- Coloured: 0.5 per cent

Age:

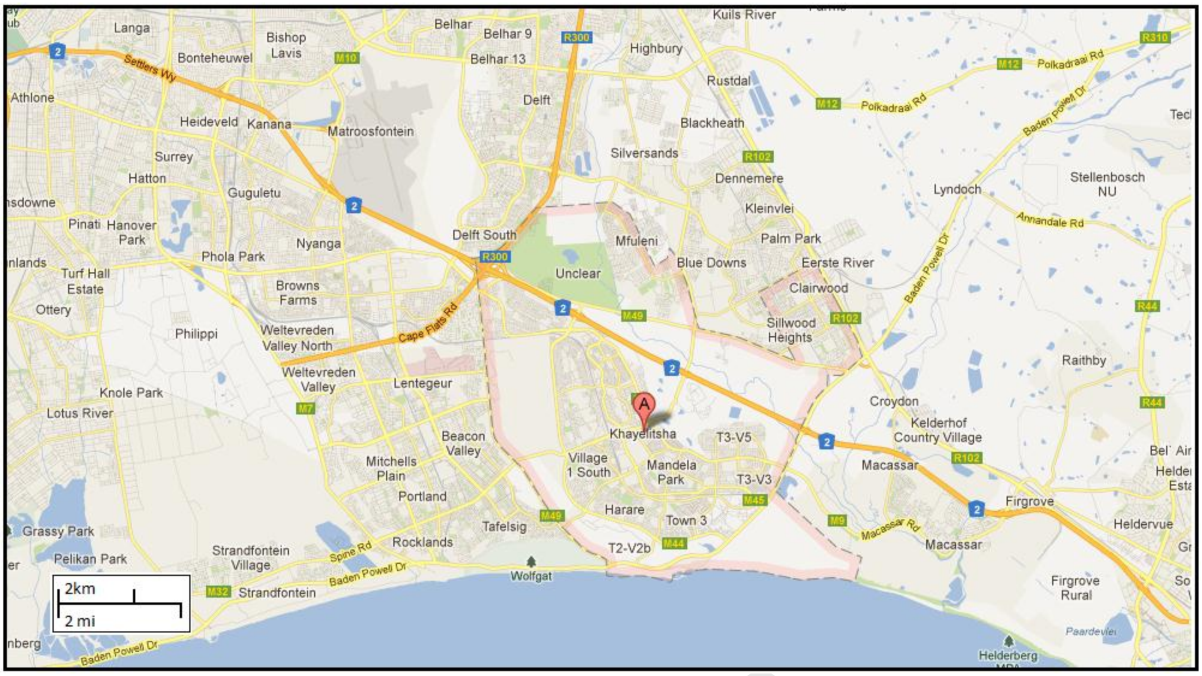
- 0 – 19 years old: 40.5 per cent
- 20 – 34 years old: 34.5 per cent
- 35 – 49 years old: 19 per cent
- 50 and older: 6 per cent

Language:

- Isixhosa: 96.5 per cent
- Sesotho: 1.6 per cent
- Other: 1.9 per cent

Further information regarding electricity coverage and access to electricity in Khayelitsha will be provided in Section 6 of the Literature Review.

Figure 1: Khayelitsha relative to other parts of Greater Cape Town



(Google, 2001)

*The data collection of this dissertation took place in the section of Khayelitsha labelled T3-V3 on the map.

2. 3. South Africa

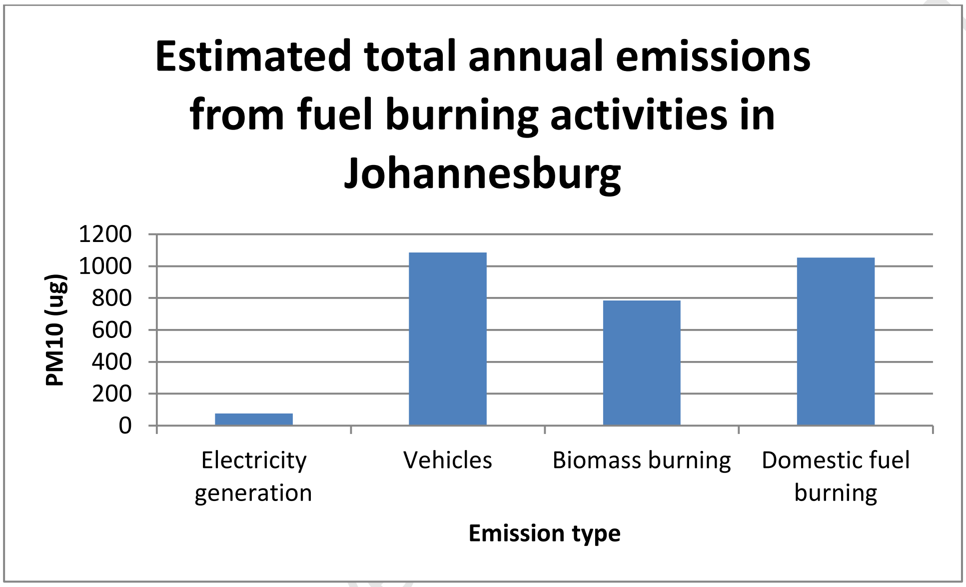
2. 3. 1. Domestic air pollution in South Africa

Of all sources of air pollution, domestic sources have by far the largest adverse effects on health in South Africa (Friedl *et al*, 2008). For example, a study commissioned by Nedlac found that, in the towns of Rustenburg and Sasolburg, domestic sources of air pollution were responsible for 69 per cent of total health impacts of ambient air pollution in the metropolitan areas (FRIDGE, 2003). Additionally, Lloyd *et al* (2004) noted that domestic air pollution correlated closely with acute respiratory infections, obstructive pulmonary disease and cancer. There is consistent evidence suggesting that exposure to domestic air pollution increases the risk of such diseases in childhood, these being the most significant cause of death of children younger than five years old (ibid). Accidental fires caused by paraffin are also a serious matter: Truran and Singh (2006) reported that paraffin related fires affect about 83 000 households each year or 2 per cent of total paraffin using households.

2. 3. 1. 1. Domestic air pollution in Johannesburg

Another Nedlac study (FRIDGE, 2003), found that industrial emissions, biomass burning and domestic fuel burning were the largest sources of Johannesburg's particulate emissions. Domestic fuel burning was found to contribute roughly a third of the total PM10 emissions (ibid), and was considered especially problematic given the high level of emissions, the winter-time and meal-time peaks (these are typically low-dispersion times) and the release of emissions in areas of high population density (ibid).

Figure 2: Estimated PM10 emissions from electricity generation, vehicles, biomass burning and domestic fuel burning in Johannesburg (2005)



(FRIDGE, 2003)

Indeed, domestic coal burning and coal fired burners were noted to be the most significant fuel burning related sources of airborne particulates in Johannesburg. It should be noted that coal-fired burners are not really an issue in Cape Town but that burning wood is indeed problematic in terms of PM10 and other harmful emissions. Table 1 shows the estimated annual emissions from domestic fuel burning activities in Johannesburg and in Cape Town (FRIDGE, 2003). It should be stated here that there are no more recent results available.

Table 1: Mean annual shares of pollutants from domestic fuel burning in Johannesburg and Cape Town

Pollutant	Johannesburg (%)	Cape Town (%)
TSP	28.63	13.64
PM_{10}	35.12	26.4
SO_2	28.66	1.49
NO_X	0.83	0.97
CO	14.98	8.02
CH_4	41.28	57.13
CO_2	11.34	3.24
TOC	3.51	7.07
Benzene	3.67	17.34
Lead	1.02	0.06

(FRIDGE, 2003)

2. 3. 1. 2. Domestic air pollution in Cape Town

Sources contributing significantly to ambient particulate concentrations in Cape Town include domestic wood burning and coal fired industrial operations (FRIDGE, 2003). Additionally vehicle emissions, illegal waste dumping and burning, tyre burning, crate burning, wood burning and open fires and shack fires contribute to this (City of Cape Town, 2006) Domestic wood burning was associated with an estimated 28 per cent of respiratory ailments that required health care and visits or hospitalisation in 2002 (ibid). Domestic fuel burning is responsible for just over 26 per cent of Cape Town's total PM10 emissions (ibid). See Table 1 above for the estimated annual emissions from domestic fuel burning activities in Cape Town. Ambient air pollution becomes a problem in Cape Town between April and September when temperature inversions and windless conditions cause a haze that hangs over a large part of the city and affects visibility (Wicking-Baird *et al*, 1997). There is more information regarding air pollution in Cape Town under section 3. 6.

2. 3. 2. Electrification in South Africa

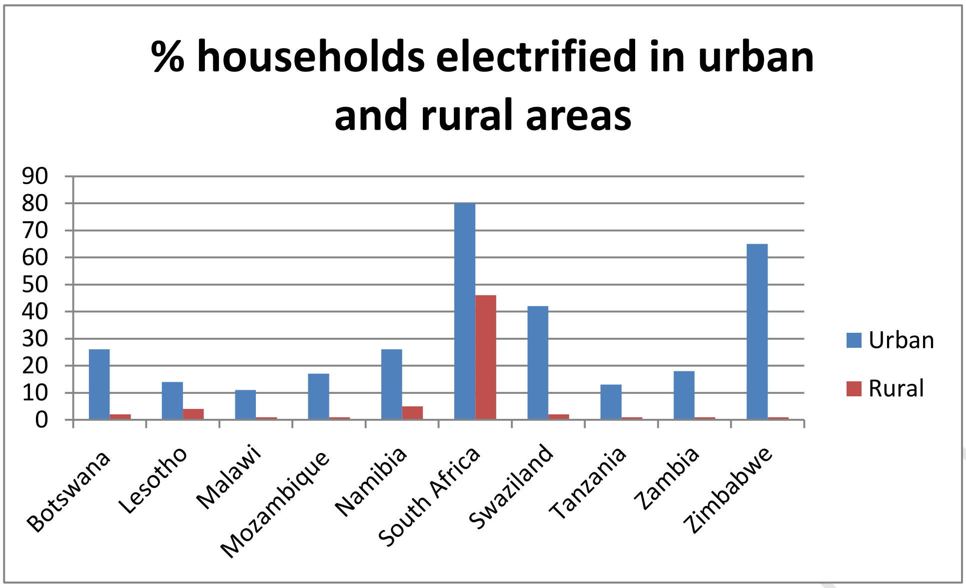
When South Africa's democratic transition occurred in 1994, the country experienced excess electricity generation capacity even during the winter months (DME, 2003), but many citizens still lacked access to electricity. Even today there is a significant discrepancy between population groups and areas in terms of electricity accessibility and ability to pay. The majority of those without access to electricity are rural South Africans. It should be noted here that the rural/urban divide and the black/white divide should not be conflated. This is certainly an issue that has been addressed since the transition, but it still needs further focus and attention.

Several electrification policies have been introduced in South Africa since 1994, but only the most significant, and most successful, will be discussed. It should be noted here that in 2005 electricity coverage in Khayelitsha (for lighting and cooking purposes) was around 76 per cent of the total number of households (City of Cape Town, 2005).

2. 3. 2. 1. The National Electrification Programme

Arising from the awareness of electrification inequality in South Africa, an Electricity-for-All initiative was established by some municipalities as well as by ESKOM. When Nelson Mandela was released in 1991 and the ANC & PAC were unbanned, this initiative was given widespread support. The new government adopted this programme and renamed it the National Electrification Programme (NEP) in 1994 (Gaunt, 2003). The NEP aimed to improve access for the poor and thereafter for all South Africans (Malzbender, 2005). In the first decade of ANC rule there were over three million households newly connected (Gaunt, 2003). In the decade between its initiation in 1991 and the year 2000 the proportion of households with electricity rose from 36 per cent to 69 per cent (ibid). As a result of this programme, South Africa has significantly higher connection rates than other countries in Southern Africa. Figure 3 below depicts electrification progress relative to other Southern African countries in 1999. To date South Africa produces almost half the entire continent's electricity output (African Development Bank Group, 2012).

Figure 3: The percentage of households electrified in urban and rural areas in Southern Africa.



(Gaunt, 2003)

The NEP started off as a grid electrification programme, though off-grid electrification was included later. The benefits of this programme are far reaching and include:

- reduced incidence of shack fires
- improved air quality
- improved public health outcomes
- improved pupil learning outcomes (students can study into the evening)

Clearly electricity provision alone is not enough. It has to displace other sources of energy historically in use. It was to this end that ESKOM introduced free basic electricity, an initiative to improve the poor's access to electricity by giving households 50kWh of free electricity each month. It should be stressed at this point that electricity, like paraffin, can be a danger hazard. Mains electricity can kill people if not used safely.

2. 3. 2. 2. Free Basic Electricity

Free Basic Electricity (FBE), also known as Basic Electricity Support Tariff (BEST) was implemented in July 2000 and makes provision for 50kWh per month per household as a free or subsidised service (Gaunt, 2003). It provides the electricity necessary for basic lighting, ironing, use of radio or TV and the occasional use of an electric kettle or hotplate (Prasad and Ranninger, 2003). To give a better idea of this, a typical 1000 watt appliance (kettle, hot-plate or microwave) could run at no cost for 50 hours a month. This makes it possible to cook and boil water for an hour a day and use only three fifths of FBE. A small 20 watt fluorescent light bulb could run for 2500 hours. This means that if a light bulb was the only appliance it could run twenty four hours a day for about three and a half months on one month's FBE. FBE is applicable to consumers using an amount equal to or less than 250kWh a month (City of Cape Town and ESKOM, 2011)

FBE, and electric connections in general, are perceived to have positive effects on real income in informal settlements such as Khayelitsha because they allow residents the opportunity to trade informally, in terms of opening a tuckshop or a food stall (ibid). For instance, it allows people to run a fridge which means they can buy food in bulk, and therefore more cheaply, and store it for personal use or for the purpose of selling it. A small fridge/freezer uses about 100 watts and could run for about 500 hours, or 11 days on FBE. There is also an important positive impact on small-scale industry and repair work that is inclined to come about as a result of electric connections in Khayelitsha. Prasad and Ranninger (2003) asked residents how this subsidy improved their lives; the answers are indicated below:

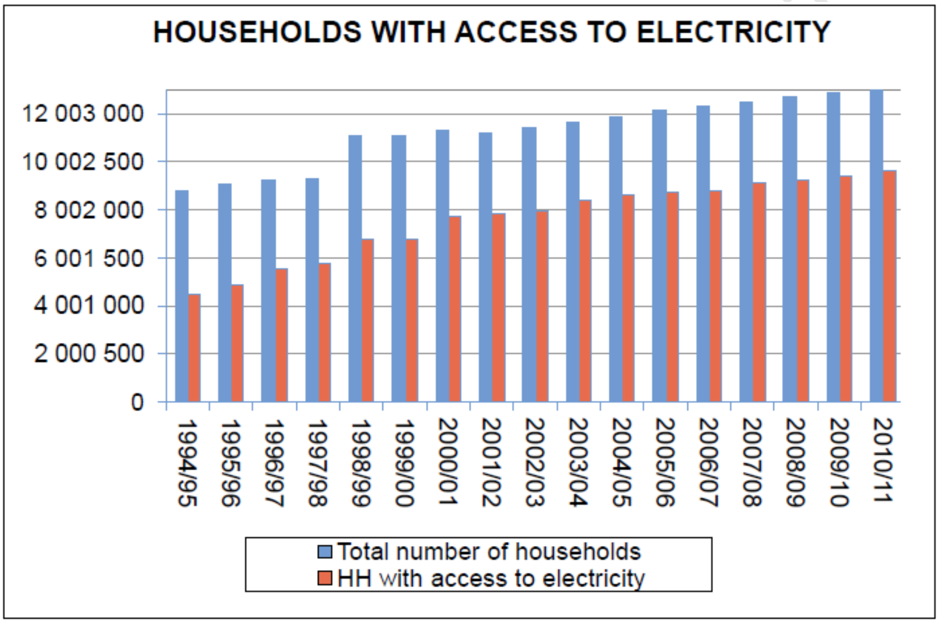
- they are able to use more electric light
- they are able to cook more efficiently
- they are able to use electricity for a longer period during the month
- they are able to use more appliances
- school children have a longer time to study
- they are able to spend more money on food
- their fuel collection journeys are reduced
- domestic air pollution is reduced
- anxiety about using electricity as a fuel is reduced

Cowan and Mohlakoana, (2005) found that the average consumption per household in Khayelitsha was 150kWh per month. This means that FBE covers one third of this cost and brings the unit cost down considerably. Of the households that were unable to afford electricity in Khayelitsha 63.4 per cent were allocated an FBE allowance in 2005 (City of Cape Town, 2005). This dissertation questions, among other things, whether it is feasible to increase the FBE above its present level and what the implications of increasing electricity tariffs might be in terms of domestic air pollution and health.

While FBE certainly has a place in South African electrification policy it also has its drawbacks. FBE does not offer the minimum needed to electrify a household for an entire month; this means that those who cannot afford the balance of electricity for the rest of the month will continue to supplement it with alternative fuels. Quite apart from this, but also a drawback of FBE, extending electrification is testing the country's ability to generate and distribute current. It is becoming increasingly important that government increases existing generating capacities and that capital is afforded to do this.

There has been great progress in South Africa in terms of household electrification. Overall, between 1990 and 2001, connections grew from just under 3 million to well over 7 million homes (Lloyd *et al*, 2004). Figure 4 below shows households with access to energy in 2012.

Figure 4: The number of households with access to electricity in South Africa



(Department of Energy, 2012)

2. 3. 3. Future Scenarios for South Africa

It seems that there are four obvious factors that will play a decisive role in future trends in the use of dirty fuels, and therefore in the prevalence of domestic air pollution. These factors can work independently to influence the dependence on fossil fuels, but in conjunction can realise quite drastic results. These four factors are oil price, housing, electricity supply and income. These factors may have an effect on South Africa as a whole but also for Khayelitsha in particular. They will be discussed briefly.

Oil Price

The oil price has a direct influence on the price of paraffin and affects the price of wood and coal indirectly.

Housing

Friedl *et al* (2008) estimated that South Africa needed/needs to build half a million subsidised houses per year between 2008 and 2015 to eliminate the housing backlog of about 2.2 million houses. The further the rate of housing delivery falls behind this rate, the greater the percentage of people that will live in thermally inefficient informal households. In such cases it is likely that these households will have to depend primarily on the combustion of dirty fossil fuels for cooking and for space heating.

Electricity Supply

In the event of an energy supply shortage, dirty fuels will serve as a backup strategy for many households. If the supply crisis persists or ceases only intermittently such fuels may remain the constant source of energy. If an energy supply crisis is avoided by increasing the price of energy an increase in dirty fuel dependence will ensue, particularly for the poor. However, an increase in FBE will place a greater burden on electricity generational capacity. In this case, energy efficiency needs to be realised on the level of all households.

Income

The future use of dirty fuels is, to some extent, dependent on whether households in low-income communities are becoming richer or poorer in terms of their real purchasing power. An increase in income is negatively correlated with the use of dirty fuels, particularly if cleaner fuels, such as electricity, are available (Friedl *et al*, 2008).

It is not to say that the abovementioned factors are the only ones that play a role in the future of dirty fuel dependence. There is an emerging expectation that there will always be an energy mix, where availability, cost and social preferences will determine the most cost-effective and socially desirable mix (ibid).

2. 4. International and local air quality standards

The government of South Africa operates in three spheres, national, provincial and local. The Constitution of South Africa [No. 108 of 1996] which provides the legislative and administrative background to all three spheres of government has environmental provisions in the Bill of Rights (1996). In terms of Section 24, everyone has the right to:

(a) an environment that is not harmful to their health or well-being and;

(b) have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that:

- prevent pollution and ecological degradation

In terms of air quality these rights were given effect in the National Environmental Management (NEM) Air Quality Act (Act 39 of 2004) which replaced the Atmospheric Pollution Prevention Act (Act 45 of 1965). The first paragraph of the Act provides for ambient air quality and emissions standards and aims:

> To reform the law regulating air quality in order to protect the environment by providing reasonable measures for the prevention of pollution and ecological degradation and for securing ecologically sustainable development while promoting justifiable economic and social development; to provide for national norms and standards regulating air quality monitoring, management and control by all spheres of government; for specific air quality measures; and for matters incidental thereto.

Since this dissertation is dealing with levels of particulate matter (PM10) in Khayelitsha, it is important to note that the Act specifies that concentrations should not exceed a 24-hour average of 180 micrograms per cubic metre and that this limit may not be exceeded more than three times in a given year. It further stipulates an annual average of 60 micrograms per cubic metre that may not be exceeded (ibid). International ambient air quality limits only differ marginally from those of South Africa. The World Health Organisation recommends, as safe minimum standards, that an average of 150 micrograms per cubic metre should not be exceeded over a 24-hour period with an annual average limit of 50 micrograms per cubic metre (WHO, 2005).

2. 5. Related work

2. 5. 1. Air quality and quality of life

That air quality has a direct effect on health is no revelation, and this knowledge has typically manifested itself in air quality standards and guidelines. Some of air pollution's acute health effects are reversible, e.g. bronchitis, tightness of the chest, wheezing and eye irritation. Others can be terminal, such as lung cancer and heart disease (World Resources Institute, 2002). The health impact of air pollution depends on the pollutant type, its concentration, duration of exposure, concentrations of other pollutants in the air and individual susceptibility. Different people are affected by air pollution in different ways (Mishra, 2003). Some groups are obviously more vulnerable to these adverse health effects than others, particularly infants, the elderly and those already suffering from respiratory conditions (World Resources Institute, 2002). It must be noted that health effects are not restricted to occasional episodes when pollutant levels are particularly high. Instead, several studies have shown that health effects may become apparent at levels below those permitted by national and international standards (ibid). In fact, according to the World Health Organisation (WHO) and others, no evidence shows that there is a threshold below which particulate matter does not induce some form of health defect, especially for more vulnerable populations (ibid).

2. 5. 2. Air quality in Khayelitsha

Khayelitsha is the largest township in South Africa and has been the focus of several studies with respect to air pollution. It is characterised by its shack housing, domestic combustion of fuels, open fires and other related activities resulting in high levels of PM10. The Khayelitsha Air Pollution Strategy (KAPS) project which was conducted in 2006 established an emissions database based on household, business and traffic surveys and aimed to improve air quality in the area as well as other informal areas of the City of Cape Town (City of Cape Town, 2006). Several sources of air pollution were found, primary ones being vehicle emissions, illegal waste dumping and burning, tyre burning, crate burning, wood burning, paraffin use, open fires and shack fires (ibid).

2. 5. 3. Current use of fuels in Khayelitsha

One of the issues raised by the City of Cape Town (2006) in the KAPS report was air pollution within households due to burning of fuels such as wood, paraffin and gas. It was found that the main cooking fuel was electricity (60 per cent), the main space heating fuel was paraffin (71 per cent), the main water heating fuel electricity (74 per cent), the main lighting fuel electricity (83 per cent), the main business fuel electricity (70 per cent). The results of this study showed that the secondary fuel used in all these instances, except for space heating, was paraffin (ibid). In fact, when assessing data for average household expenditure on fuels, it was seen that paraffin expenditure was the highest (ibid). Although 76 per cent of the surveyed households had access to electricity, 92 per cent had some expenditure on paraffin (ibid). A particular issue highlighted in the study was the preferred use of wet (green) wood in place of dry wood because it is believed to burn more slowly (ibid). While wet wood is typically used outdoors it is known to release far more smoke, as well as far 'dirtier' smoke, than does dry wood and therefore adds significantly to the air pollution problem in Khayelitsha.

2. 5. 4. Energy expenditures

According to the City of Cape Town (2006) paraffin is bought by most residents of Khayelitsha on a weekly basis (43 per cent) and is typically bought in 5 litre units. Residents who purchase gas normally do so monthly (82 per cent) and normally buy 5kg at a time (ibid). The majority of those who buy wood do so weekly (37 per cent) and buy it by the trolley load as opposed to the van load, truck load, head load or bag load (ibid). Finally, most residents buy their electricity monthly (75 per cent) and normally pay for it with R50.00 or R100.00 coupons (ibid). Paraffin and wood are easily available from supermarkets close by as well as from informal traders within the township (ibid). Table 2 shows the average expenditure on energy per month by size of household in Khayelitsha:

Table 2: Average energy used per month for varying household sizes in Khayelitsha

	Size of household		
Average energy used per month	1-4 people	5-8 people	9-12 people
Electricity	R70.55	R93.00	R80.23
LPG	R5.41	R3.24	R3.14
Paraffin	R248.37	R287.11	R205.21
Candles	R4.53	R11.11	R6.80

(Annecke *et al*, 2008)

Paraffin is by far the biggest expense in all three households followed by electricity. Households of 5-8 people spent the most on electricity, paraffin and candles and households of 1-4 people spent the most on LPG.

2. 5. 5. Electrification in Khayelitsha

Cooking and heating water and homes with solid or liquid fuels results in adverse health impacts. Exposure to wood smoke is believed to have the greatest negative externality in terms of health, and the use of paraffin for cooking purposes has been associated with fires leading to the destruction of hundreds of homes annually and severe burns, as well as several deaths (Lloyd *et al*, 2004). LP gas appears to be the only fuel that does not lead to deteriorating health but it is more expensive than other fuels (ibid). It is unsurprising that electricity has a large role to play in informal settlements such as Khayelitsha. According to the Department of Provincial and Local Government (Department of Provincial and Local Government, 2006), 76 per cent of households in Khayelitsha have access to electricity. This does not necessarily mean that 76 per cent of households regularly use electricity, only that it is available to them. The cost of electricity, and the fact that 24 per cent of households are not officially connected, has left Khayelitsha with many makeshift connections, which are both unlawful and dangerous (City of Cape Town, 2006).

Illegal electricity connections are a great concern and are the cause of many deaths in Khayelitsha. In March 2011 there were riots that lasted for several days because of the escalating number of deaths in the area due to live-wire shocks (Damba, 2011). Added to this, illegal electricity connections can be a serious fire hazard, particularly in winter when rain and wind increase the probability of unsafe connections causing damage. Illegal connections can also increase power outages as meters under-register the electricity required in an area.

2. 6. Barriers to energy use

Ongoing data collection in Khayelitsha has been useful in showing historic trends. One of these is that it takes poorer households close to ten years to make the transition from the use of paraffin and gas to full electricity use (Cowan and Mohlakoana, 2005). The introduction of Free Basic Electricity in 2000 appears to have assisted increased energy use but Annecke *et al* (2008) suggest that the extent of this increase is unknown.

One of the major barriers to electricity use is that some households don't have it installed at all. The cost of increasing electricity connection cover is very high. Another barrier is lack of income. This leads to a shortage of the white-goods needed to use electricity efficiently. In a 2005 study 35 per cent of households that had access to electricity didn't have electric stoves and had to cook on gas or, to a greater degree, on paraffin (Cowan and Mohlakoane, 2005).

In terms of space heating, fewer than 15 per cent of households owned electric heaters while over 40 per cent had paraffin heaters (ibid). Despite this, Lloyd *et al* (2004) noted that some electricity connections had remained idle for over a year when they conducted their study. There are a few indications that in some parts of the country there is indeed a failure to use electricity although there has been sufficient supply. Lloyd *et al* (2004) suggested the following reasons for this:

- owners of households possess appliances used for cooking and for space heating that use wood or paraffin, but not electricity
- due to the fact that households cannot afford many of the available electrical appliances, household owners often falsely believe that they would not be able to afford the running costs of electricity
- cookers and heaters that function on wood or paraffin are often multi-functional and so to purchase separate electrical appliances is both impractical as well as expensive
- owners of households are familiar with 'traditional' appliances that function on wood and paraffin and often lack the confidence and the education to use electrical appliances
- elderly people are sometimes found to want to continue burning wood because fire depicts a sign of life to visitors and to ancestors.

2. 7. Theoretical Framework

2. 7. 1. Cost-effectiveness analysis

One of the most common methods of evaluating air pollution control interventions is cost-benefit analysis. On the one hand, costs associated with the intended intervention are easily discernible and are typically incurred by three economic sectors, namely the private sector, the society at large and the governmental regulatory authority (Voorhees *et al*, 2001). The costs include both direct and indirect costs. The direct costs are the capital and operating costs and the indirect costs include the broader effects of shifts in economic activity between industries. The benefits, on the other hand, are not as easily calculated in monetary terms. The benefits that might be derived from the intended intervention include avoided health effects, sick days gained, amenity value gained and so on. Some of these, however, are not easily quantifiable. Added to this, it is possible that some costs and benefits are not foreseeable which means that any cost-benefit analysis may well become meaningless. It was deemed that a full cost-benefit analysis was not necessary for this dissertation, especially since the problem is not considering specific interventions but rather how a reduction in PM10 might benefit the inhabitants of Khayelitsha. Cost-effectiveness analysis is a widely used alternative to cost-benefit analysis especially in areas such as health and defence policy.

The purpose of cost-effectiveness analysis is to find the most inexpensive means of achieving a given outcome. The actual details relevant to this dissertation will be discussed further on. Since cost-effectiveness analysis does not quantify benefits in monetary terms, it inevitably involves two different metrics: costs are often expressed monetarily while the effectiveness of an intervention can be measured in non-pecuniary units, for example micrograms per cubic metre of PM10 reduced. Typically, the ratio of the two measures is what forms the basis for ranking alternative interventions. It is important at this stage that a base from which to compare alternative interventions is chosen. The most commonly used approach is the cost-effectiveness ratio, where the costs of a chosen intervention are divided by its corresponding outcome. The welfare impacts of increasing FBE would be found by using dose-response functions. In other words, where health is the desired outcome dose-response functions will be used by looking at reductions in PM10 levels across a range of interventions. This will be expanded on in chapter 5.

2. 8. Mexico City: Case Study

The problem of air pollution is widespread, but has been a particular focus in cities whose geographic and economic situations accentuated the problem. Los Angeles is one well-known case, and is noted for having successfully addressed the problem. Another, which has put much effort into pollution control, is Mexico City. Such case studies can provide useful background for the analysis of local air quality strategies.

In 1992, The United Nations described Mexico City's air as the most polluted on the planet. Six years later, Mexico City was described as, "the most dangerous city in the world for children" in terms of air pollution (Hibler, 2008). Unfortunately, despite over a decade of stringent pollution control measures the problem persists. There are many variables that add to this problem: industrial growth, population boom, economic growth, increased energy consumption, urban sprawl and the proliferation of vehicles (ibid). The severe air pollution problem in Mexico City has prompted significant research into air quality management and policy.

According to Molina and Molina (2004), the sources of pollutants include emissions from the combustion of fossil fuels in vehicles and for industrial processes, energy production, domestic cooking and heating and high dust levels due to unpaved roads and barren landscapes. Unfortunately the city's topography accentuates the problem. Mexico City's location in a crater means that much of its air pollution is trapped above the city. In Khayelitsha, the problem is slightly different, with the top five sources of PM10 arising from windblown dust, the combustion of dirty fuels and wood burning, waste and refuse burning, tyre burning and vehicle emissions (City of Cape Town,, 2006). It is not the city's topography that accentuates the problem, as in the case of Mexico City but rather the Cape Town temperature inversions. The Khayelitsha region lies slightly lower than its surroundings and its proximity to the sea makes the region vulnerable to temperature inversions. Inversions occur frequently in Cape Town and act as an air 'lid' which traps pollution in the lower atmosphere.

As with Khayelitsha (which, according to the City of Cape Town (2005) has been growing at an annual rate of 5.3 per cent), rapid population expansion has been one driver of Mexico City's severe air pollution. Table 3 indicates the rapidity of Mexico City's expansion between 1930 and 2010. In 1950 the population was just under 3 million people, but by 2000, 50 years later, the population had increased more than sixfold to over 18 million people. Mexico City grew consistently faster in terms of population than the rest of Mexico: bet ween 1950 and 2000 the share of Mexico City relative to the national population grew by 65 per cent.

Table 3: Population growth in Mexico City, 1930-2010

	Mexico City		National		
Year	Population	Rate of growth	Population	Rate of growth	Share of national population
1930	1,048,970	5.6	16,552,722	1.72	6.34
1940	1,644,921	4.5	19,653,552	1.73	8.37
1950	2,952,199	5.85	25,789,626	2.72	11.45
1960	5,125,447	5.52	34,923,129	3.03	14.68
1970	8,623,157	5.2	48,225,238	3.23	17.88
1980	12,994,450	4.1	66,846,833	3.27	19.44
1990	15,274,256	1.62	81,249,645	1.95	18.8
2000	18,396,677	0.84	97,361,711	1.81	18.9
2010	20,450,000		112,336,538		18.2

(Source: Disaster Risk Management, 2006)

Due to its rapid population expansion, Mexico City underwent considerable transformation in urban areas and demographics. Between 1950 and 2000, for example, the urbanised area has increased more than ten times (Molina and Molina, 2004). This has obvious implications for industrial growth, energy consumption and vehicle proliferation. Studies have shown that vehicle emissions contribute extensively to air pollution, even more so than any other factor (ibid). Increasing the geographic dispersion of the urban population also increased transport demand by raising the number and length of trips. Mexico City has been experiencing economic growth of between three and five per cent per annum and is expected to continue doing so in the future (ibid). This will mean more vehicles in circulation, more vehicles per inhabitant and longer trips.

Over the past few years, the Mexico City government officials have taken major steps to reduce air pollution in the region and have focused primarily on reducing transport-related emissions, while at the same time trying to enhance mobility. They have tried to:

- Reduce the use of private vehicles: To do this the government has encouraged a programme called 'Hoy No Circular' (today my car doesn't move). This is intended to limit the number of private vehicles and encourage car pooling

- Control vehicle conditions: Enforce an increasingly strict and technically sophisticated Vehicle Verification Program for half-yearly inspection of vehicle emission control systems

- Change fuels: Improve fuel quality by reducing the sulphur content in gasoline and diesel fuel so that new fuel technologies can be introduced

- Extend public transport: Increase the use of high-capacity public transportation by extending the metro lines, introducing bus rapid transit and improve service quality and personal security

- Provide low-interest loans for taxi substitution

- Construct relevant roadway and other infrastructure

While these measures do indeed ensure that vehicle emissions are lower than they were previously, the solution of the air pollution problem in Mexico City will require a great deal of sustained effort. While the domestic combustion of fuels is much less of a problem in terms of emissions in Mexico City it is still a problem in terms of human health. The total electricity coverage in Mexico City is at 97 per cent with almost 100 per cent coverage in urban areas and around 95 per cent in rural areas (World Bank, 2004). In Khayelitsha there have also been some efforts to reduce pollution, such as planting of wind-breaking trees, paving main roads, education on alternative cleaner fuels, provision of additional refuse skips for waste material, improved service delivery and deposit-refund system for tyres (City of Cape Town,, 2006). To date these initiatives have been mildly successful but have certainly not decreased the prevalence of PM10 in the area markedly.

While the air pollution problem in Mexico City was not exactly the same as that in Khayelitsha, it is a good example of how officials intervened to reduce air pollution. The informal sector in Mexico City during this time was a major contributor to air pollution, just as it is in Khayelitsha in the forms of tuckshops, beer brewing and public braaing. Brick-making in particular has generated important economic benefits although environmental impacts were almost completely ignored. Mexico City supports several hundred brick-making kilns, many of which are old, traditional kilns and which are fired with a variety of cheap, highly polluting fuels such as plastic refuse, used tyres, manure, wood scrap and used motor oil (Blackman and Bannister, 1998). In such cases, traditional kilns are leading sources of air pollution. The most common regulatory strategy in this case has been to ban dirty fuels (ibid). Again, this is a good indication of how Mexico City authorities undertook their duties to protect the environment as well as human health.

Chapter 3

Methodology

Objective 1

To test the sensitivity of domestic air quality to the level of electrification in a household.

Method

The first objective was achieved by testing the air quality in five separate households in Khayelitsha (see Town 3, Figure 5), each using a different mix of energy sources. The households were selected by the translator, who had a good idea of what each household's energy use was, and who chose households that used different energy mixes. Outdoor air quality varied over the sampling period and an attempt was made to correct for this by taking into account ambient air quality readings. A number of households use no electricity at all but rely on other fuels for warmth, lighting and cooking. Other households use some electricity but rely on alternative fuels for energy during different times of the day or at night and some households rely on electricity alone. The differences in fuel usage in these households were recorded for later comparison. A translator helped identify the necessary households and ensured that the residents whose homes were used understood the process. Homeowners were remunerated for their support with R20...

Monitoring was performed using a *minivol* mobile air quality monitor. Each household was monitored three times, each monitoring period being 24 hours as to capture a full day's round of pollution from cooking and space heating activities. It was decided that three separate samples from each household would be taken so that any irregular readings could be averaged out. It was also important that the monitor was placed in a similar place in each house. In each case the monitor was placed in the 'living area', or where the most time was spent by most individuals during the day.

The five households yielded 15 samples of domestic air pollution. The filters placed in the air quality monitor (and replaced every 24 hours) were weighed before and after each session on a five decimal point chemical balance. The filters were handled with tweezers and each was weighed three times and the masses averaged to ensure that the readings were accurate. The readings were always recorded immediately. The filter weights, along with ambient air quality readings from the city's local air quality monitoring stations, two of which were located in Khayelitsha, were inserted in equation 1 below to derive the prevalence of particulate matter in each instance. These readings were then compared with readings from ambient air quality monitors in Khayelitsha to validate the results.

The formulae used to obtain the domestic PM10 levels in each household on each day are provided below.

Equation 1: calculate the air flow rate at ambient conditions, Qact

$$Qact = (mvol \times Qind + bvol) \times \sqrt{\frac{Pstd}{Pact} \times \frac{Tact}{Tstd}}$$

Where: mvol = 1.1409

Qind = rotameter indicated flow rate

bvol = -0.4251

Pstd = standard atmospheric pressure, 760mmHg

Pact = actual ambient pressure, mmHg

Tstd = standard temperature, 298K

Tact = actual ambient temperature, K

Equation 2: indicates the volume of air that passes through the filter during a sampling period at actual ambient conditions, Vact, in cubic metres

$$Vact = \frac{60min/hr \times Qact \times thr}{1000/m3}$$

Where: thr = sampling period, in hours

Equation 3: corrects the volume of air under actual ambient conditions of temperature and pressure, to that which would occur under standard conditions

$$Vstd = Vact \times \left[\frac{Pact}{Pstd}\right] \times \left[\frac{Tstd}{Tact}\right]$$

Equations 4 (PMact) and 5 (PMstd): To calculate the particulate concentration, the net mass gain of the filter is divided by the volume of air that passed through the filter. Use Equation 4 for mass at actual conditions and Equation 5 for mass at standard conditions

$$PMact = \frac{M_{PM}}{Vact}$$

OR

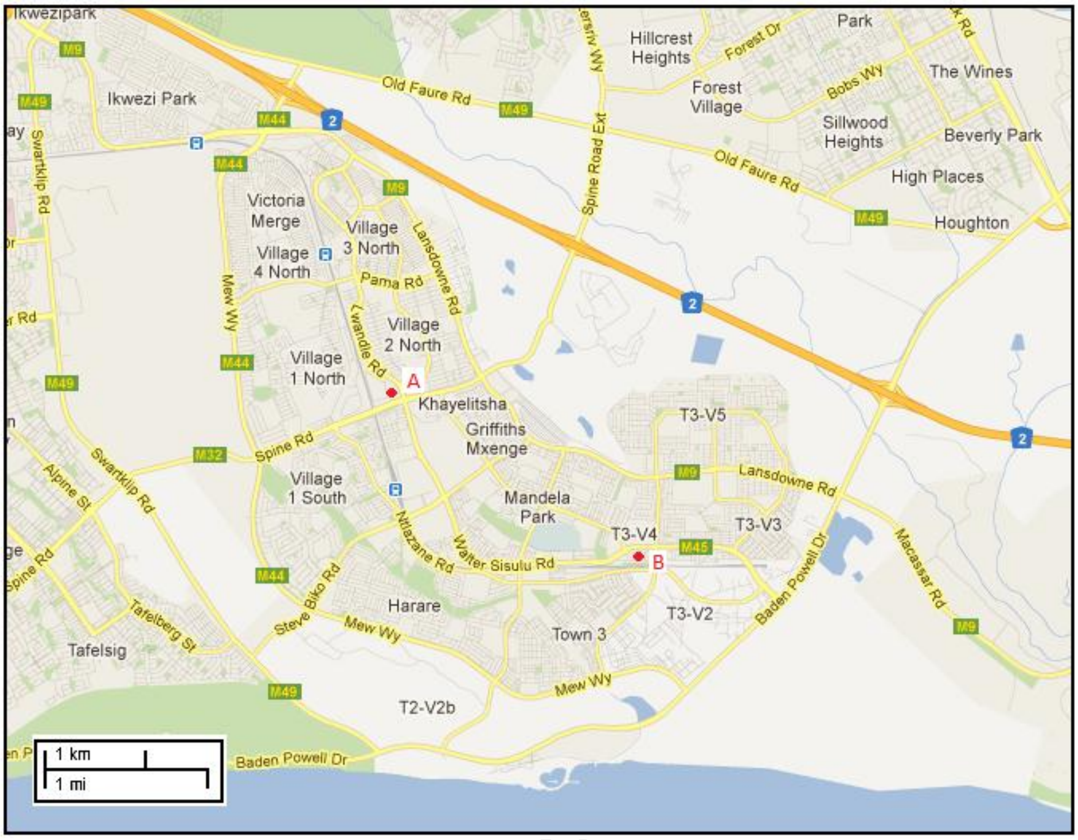
$$PMstd = \frac{M_{PM}}{Vstd}$$

Where: PMact = PM concentration, in micrograms (μg) per cubic meter (actual)

PMstd = PM concentration, in micrograms (μg) per cubic meter (standard)

M_{PM} = Mass of particulate matter collected on one filter, in micrograms (μg)

Figure 5: Location depicting Khayelitsha, the ambient air quality monitor station and the sample site



(Source: GoogleMaps)

*The red dot titled 'A' on the corner of Kwandile Rd and Spine Rd depicts the location of the stationary ambient air quality monitor station and the red dot titled 'B' depicts the location of the sample site.

Objective 2

To gain insight into how the residents of Khayelitsha currently live and how they think electrification throughout the region may change their lives, if at all.

Method

Within this objective there are two parts; firstly to establish how the residents of Khayelitsha live and secondly how they consider electrification throughout the region may change their lives. For the first part objective questions were asked regarding the number of residents in each household that was monitored, the number of rooms in each household, the construction material of the household, and whether there was ventilation or not. A simple verbal question/answer method was sufficient to attain the relevant information. The responses were recorded immediately.

To accomplish the second part of the objective an informal approach by means of open-ended conversation was selected. The reason this type of approach was chosen is because the answers needed to be as natural and as honest as possible. In other words, it was important to avoid the Hawthorne Effect in which subjects improve or modify their behaviour in response to the fact that they know that they are being studied (McCarney *et al*, 2007). It was never intended that there should be answers to specific questions, instead a few general comments that expressed how residents feel about electricity coverage in the region sufficed. This would include such things as cultural responses to electrification as well as perceptions of the affordability of- and accessibility to electricity relative to other fuels. A translator well known to the subjects of the data collection ensured that they understood the purpose of the study and the relevance of the questions. This is likely to have reduced the possibility of the Hawthorne Effect because the subjects felt comfortable with the translator who had great rapport with them.

<u>Objective 3</u>

To establish the likely welfare implications of electricity pricing policies.

<u>Method</u>

This third objective concerns the estimation the elasticity of household demand, and the factors that determine it. In addition there was a need to answer the following questions:

- Is increasing the free household allocation from 50KwH per month to 100kWh per month worthwhile in terms of health benefits?
- How much electricity do Khayelitsha homes use now, and how much would it cost to increase the free allocation?
- Is this cost worth potential decreases in indoor as well as ambient air pollution?

A cost-effectiveness analysis with relevant dose-response functions was carried out in an attempt to answer these questions. Dose-response functions were used to estimate the health outcomes associated with a 10μg/m^3 increase in PM10. Once these were established the health benefits that arise from using electricity, for domestic use, instead of 'dirty' fuels were calculated.

Chapter 4

Results and discussion

4. 1. Opening comments

The data collection period took place from the 26th of March until the 18th of April 2012 in South Africa's largest township, Khayelitsha in the Western Cape. As was discussed in the Methodology, air pollution tests were conducted three times in each of five different households, giving a total number of 15 samples. The monitor was run in each household for 24 hours to ensure that the results would reflect an entire day's activities. In each instance, the mobile air pollution monitor was placed in the living area, or the area where the most time is spent by most individuals during the day. The results were recorded and are indicated below.

4. 2. A brief characterisation of each househol

In order to establish the day-to-day living conditions within each household, their characteristics will be discussed. In each case the building material of each household is discussed as well as the number of rooms, number of inhabitants, ventilation and the fuels typically used for cooking space heating and heating water.

The first household was a tin and corrugated iron construction on a wooden frame, with cardboard used in some places. The building had two rooms, a main room used for social activities, and a bedroom. The former was used for eating and also for cooking. The kitchen part of the room was situated closest to the door which was the only source of ventilation in the house. The bedroom was off the side of the main room and slept between five and eight people, three of which were young children and three of which were older brothers that did not stay there during the week. The fuels used for cooking, space heating and heating water were Paraffin and LPG, where LPG was the preferred and most frequently used fuel.

The second household was also built primarily from tin and corrugated iron. It comprised a single rectangular room that served as kitchen, living area and bedroom. The kitchen was closest to the door of the household which was the only source of ventilation. The living area/bedroom was situated at the other end of the household. Eight people shared the bedroom; two adults, one teenager, two children above the age of five and three children under the age of five. Much like the first household, LPG was the preferred cooking and heating fuel but paraffin was used in some instances. Both the abovementioned households are typical of the informal ‘shack’ style of construction that makes up many of Khayelitsha’s informal dwellings. Both households had electrical connections, although they were rarely ever used due to their being illegal connections with frequently damaged lines. Both households would be considered low-income by Khayelitsha standards.

The third household was built with brick and concrete. This household was the largest of all and had three rooms, two bedrooms that stood next to each other and one spacious kitchen and living area that ran the length of the two bedrooms. There were windows in both the bedrooms but none in the kitchen/living area. Despite the fact that there were windows in the house they were generally kept shut to stop wind-blown dust entering the house. The entrance into the house was closest to the kitchen and was the only source of ventilation in that room. There were only three permanent inhabitants of this household, all of whom were adults, and paraffin was their primary fuel. Despite the fact that this household was more affluent than the first two households the main source of fuel was still paraffin. When asked about this, the residents said that electricity was used for lighting but not for cooking and heating because it becomes too expensive.

The fourth household that was tested for domestic air pollution was also made from brick and concrete. This household was one large room that was used as a bedroom as well as a kitchen and a living area. Despite the relatively more expensive construction there were no windows in the house and no other source of ventilation than the door which was nearest to the living room and furthest from the bedroom and the kitchen. There were five people living in this household: two adults and three young adults. The main cooking fuel was paraffin and the reasons given for this were much the same as for the previous household.

The fifth household that was tested for domestic air pollution was also made from brick and concrete. The household was divided into two rooms; one bedroom and one spacious kitchen/living area. There were no windows and the door, situated closest to the living area and furthest from the kitchen and the living room, was the only form of ventilation. There were four people living in this household. The predominant cooking fuel was wood which was mainly used outside but paraffin was used for indoor cooking and heating. The main reason for using wood in this instance was that electricity connections were faulty due to illegal connections.

It should be noted here that four out of five of the abovementioned households had an electrical connection. Despite this, there is a greater preference for gas or paraffin because often connections are faulty. Also, in the long term, electricity is perceived to be more costly than using paraffin. In each household there appeared to be little or no use of ‘white goods’ such as a hotplate, kettle or a fridge. These goods can be quite costly and energy-demanding and if paraffin is the preferred cooking fuel then the need to purchase such items does not exist.

4. 3. Results

In the following section the results of the domestic air pollution tests will be revealed as will information regarding ambient air pollution in Khayelitsha. The PM10 results were derived from calculations that can be understood from the methodology.

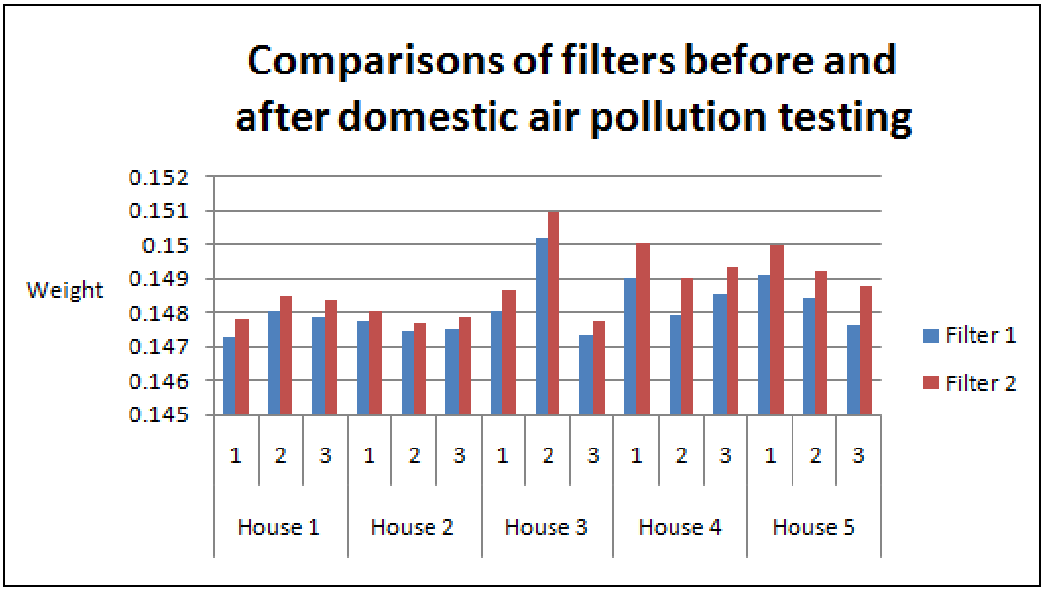
4. 3. 1. Filter mass

See the following table for change in filter mass over a 24 hour period.. Figure 6 thereafter shows a graphical display of this information with a comparison in weight between Filter 1 (before testing for domestic air pollution) and Filter 2 (after testing for domestic air pollution), in grams.

Table 4: Change in filter mass over a 24 hour period

Household	Day	Date	Filter weight 1 (g)	Filter weight 2 (g)	Change in mass (g)
1	1	26.3.12	0.14727	0.14778	0.00051
	2	27.3.12	0.1473	0.14727	0.00050
	3	28.3.12	0.14787	0.14833	0.00046
2	1	30.3.12	0.14773	0.14799	0.00026
	2	2.4.12	0.14754	0.14766	0.00022
	3	3.4.12	0.1475	0.14785	0.00035
3	1	4.4.12	0.1477	0.14871	0.00066
	2	5.4.12	0.1502	0.15132	0.00070
	3	10.4.12	0.14742	0.14776	0.00041
4	1	11.4.12	0.14859	0.15002	0.00100
	2	13.4.12	0.1477	0.149	0.00110
	3	14.4.12	0.14851	0.14931	0.0008
5	1	16.4.12	0.14898	0.14993	0.00085
	2	17.4.12	0.1481	0.14919	0,00079
	3	18.4.12	0.14781	0.14873	0.00112

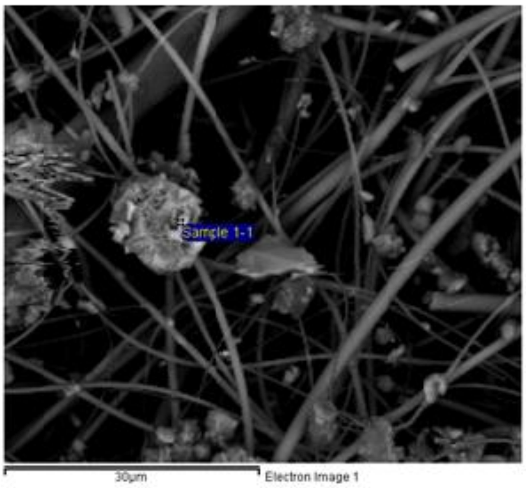
Figure 6: Comparisons of filters before and after domestic air pollution testing



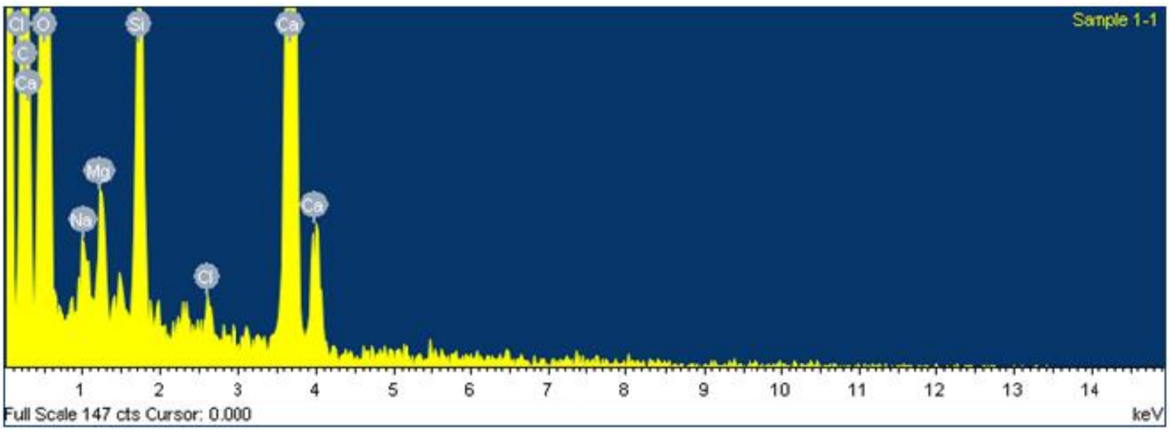
The increases in filter mass as a result of airborne particulates varied between 0.0002g (Household 2, day 2) and 0.00112g (Household 5, day 3). The average change in weight for Household 1 was 0.00047g, Household 2 was 0.00028g, Household 3 was 0.0.0006g, Household 4 was 0.001g and Household 5 was 0.00092g.

Once the data collection had been completed and all the samples had been weighed and recorded one filter from each house was taken to the Scanning Electron Microscope (SEM) laboratory for further examination. This provided details of the appearance of the particulates and a spectrographic analysis of their contents. This makes it possible for more detailed household pollution comparisons. An example of an image taken from the microscope from the first household is shown in Figure 7 below.

Figure 7

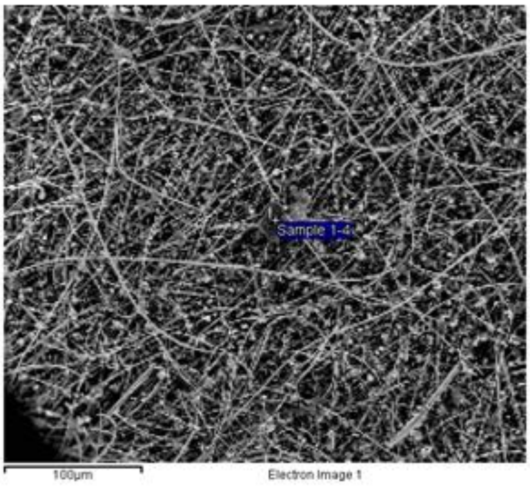


Element	Weight%	Atomic%
C K	22.07	30.59
O K	57.79	60.13
Na K	0.48	0.35
Mg K	1.07	0.74
Si K	2.57	1.52
Cl K	0.39	0.19
Ca K	15.62	6.49
Totals	100.00	

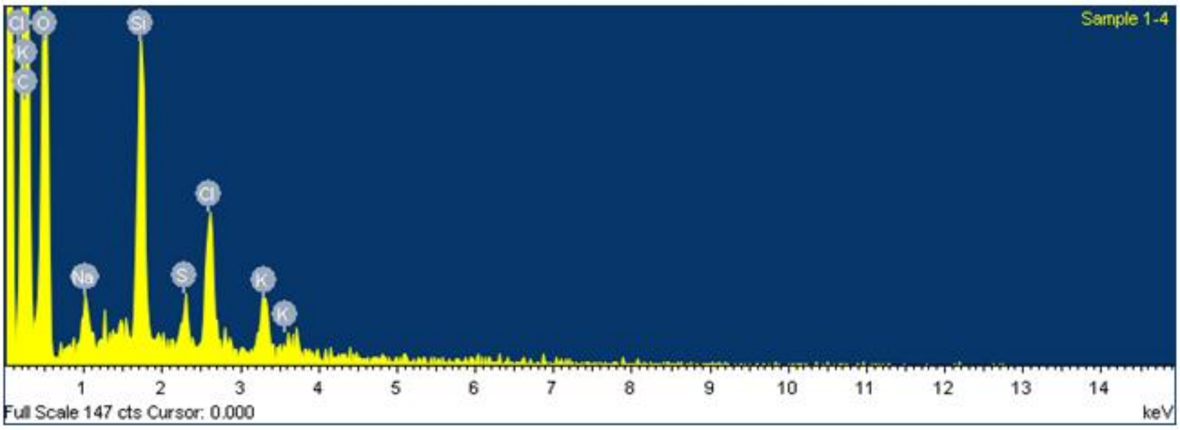


The mass-spectrometer reading is taken from the visible labelled unit of particulate matter marked ‘Sample 1-1’ in the photograph above. The elements found in each sample of the filter are recorded graphically as well as numerically. Please note that the high silicon content is largely due to the fact that the filters have a silicon base. This was established by scanning a clean filter. See figure 8 below for another sample from the same household as above but with a higher carbon content.

Figure 8



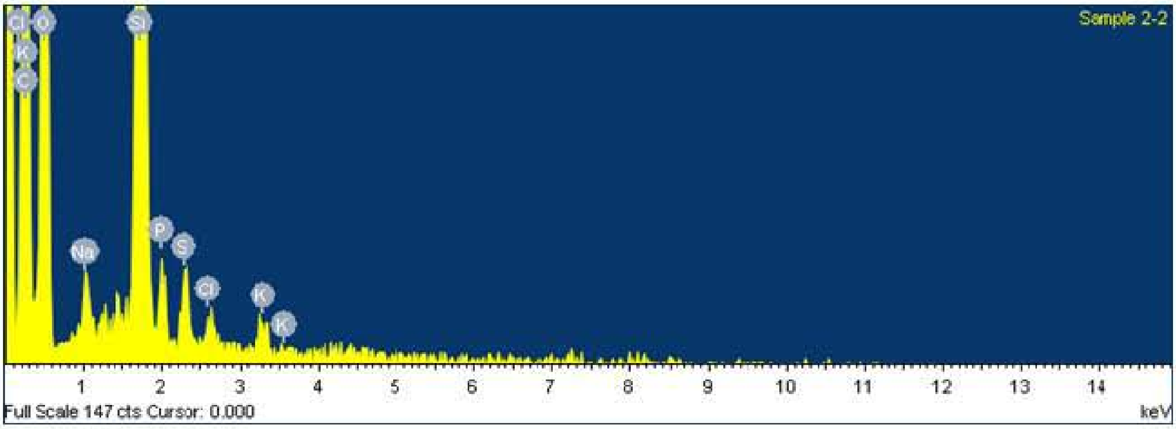
Element	Weight%	Atomic%
C K	49.29	60.03
O K	36.29	33.18
Na K	0.95	0.61
Si K	6.06	3.16
S K	1.08	0.49
Cl K	4.19	1.73
K K	2.13	0.80
Totals	100.00	



See Figure 9 below for a sample from Household 2 where the carbon content is also very high but the appearance is quite different and the size of the particulate matter is much smaller.

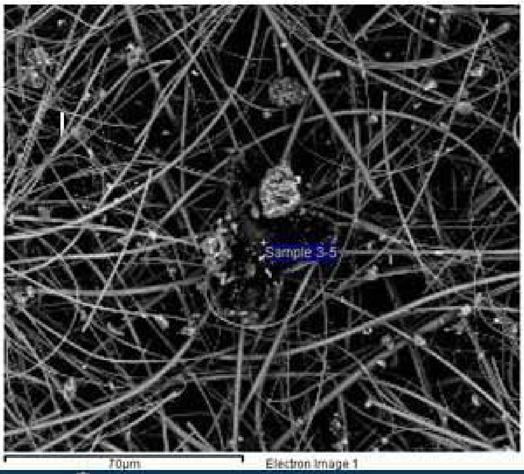
Figure 9

Element	Weight%	Atomic%
C K	40.81	52.07
O K	38.36	36.74
Na K	0.69	0.46
Si K	17.11	9.54
P K	0.95	0.47
S K	1.02	0.49
Cl K	0.45	0.19
K K	0.61	0.24
Totals	100.00	



Figures 10, 11 and 12 below show further information for Households 3, 4 and 5 respectively.

Figure10



Element	Weight%	Atomic%
C K	64.12	73.64
O K	26.16	22.55
Na K	0.77	0.46
Mg K	0.40	0.23
Si K	3.29	1.62
Cl K	0.54	0.21
Ca K	3.09	1.06
Mo L	1.64	0.24
Totals	100.00	

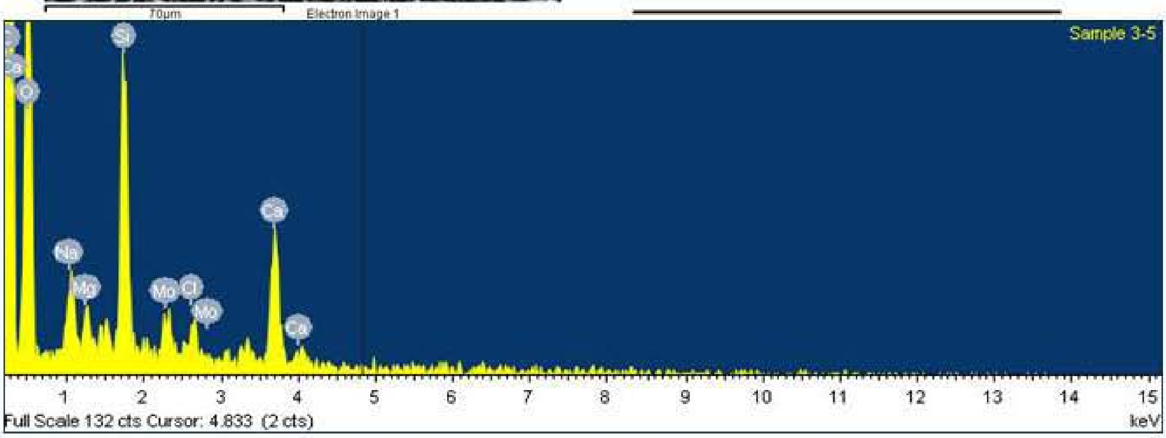
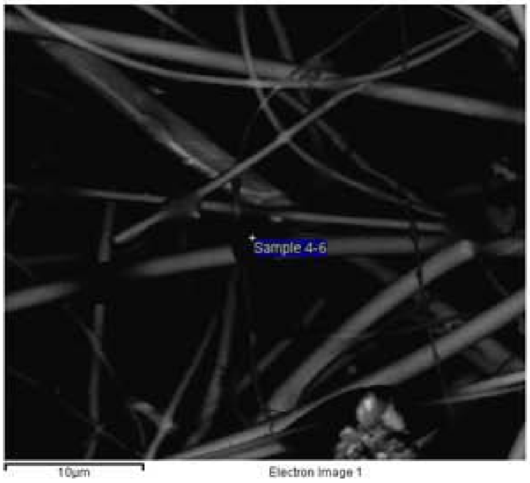


Figure 11



Element	Weight%	Atomic%
C K	73.32	80.07
O K	21.20	17.38
Si K	5.48	2.56
Totals	100.00	

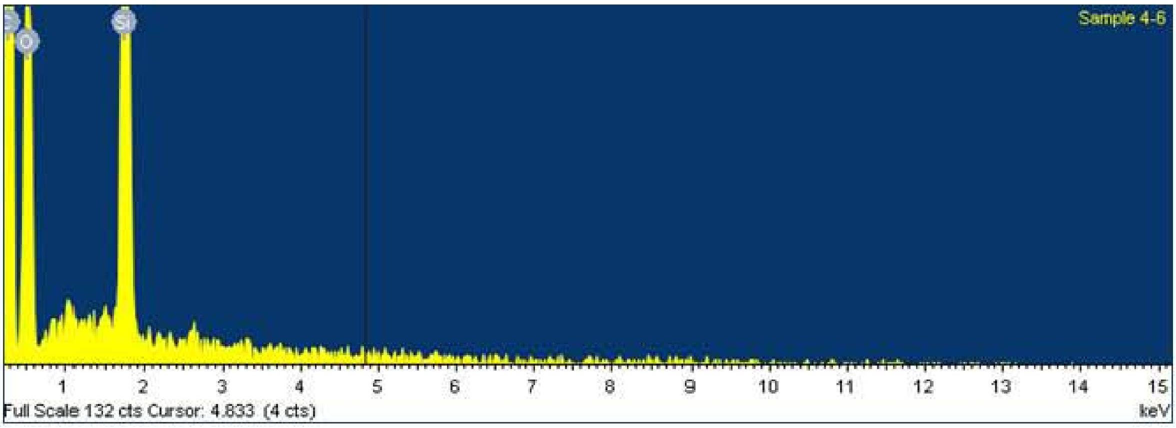
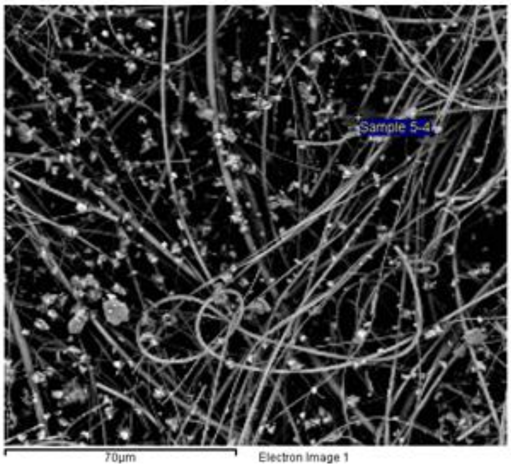
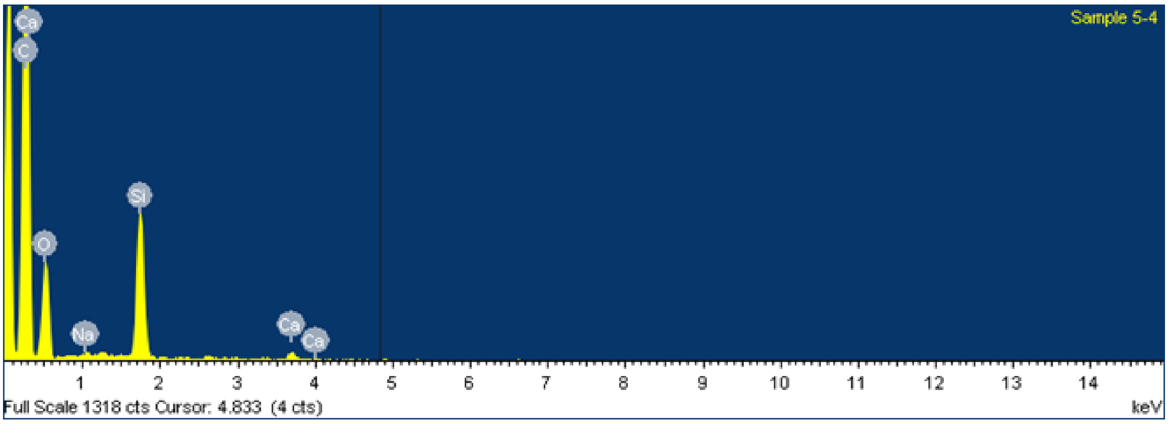


Figure 12



Element	Weight%	Atomic%
C K	67.20	75.30
O K	25.03	21.05
Na K	0.23	0.14
Si K	6.84	3.28
Ca K	0.70	0.24
Totals	100.00	



4. 3. 2. Actual domestic PM10 concentration

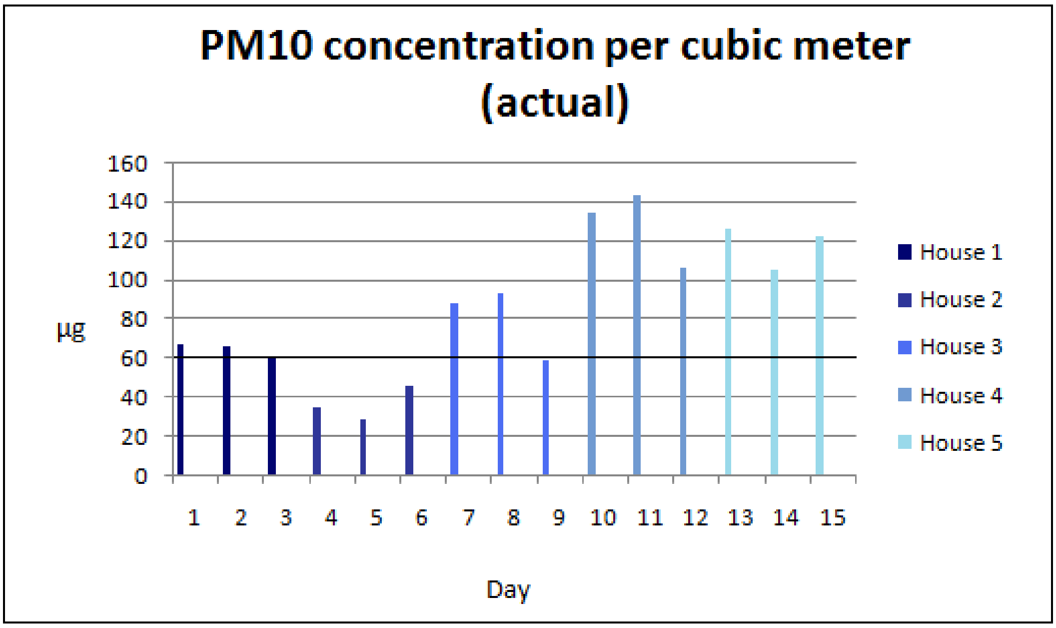
The average actual PM10 concentrations in each household were as follows: Household 1 was 64.64μg, Household 2 was 36.74μg, Household 3 was 79.78μg, Household 4 was 127.8μg and Household 5 was 118.01μg. Table 5 below shows the actual domestic PM10 reading for each household on each day that was tested. It is worth mentioning again that the Air Quality Act stipulates that an annual average of 60 micrograms per cubic metre may not be surpassed. The average taken from the ambient PM10 readings was 49.43μg which satisfies the Air Quality Act however the average taken from the domestic PM10 readings was 83.4μg which is significantly higher than the 24 hour average allowed by the Act. This is an extremely relevant finding and stands at the very core of this dissertation. The controls set by the Air Quality Act were set because they were seen as an important health standard, so the fact that the average PM10 reading exceeded these standards by over one-third reveals a rather pressing problem.

Table 5: Domestic and ambient PM10 readings

Household	Day	Domestic PM10 (act)	Ambient PM10
1	1	67.12	46
	2	66.16	40
	3	60.64	45
2	1	34.57	33
	2	29.26	No data
	3	46.38	No data
3	1	87.99	No data
	2	92.81	74
	3	58.55	41
4	1	134.38	54
	2	142.94	87
	3	106.08	30
5	1	126.3	46
	2	105.49	47
	3	122.24	50

Figure 13 below shows the daily PM10 concentration in each household.

Figure 13: PM10 concentration per cubic metre (actual)



It can be seen from these results that windows have little if any effect as a source of ventilation. This can be attributed to the fact that windows are mostly kept shut in order to keep wind-blown dust and smoke from entering the house. Keeping the windows closed also serves as a deterrent against petty crime. It seemed too, that most doors were kept closed during the day for safety as well as for privacy which means that there were often very low levels of ventilation.

As was discussed in the Literature Review, it has been determined that electricity has a negligible contribution to domestic air pollution. Paraffin was seen to be somewhere in the middle of the lowest and the highest. This was followed by natural gas and LPG with coal and wood having the highest footprint. This suggests that the households with the lowest actual PM10 per cubic metre, which were Households 1 and 2, were likely to substitute away from paraffin and towards the 'healthier' LPG alternative. During the three days that air pollution was tested in these households gas was mainly used, despite the fact that paraffin is generally the most commonly used fuel. Also, Household 5, which used wood for much of its cooking activities, had the second highest PM10 concentrations; even though the wood was burnt outside of the household it certainly appeared to have an effect on the PM10 prevalence in the immediate area. Households 3 and 4 which used paraffin and rarely ever switched to other fuels had amongst the highest PM10 records; in fact Household 4 was the highest with an average PM10 prevalence of almost four times the lowest household. The net level (the difference between domestic and external levels) can be seen in the table below:

Table 6: The difference between domestic and external levels of air pollution

		Ambient PM10 (μg)	Domestic PM10 (μg)	**Net level** (μg)
House 1	1	46	67	**21**
	2	40	65	**25**
	3	45	60	**15**
House 2	4	33	33	**0**
	5	No data*	29	**No data**
	6	No data*	46	**No data**
House 3	7	No data*	86	**No data**
	8	74	92	**18**
	9	41	57	**16**
House 4	10	54	123	**69**
	11	87	143	**56**
	12	30	104	**74**
House 5	13	46	124	**78**
	14	47	102	**55**
	15	50	120	**70**

*The monitoring stations sometimes give trouble (electricity problems, poor connections or settings) which may result in a lack of data in some instances.

It should also be observed that Households 1 and 2 had the lowest measures of PM10. There are two possible explanations for this. The first has already been discussed above, where LPG serves as a 'healthier' substitute for paraffin and so keeps PM10 at lower levels. The second explanation has to do with the building materials for each house. Households 1 and 2 were built from tin and corrugated iron while the remaining three households were built from brick and concrete. Households made from tin and corrugated iron are typically built from second hand materials and construction is inexact leaving spaces and gaps through which domestic air can filter out, despite the fact that there are no open windows.

4. 3. 3.. Ambient PM10 concentration

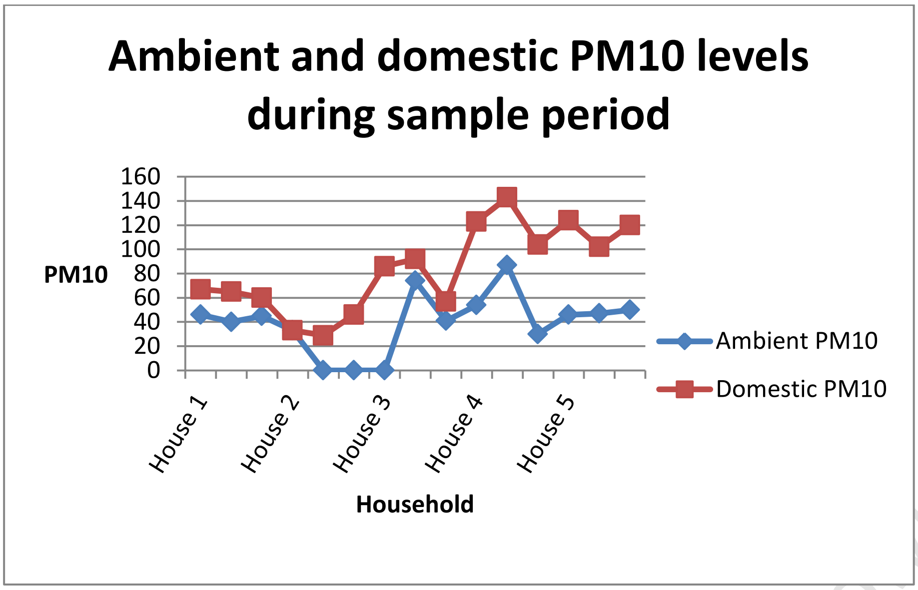
The ambient PM10 readings collected from stationary monitor sites in Khayelitsha give an indication of the outdoor 24-hour prevalence. Table 7 below shows the dates that the domestic air pollution tests were carried out on and the relevant ambient and domestic PM10 readings.

Table 7: Ambient and domestic PM10 readings

Date	Ambient PM10 (μg)	Domestic PM10 (μg)
26/03/2012	46	67
27/03/2012	40	65
28/03/2012	45	60
30/03/2012	33	33
02/04/2012	No data	29
03/04/2012	No data	46
04/04/2012	No data	86
05/04/2012	74	92
10/04/2012	41	57
11/04/2012	54	123
13/04/2012	87	143
14/04/2012	30	104
16/04/2012	46	124
17/04/2012	47	102
18/04/2012	50	120

As was expected, the domestic PM10 readings are higher than the ambient PM10 readings in every case except for one (30/3/2012) where they are equal. See Figure 14 below for a graphical representation of the above information. It can be seen that the domestic readings of PM10 coincide with the ambient readings of PM10, although the former is much higher.

Figure 14: Ambient and domestic PM10 levels during sampling period



4. 4. Legal provisions

As mentioned in the Literature Review, the National Environmental Management (NEM) Air Quality Act (Act 39 of 2004) does not permit ambient concentrations of PM10 to exceed a 24-hour average of 180 micrograms per cubic metre more than three times a year, and sets a 60 micrograms per cubic metre ceiling to the annual average. During the sample period there were five days in which domestic PM10 levels rose above 100 and on one occasion rose to almost 150 micrograms per cubic metre. The average of the fifteen samples above was 85.39 micrograms per cubic metre. If this trend were to continue throughout the year, the annual average limit of 60 micrograms per cubic metre would be far surpassed. Although the average ambient PM10 reading of 49.42 micrograms per cubic metre does not surpass the average annual limit, it is nonetheless relatively high particularly since data were collected during March and April, two of the warmest months during the year. This means that there is no need for inhabitants to burn fuel for the purpose of space heating, which undoubtedly increases domestic PM10 levels considerably. In terms of ambient air pollution however, the most important contributing factor to high readings is the likelihood of temperature inversions.

4. 5. Conclusion

The data have revealed some insights in terms of PM10 and its relation to energy source mixes, building material, ambient readings and legal provisions. The results of this study suggest that the combustion of fuels (other than gas) within households increases the prevalence of PM10 significantly and that paraffin and wood smoke are the biggest contributors to this. It has been seen that LPG is an adequate substitute for fuels that permit high pollution levels such as paraffin, but because of its price paraffin is often chosen instead. Electricity would be the best solution in terms of lessening the incidence of PM10, since it is a 'cleaner' and 'healthier' source of energy and could replace LPG, paraffin and wood. Unfortunately, due to high prices of electricity and the inability to access it, this is currently not a feasible option for most household owners in Khayelitsha. The cost of 'white goods', or goods that function off electricity, is another issue. A cost-effectiveness analysis will establish whether providing more connections as well as more affordable electricity to the township is a worthwhile venture.

This study showed that domestic PM10 levels are typically well above those outdoors. This makes sense since particulate matter disperses more rapidly outside a household than inside. This is especially true when there is little indoor ventilation to allow domestically generated pollutants to escape. The presence of windows in a household has a negligible effect on indoor air pollution. This is because they are mostly kept shut to avoid windblown dust to enter the household.

These results also showed that the high incidence of domestic air pollution, as well as ambient air pollution, requires further research and understanding. In terms of legal provisions, the average of the domestic air pollution sample in Khayelitsha far exceeds the annual average of 60 micrograms per cubic metre per year. Finally, it should be recognised that these conclusions are not precise or perfectly accounted for. It should be considered that while the high levels of PM10 in the area are attributable to many variables, the conclusion that the combustion of such fuels increases PM10 above the allowable amount is well founded. The conclusion that improving the availability and affordability of electricity may reduce levels of airborne particulates accords with *a priori* theory.

Chapter 5

Cost-effectiveness analysis

5. 1. Introduction

Cooking and heating with solid fuels on open fires or poorly ventilated stoves leads to indoor air pollution. The resulting small particulates are harmful and penetrate deep into the lungs and give rise to adverse health effects. Exposure is particularly problematic for women and children, who spend much of their time indoors and close to the point source of the pollution.

The WHO has stated that around 18 per cent of South Africans rely on solid fuels and that close to 1000 deaths annually can be attributed to solid fuel use. (World Health Organisation, 2007). Also, the number of Disability Adjusted Life-Years (DALYs) attributable to solid fuel use in South Africa is 20800 (ibid). Additionally, in high-mortality developing countries such as South Africa, indoor smoke is responsible for an estimated 3.7 per cent of the overall disease burden, making it the most lethal killer after malnutrition, unsafe sex, and lack of safe water and sanitation (ibid). Indoor air pollution from household use of solid fuels was estimated to be of some cause to around 0.5 per cent of all deaths in South Africa in 2000 (Norman *et al*, 2007). During the same period, the loss of healthy life years comprised 0.4 per cent of the total at 60 934 DALYs (ibid). More recent data is difficult to find and it appears that there is room for more research in this particular field. Further information regarding dose-response functions for deaths (all causes), respiratory hospital admissions, LRI in children, COPD and sick leaves is discussed in greater detail under section 5.4.

This section will discuss the health risks that arise due to indoor air pollution. The use of polluting domestic fuels has been identified as a problem in South Africa's low income areas, such as Khayelitsha, adding to the risks of fire (damage to health and property) and particulate air pollution. It is important to mention that health risks include the risk of pneumonia, tuberculosis and chronic obstructive pulmonary disease, low birthweight, cataracts, cardiovascular events and a variety of mortality cases in both children and adults (ibid). The international literature on the abovementioned health risks is extensive and allows a measure of benefit transfer. What little research has been done in South Africa yields few precise results. While local studies are important for the purposes of this study, the fact that they yield little meaningful information means that international data must be considered. In this case some key results from global literature will be summarised and local literature will be used to show the scope of the problem in South Africa. The issue in the Western Cape has been a persistent one and is a great concern to the city. A few major studies have been conducted in this area in the past eight years but none have focused on the cost-effectiveness of interventions such as electrification.

5. 2. Health risks associated with indoor air pollution

5. 2. 1. Paraffin

Increasing FBE could lower dependence on paraffin which is the most common fuel after electricity. Apart from the fact that paraffin is a source of particulates when burned, it is also extremely dangerous. Most obviously accidents with paraffin devices lead to fires. These can originate from malfunctions of the appliances, improper placement (unsteady surfaces or near curtains or tablecloths), use of polluted paraffin (which may become highly explosive if used when mixed with water or other fuels). Fires are particularly dangerous in areas such as Khayelitsha where households are densely located and constructed from flammable materials such as wood and cardboard. Paraffin also poses a direct health threat through inhalation. It has the appearance of water and is often stored in recycled beverage containers. Children who drink it accidentally have been seen to be vulnerable to a chemical pneumonia. Young children are also at the highest risk of paraffin poisoning, which accounts for about 60 per cent of paediatric poisonings in South Africa (Schwebel *et al*, 2009).

The relative dangers of paraffin are shown in Table 8 which presents the number of paraffin and LPG related incidents per 100000 tons sold for the year 2001:

Table 8: Incidence dues to paraffin and LPG usage

	Homes	Injuries	Deaths
Paraffin	16 700	1 700	1 000
LPG	9	9	5

(Lloyd, 2002)

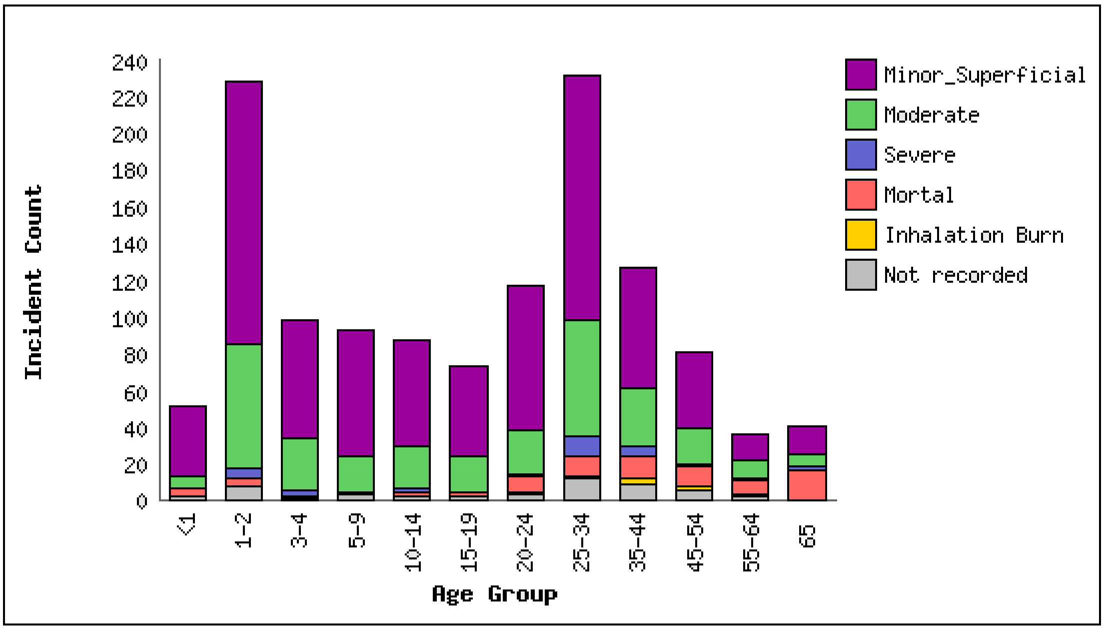
The serious social consequences of paraffin use were further demonstrated in a report to the Paraffin Safety Association of South Africa (2001) which concluded that, in South African township settlements:

- At least 80 000 children drink paraffin annually

- At least 55 000 children contract pneumonia after drinking paraffin annually
- At least 400 children die from paraffin-induced chemical pneumonia annually
- There are at least 45 000 paraffin-related fires and 50 000 paraffin related burns annually, resulting in about 3 000 deaths
- around 23 per cent of paraffin-related injuries affect children between the ages of one and two annually
- At least 100 000 homes are destroyed as a result of paraffin-related fires annually

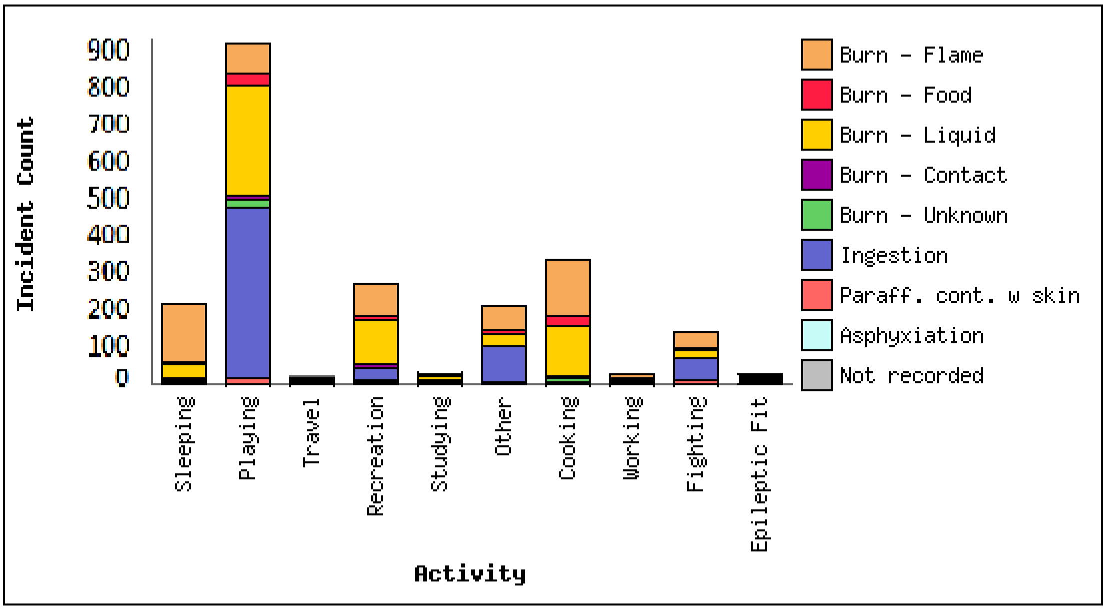
In the Western Cape between 1996 and 2007 the amount of paraffin used for cooking rose by 14.03 per cent. Paraffin used for heating went up by 14.7 per cent, paraffin used for lighting went up by 7.01 per cent and overall paraffin sales went up by 40.87 per cent (Paraffin Safety Association, 2012). Also, between 1999 and 2005 the number of shack fires in informal settlements in the Western Cape went up by 37 per cent from 967 to 1327 incidents (ibid). See Figures 16 and 17 below

Figure 15: Paraffin-related incident count in terms of age and injury cause



(Source: Paraffin Safety Association, 2012)

Figure 16: Paraffin-related incident count by activity and injury cause



(Source: Paraffin Safety Association, 2012)

5. 2. 2. Respiratory illness in children

International findings suggest that pneumonia and other ARIs represent the single most important cause of death for children under five years old and that significant exposure to indoor air pollution more than doubles the risk of pneumonia and is thus responsible for more than 900 000 of 2 million annual deaths due to pneumonia (WHO, 2005). As early as 1982, a local study found that of 132 infants with severe lower LRIs treated in an outpatient clinic, 70 per cent were exposed to consistent levels of smoke from cooking and heating (Kossove, 1982). A study conducted in 1990 supported this finding and reported that acute respiratory infections (ARI), such as pneumonia, were the principal cause of death amongst young children in large parts of South Africa (Von Schirnding *et al*. 1991). Indeed, Wichmann and Voyi (2006) argues that respiratory ill health is the main reason for use of health services in South Africa.

Acute respiratory infection can be classified as upper respiratory tract infections (URIs) or lower respiratory tract infections (LRIs). The upper respiratory tract consists of the airways from the nostrils to the vocal cords in the larynx, including the paranasal sinuses and the middle ear. The lower respiratory tract covers the continuation of the airways from the trachea and bronchi to the bronchioles and alveoli (Wichmann and Voyi, 2006). While the degree to which polluting fuel smoke can aggravate the risk of ARIs is not well quantified; it is known that there is a positive correlation between exposure and diminished respiratory immune defence mechanisms. It is also known that exposure is highly correlated with women as well as children below the age of five (ibid).

Data on the prevalence of ARIs in adults and children in South Africa as a result of polluting fuel smoke is difficult to find and very little research has been conducted that give relevant statistics. Wichmann and Voyi (2006) however, researched the effect that exposure may have on children. They reported that 19 per cent of children below the age of five years had experienced an acute LRI event in the two weeks preceding the study. Also, children living in households with other children were less likely to have an acute LRI event (15 per cent compared with 20 per cent) because they were often inclined to play outside and children whose mothers have less than three years education have more acute LRI incidences compared to other groups. This information shows education is highly relevant when it comes to avoiding adverse health impacts due to indoor air pollution that results from the combustion of solid fuels. Additionally, children living in households using polluting fuels were 26 per cent more likely to have an acute LRI event compared with those living in households using low polluting fuels for cooking and space heating. It was also seen that indoor pollution has a greater effect on the health status of individuals than outdoor air pollution (pollution from industry, transportation sources, fertilisers, allergens, fungal spores etc). This study concludes that exposure to cooking and heating smoke from polluting fuels is significantly correlated with LRI prevalence in children younger than the age of five.

According to the WHO (2005), in most societies, women are in charge of cooking and consequently spend between three and seven hours per day near the stove. It follows that 59 per cent of all indoor air pollution-attributable deaths fall on women (ibid). Young children are affected by this statistic as in African society they are typically carried on their mother's back or kept close to the hearth for warmth. As a result of this behaviour, infants spend a great deal of the first years of their lives breathing in indoor air pollution and it has been estimated that 56 per cent of all indoor air pollution-attributable deaths occur in children under five years old (ibid). Young children are more susceptible to LRIs than any other demographic for a number of other reasons. The epithelial linings of children's lungs are not fully grown resulting in greater permeability of pollutants (Pande, 2000) and their immune systems are not fully developed which means that the body's defence against infection is limited (Smith *et al*, 2000). Additionally, young children have higher respiration rates than adults and they have a larger lung surface area relative to the rest of their body, they therefore breathe in about 50 per cent more air under normal breathing conditions (Moya *et al*, 2004). Using data from studies conducted locally. The WHO estimates that 1 000 people die annually from indoor air pollution exposure in South Africa and that of these, 450 children die of LRIs (WHO, 2007). Burden of disease estimates done by the South African Medical Research Council suggests however, that indoor air pollution caused substantially more deaths in South Africa (2 489) which included 1 428 deaths of children under the age of five due to exposure (Norman *et al*, 2007). Estimates done by the WHO and Norman *et al* are actual deaths and not statistical deaths attributable.

5. 2. 3. Non respiratory illness in children

5. 2. 3. 1. Low birthweight

Evidence has been emerging that indoor air pollution increases the risk of adverse pregnancy outcomes (Smith, 2002) including foetal mortality, low birth weight, preterm birth and intrauterine growth retardation (Glinianaia *et al*, 2004). According to Pope *et al* (2010) there is a significantly (38 per cent) increased risk of low birth weight from high levels of exposure to indoor air pollution, and an associated reduction in birth weight of 96.6g. Additionally it was observed that there is a 51 per cent increase in risk of stillbirth associated with high levels of exposure to indoor air pollution (ibid). There is biological plausibility that supports the findings that there is an association with adverse pregnancy outcomes and indoor air pollution. Smoke from solid fuel combustion produces pollutants which can be absorbed into maternal blood, cross the placental barrier and have direct toxic effects on the foetus (ibid). Also, as a result of this process a developing foetus can be deprived of oxygen leading to intrauterine retardation and risk of low birth weight or stillbirth. Biomass combustion has been shown to be qualitatively similar to tobacco burning, covering the range for passive to heavy active smoking (Scherer *et al*, 1990).

5. 2. 3. 2. Nutritional deficiency

Mishra and Retherford (2007) suggest that exposure to smoke from the combustion of solid fuels can contribute to conditions such as anaemia and stunted growth normally associated with nutritional deficiencies in young children. This is not to say that smoke causes nutritional deficiency but that it may aggravate some of the symptoms associated with it. Their analysis shows a prevalence of moderate to severe anaemia significantly higher among children living in households using solid fuels than among children that live in households where cleaner fuels are used (ibid). Prevalence of severe stunting is also apparent in children living in households that use solid fuels (ibid). According to a comparative risk assessment conducted by the World Health Organisation, under-nutrition is estimated to be by far the largest contributor of global burden of disease, much of which can be associated with indoor air pollution (WHO, 2002). It should be noted that this is not a spurious correlation but that multiple logistic regression was used to deal with other, possibly influential, variables.

5. 2. 4. Respiratory illness in adults

5. 2. 4. 1. Interstitial lung disease

Interstitial lung disease, or 'hut lung', represents the non-infectious, non-malignant respiratory manifestations of chronic, high level exposures to biomass smoke (Diaz *et al*, 2006). It includes chronic bronchitis and chronic obstructive pulmonary disease, where prevalence is reportedly high among communities that risk exposure (ibid). In a report conducted by the World Health organisation indoor smoke was ranked as the second largest environmental contributor to poor health after unsafe water and sanitation (WHO, 2002).

5. 2. 4. 2. Chronic obstructive pulmonary disease

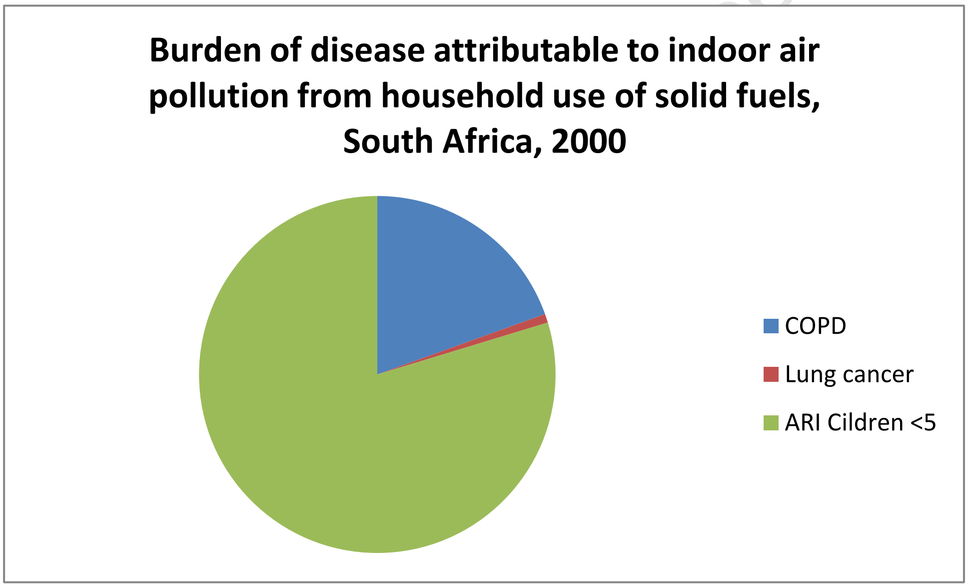
It has been observed that chronic obstructive pulmonary disease (COPD) has a strong correlation with indoor air pollution (Fullerton *et al*, 2008). The WHO (2005) reports that women exposed to indoor air pollution are at a much higher risk in terms of suffering from COPD than women who cook and heat with cleaner fuels such as electricity or gas. While women are more adversely affected by indoor air pollution, men also face high exposure and their risk of chronic respiratory disease almost doubles, resulting in an overall death count of approximately 700 000 out of 2.7 million global deaths due to COPD (ibid). In terms of a South African perspective, about 560 COPD deaths are attributable to solid fuel use in people over 30 years old (WHO, 2007). Pauwels *et al,* (2001) project that COPD will be the fifth most burdensome health condition by 2020. See Table 9 and Figure 17 below for the burden attributable to indoor air pollution from household use of solid fuels for South Africa in 2000.

Table 9: Male and female deaths and DALYs due to ARI infections, COPD and lung cancer

	Male		Female		Person	
Outcome	Deaths	DALYs	Deaths	DALYs	Death	DALYs
ARI infections	732	25 052	696	23 527	1428	48 579
COPD	304	2 957	721	8 920	1 025	11 877
Lung cancer	16	197	21	281	37	478
Total	**1052**	**28 206**	**1438**	**32 728**	**2490**	**60 934**
Percentage total burden	0.4%	0.3%	0.6%	0.4%	0.5%	0.4%

(Norman *et al*, 2007)

Figure 17: Burden of disease attributable to indoor air pollution from household use of solid fuels in South Africa, 2000



(Norman *et al*, 2007)

Added to these statistics, there were 69195 hospital admissions in Cape Town in 2011 that were linked to COPD (FRIDGE, 2003)

5. 2. 4. 3. Tuberculosis

Evidence is emerging that the incidence of tuberculosis (TB) is increased among those exposed to indoor air pollution from the combustion of solid fuels (Fullerton *et al*, 2008). Although these findings have not been seen in all studies, overall the evidence supports the hypothesis that exposure to respirable pollutants from combustion of solid fuels increases the risk of TB infection and disease (Lin *et al*, 2007). Again, this study has accounted for the influence of other variables.

5. 2. 4. 4. Lung cancer

As can be seen in Figure 17 above, lung cancer is responsible for a small portion of deaths due to indoor air pollution in South Africa. While this disease is not as common as ARIs and COPD it is nonetheless a significant health burden to be considered when discussing indoor air pollution. According to the World Health Organisation (2005), exposure to smoke from coal fires doubles the risk of lung cancer. Every year, indoor air pollution is responsible for approximately 15000 deaths from lung cancer globally (ibid).

5. 2. 5. Non-respiratory illness in adults

5. 2. 5. 1. Cardiovascular disease

Particulate air pollution is statistically and mechanistically linked to increased cardiovascular disease (Brook *et al*, 2004). Following this, epidemiological studies have demonstrated a consistent increase risk of cardiovascular events in relation to both short- and long-term exposure concentrations of particulate matter (ibid). The pollutants that are associated with the indoor combustion of fuels are associated with increased hospitalisation (Poloniecki *et al,* 1997) and mortality due to cardiovascular disease (Pope *et al,* 2004), especially with those already suffering adverse heart conditions (Smith *et al*, 2001). The latter finding was reinforced by Dominici *et al* (2003) who estimated that with each 10μg/m^3 increase in PM10s, daily total and cardiopulmonary mortality increased in the short term by 0.21 per cent and 0.31 per cent respectively. Added to this, 35981 deaths in Cape Town were linked to cardiovascular mortality due to PM10 related emissions in 2011 (FRIDGE, 2003). There were also 19375 hospital admissions in 2011 related to cardiovascular disease from PM10 emissions.

5. 2. 5. 2. Cataracts

The prevalence of cataracts and even blindness is high in communities associated with indoor air pollution (Saha *et al,* 2005). Their data in support of this association is provided in Table 10 below:

Table 10: Cataract incidence from paraffin, LPG and wood usage

Fuel use	Percentage with cataracts	Percentage with eye irritation
Paraffin	28.2	31
LPG	10.3	24.1
Wood	28.9	26

(Saha *et* al, 2005)

It should be noted that any possible confounders were taken care of for the purposes of this study. The results are limited in that they do not show observations for mixed fuel sources. It is nonetheless interesting to see that paraffin and wood are the most severe pollutants with regards to cataracts while all three fuel sources allow high chances of irritations of the eyes. While these conditions are not fatal they do affect quality of life and must be considered significant in terms of adverse health effects.

5. 2. 5. 3. Asthma

Asthma is a disorder that causes the airwaves of the lungs to swell and narrow, leading to wheezing, shortness of breath, chest tightness and coughing. In 2011 in Cape Town there were 52588 hospital admissions and health care visits due to Asthma related to PM10 incidence (FRIDGE, 2003).

5. 2. 6. Risk factors and associated deaths and DALYs

Summarised below is a selection of risk factors, diseases, injuries and conditions with associated death and DALY percentages taken from the South African National Burden of Disease survey 2000,

Table 11: Total deaths and DALYs from varying risk factors

Risk Factor	Percentage total deaths	Percentage total DALYs
Maternal underweight	2.3	2.7
Vitamin A deficiency	0.6	0.7
Indoor air pollution	0.5	0.4
Iron deficiency	0.4	1.1

(Norman *et al*, 2007)

Table 12: Total deaths and DALYs from varying diseases, injury or conditions

Disease, injury or condition	Total deaths (%)	Total DALYs (%)
Ischaemic heart disease	6.6	1.8
Tuberculosis	5.5	3.7
Lower respiratory infections	4.4	2.8
COPD	2.5	
Low birth weight	2.2	2.6
Asthma	1.3	2.2
Trachea/bronchi/lung cancer	1.3	
Cataracts		0.9

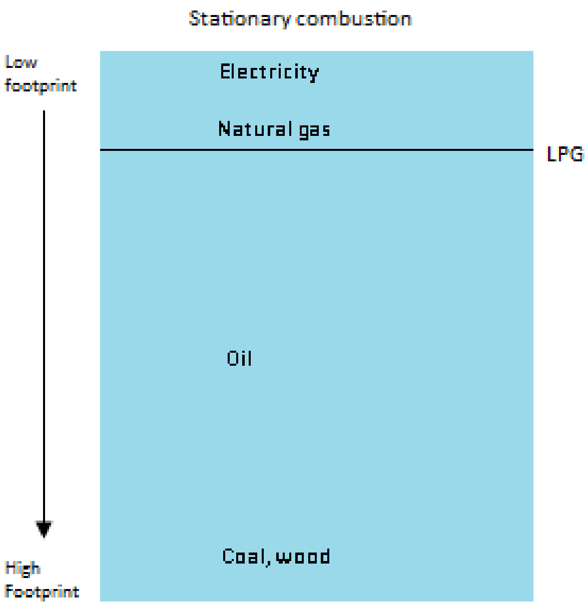
(Norman *et al*, 2007)

5. 3. Discussion

It has been seen from the evidence above that indoor air pollution is a major driver of adverse health effects, with women and children below the age of five, whose vital organs are still developing, being the most susceptible to exposure to indoor air pollution.

The 'energy ladder' model has been used to categorise energy sources along a hierarchy according to their cost, ease of use, technological advancement and the concentrations of air pollution that they produce. At the bottom of the 'ladder' are solid biomass fuels such as cow dung, crop residues and wood. Biomass fuels are followed by coal, charcoal and paraffin and following this are 'modern fuels' such as LPG and natural gas. Electricity, the cleanest fuel, is situated at the top of the ladder. This can be seen easily in Figure 18 below:

Figure 18: Energy ladder



(Atlantic Consulting, 2009: 4)

Following this, between 1994 and 2000 NEP electrified over 5.2 million houses which translates to a rate of just over 2 300 households per day (Department of Energy, 2011). As a result, the proportion of households with access to electricity increased from 36 per cent to 63 per cent between 1994 and 2000, and by 2006 73 per cent of households had access to electricity (Department of Minerals and Energy, 2006). Between 1996 and 2007, there was a 20 per cent increase in the proportion of households using electricity for cooking and a 14 per cent increase in electricity used for heating (Statistics South Africa, 1998, 2003 & 2007). Gas use remained relatively static while there were decreases in paraffin, wood and coal for both cooking and heating purposes (ibid). It was stated earlier that the use of paraffin is rising and while this is true in general for the Western Cape, it should be seen that once houses have been connected there is a shift from the use of solid fuels to electricity where it can be afforded. The table below shows that the use of paraffin as the major fuel is decreasing.

Table 13: Main fuels used for cooking and heating between 1996 and 2007

	Primary cooking fuel (%)			Primary heating fuel (%)		
Year	1996	2001	2007	1996	2001	2007
Electricity	47	51	67	45	49	59
Gas	3	3	2	1	1	1
Paraffin	21	21	15	14	15	13
Wood	23	21	15	27	25	20
Coal	4	3	1	8	7	4
Other	2	1	0	5	3	3

Statistics South Africa (1998, 2003 & 2007)

It is encouraging to see the progression of the South African population up the energy ladder between 1996 and 2007. Adding to this there was a higher than average increase in cleaner fuel use amongst rural South African households (Barnes *et al*, 2009). Unsurprisingly, the use of electricity has been associated with a significant decrease in indoor air pollution (Rollin *et al*, 2004) and found to be significantly protective of respiratory health (Dudley *et al*, 1997). As Barnes *et al* (2009) rightly point out, electricity access does not necessarily imply a displacement of polluting fuels, particularly among the poor. The use of multiple fuels remains a concern after electricity, or other clean fuels, has been guaranteed. This is where price plays an important role. This leads us to our next section regarding the effect that increasing the current FBE may have on health.

5. 4. Possible interventions

There are several interventions that can be implemented in the interests of reducing domestic air pollution resulting from the indoor combustion of solid fuels. Some of these interventions include switching to improved stoves, solar energy, improved ventilation, improved education and the introduction of alternative electricity (or other 'cleaner fuels') pricing schemes. Some of these interventions are more costly than others, some are easier to implement and some need to be further researched to ascertain the value of implementing them. Improving ventilation for instance might not be extremely costly and would reduce the prevalence of indoor air pollution and PM10 markedly. Improving education regarding the risks that indoor air pollution poses might also cause a change in behavioural and lifestyle patterns thereby reducing the ingestion and inhalation of noxious pollutants. While switching to improved stoves would be effective it would be costly to residents and it seems there may be more efficient interventions that can achieve a similar decrease in domestic air pollution. Paulsen (2010) found that residents were willing to spend up to R100 on new paraffin stoves and that they would typically be replaced when they showed signs of unsatisfactory functioning or excessive smoking. Also, switching stoves does not sufficiently reduce the use of paraffin which has other negative health externalities than air pollution, such as ingestion and burn injuries. Solar energy has extremely high implementation costs and with technologies improving all the time it seems better to postpone such an intervention. It is worthwhile however, to mention that some low-cost solar water heating options have already been implemented with considerable success in Khayelitsha (the Kuyasa Project). Introducing alternative pricing schemes can also be expensive since the cost of such policies must be borne somewhere. Pricing strategies could include the introduction of a stepped-tariff, increasing existing provisions at reduced rates and so on. In this instance only FBE will be discussed.

5. 5. Cost-effectiveness analysis

5. 5. 1. FBE

To recap, Free Basic Electricity (FBE) was implemented in July 2000 and makes provision for 50kWh per month per household as a free or subsidised service (Gaunt, 2003). In essence, FBE provides the electricity necessary for basic functions such as lighting, ironing, use of a radio or TV and the occasional use cooking of appliances (Prasad and Ranninger, 2003). Ultimately this means that a kettle, hot-plate or microwave could run for 50 hours and a 20 watt fluorescent light bulb could run day and night for about three and a half month's on one month's quota.

FBE may also have indirect or 'knock-on' benefits. One such is the impact of electricity on the range of potential economic activities open to residents in informal settlements. FBE is distributed to residents who consume 250kWh or less each month.

5. 5. 2. Costs of increasing FBE

In this section the costs of increasing FBE by 100 per cent to 100kWh will be assessed. The results will be an approximation based on a few of the findings of adverse health effects as discussed above. The UCT Report estimated that the annual cost of FBE at a level of 50kWh per month would be around R2.4 billion in 2010 (University of Cape Town, 2002). It was mentioned earlier that 76 per cent of households in Khayelitsha have access to electricity. This translates to 65397 households (City of Cape Town, 2005). If the cost of 1kWh of electricity is 60.83 cents for 2012 (ESKOM, 2012), then the overall collective cost for 50kWh FBE allowance for all households would amount to R1 989 049.76. This is obviously the most that it would cost for FBE to reach all currently electrified households in the township, but itprovides a simple baseline estimate nonetheless.

5. 5. 3. Increasing FBE

If FBE were increased by 100 per cent there would be a 50kWh increase from 50kWh to 100kWh. With the added free electricity there is a lot more that can be done in terms of cooking and heating.

According to the World Health Organisation (2005), in most societies, women are in charge of cooking and consequently spend between three and seven hours per day near the stove. It is important to consider this statistic. In the case of an electrified household the three to seven hours referred to by the WHO will not be three to seven hours with the stove turned on; it is only in the case of homes using an open fire or coal/wood burning stove that combustion continues for the whole period. With electricity (or gas) the heat is instant and it only needs to be turned on when it is needed. In this instance, then, if cooking only consumes one hour of the day on a 1000 watt plate then it is possible to cook for an extra 50 days. If one accepts the WHO notion of a stove on from 3 to 7 hours a day, then the extra 50kWh could last a household between 7.1 days to 16.7 days if used for cooking only. This result was achieved by dividing the 50kWh by 7 and by 3 respectively. This means that in an average month there would be between 23.7 per cent and 54.6 per cent less indoor air pollution from the combustion of solid fuels. This is a significant improvement since domestic air pollution could decrease by up to half each month. The point here is that by increasing electricity coverage and access there would be a significant decrease of open fire use of 3 to 7 hours. Added to this, electricity is needed for a far lesser time. With the additional FBE a typical 1000 watt appliance such as a kettle, hot-plate or microwave could run for an extra 50hours. A basic 20 watt fluorescent light bulb could run for 5000 hours, the equivalent of about 7 months day and night on one month's FBE allowance. Taking an average PM10 score ($85.39\mu g/m^3$) from the samples collected for the purposes of this dissertation, this would translate to between 6 and 14 micrograms of PM10 per cubic metre (at a rate of between 7.2 per cent and 16.6 per cent less indoor air pollution). It follows that there would be a far greater reduction in indoor air pollution, perhaps even up to 50 per cent which could reduce the PM10 dose by 42.7 micrograms per cubic metre.

In order to convert the reductions in micrograms of PM10 to health benefits it is important to discuss dose-response functions. A dose-response relationship describes how the likelihood and severity of adverse health effects (the responses) are related to the amount and condition of exposure to the agent (dose) (EPA, 2012). Typically as the dose increases, the measured response also increases (ibid). In this instance, LRI in children and COPD will be considered in terms of dose-response functions. The reason for this is that the dose-response functions for these two health conditions were the easiest to find and because of the extensive research done on them they are also the most reliable. As mentioned earlier there have been associations made between particulate levels and TB, lung cancer and cataracts; there are, however, no dose-response functions available.

5. 5. 4. Dose-response functions

A selection of PM10 dose-response functions are provided in Table 14 below.

Table 14: Dose-response functions for different health outcomes due to a 10μg/m^3 increase in PM10

Health outcome	Dose-response per 10μg/m^3 (%)	Source
Deaths (all causes)	0.75	(COMEAP, 1998)
Respiratory hospital admissions	0.80	(EAHEAP, 1999)
LRI in children	4	(Romieu *et al*, 2006)
COPD	2.4	(Voelkel *et al*, 2008)
Sick-leaves	6	(Hansen and Selte, 1997)
Cardiovascular mortality	1.3	(FRIDGE, 2003)
Respiratory mortality	3.0	(FRIDGE, 2003)
Pneumonia hospital admissions	1.5	(FRIDGE, 2003)
COPD hospital admissions	2.5	(FRIDGE, 2003)
Asthma hospital admissions	1.9	(FRIDGE, 2003)
Increased asthma symptoms	2.9	(FRIDGE, 2003)
Increased cough	1.5	(FRIDGE, 2003)
Increased respiratory symptoms	3.6	(FRIDGE, 2003)

The dose-responses above are mean figures (implying a linear relationship between pollutant and health response). A percentage change in the health outcome correlates with a 10μg/m^3 increase in PM10. For example, the stated increase in PM10 of 10μg /m^3 is associated with a 0.75 per cent increase in all deaths related in some way to PM10, a 0.8 per cent increase in respiratory hospital admissions, a 4 per cent increase in LRI in children and a 2.4 per cent increase in chronic obstructive pulmonary disease. In order to establish the relevance of these statistics see the following section on the benefits that can be achieved from this.

5. 5. 5. Benefits from increasing FBE

Taking the abovementioned dose-response functions and measuring them against some of the data that was discussed previously the following results were established should PM10 be decreased by $10\mu g/m^3$:

- According to the 2001 census (City of Cape Town, 2005) there are 20619 households that do not have access to electricity. This translates to 24 per cent of households that cannot enjoy the benefits of electricity or of FBE. If FBE increases by 50kWh and if coverage in Khayelitsha increases to 100 per cent then it would be reasonable to say that indoor air pollution would decrease to almost zero and that ambient air pollution would also decrease, although to a lesser extent. The major benefits however are likely to be in work-days regained. This can be seen in the point below.

- The average number of people per household in Khayelitsha is four (City of Cape Town, 2006) and the average number of work days lost per person is somewhere between 8.75 and 15 per year. This means that if coverage is extended from 76 per cent of households in Khayelitsha to 100 per cent between 721665 and 1237140 work days can be saved annually.

- By increasing the FBE allowance outdoor pollution levels would drop. The most significant change, however, is that indoor air pollution levels would drop closer to the outdoor levels. The actual extent to which the indoor and outdoor levels of air pollution would decrease is unknown but one can imagine that the gap between the two would close considerably. There are obviously other driving factors that affect the prevalence of ambient air pollution such as outdoor fires, tyre burning, car exhausts and dust. In this case, FBE will have a very small effect on the outdoor levels of pollution.

- Between 13 and 14 lives could be saved that would otherwise have been claimed by COPD due to solid fuel use.

- Cardiovascular mortality could decrease by around 468 deaths.

- Respiratory mortality could decrease by around 2491 deaths.

- Pneumonia hospital admissions could decrease by around 623.

- COPD hospital admissions could decrease by around 3402.
- Asthma hospital admissions could decrease by around 999.

From the LRI and COPD statistics alone it can be seen that there are some significant changes that can come about from a relatively small decrease in PM10 levels. There would also be relative positive effects on the incidence of pneumonia, cardiovascular disease and asthma. Tuberculosis, low birthweight, cataracts, cardiovascular events and a variety of other mortality cases in both children and adults are more than likely to decline.

5. 6. Limitations

When considering the effectiveness of an intervention in reducing exposure to indoor air pollution, it is important to be cautious about assuming that reductions of adverse health risks will be of a particular magnitude. The relationship between child LRIs and indoor air pollution for example, is complex, and there are a number of variables that may contribute to the fact that there is a significant relationship between the two. In certain contexts, there are a number of factors that are likely to influence the relationship. Some issues such as poor living conditions and lack of adequate health care for example, may play a stronger role in the prevalence of child LRIs in rural communities than indoor air pollution. It should also be noted that although interventions such as improving electricity accessibility and affordability are beneficial in terms of health risks it is likely that there will still be a prevalence of indoor air pollution. The fact that most households in areas such as Khayelitsha normally use a mix of fuels means that this trend will most likely continue in the future. It is important then, to acknowledge that interventions such as the one discussed above do not intend to achieve a 'pollution free' environment but rather to ensure that health risks are lessened.

In addition, in rural areas there is often a financial inability to afford the appliances relevant to electricity, such as electric stoves or heaters. Switching appliances can be costly as well as intimidating.. Even under circumstances where electricity is affordable and available there are often still cheaper fuels, such as wood which can be collected free of charge and which may be found close to the living environment. In such a case, it is highly unlikely that the more expensive fuel will be preferred. It should also be considered that other factors that provide resistance to such interventions include cultural preferences. For example, fires are often preferred because they provide the feeling of hospitality and a feeling of welcome.

5. 7. Discussion

There is sufficient information from the surveys above to show that electricity and gas can reduce domestic pollution. In fact, it is plausible to assume that their widespread use would reduce ambient air pollution too.

As was established above, a decrease in PM10 of $10\mu g/m^3$ can have a significant effect on health in South Africa. There would be a considerable decrease in the overall deaths from indoor air pollution as well as for deaths from LRIs among children younger than five years old and deaths from COPD. There would also be fewer hospital admissions from these illnesses as well as fewer cases of pneumonia, tuberculosis and chronic obstructive pulmonary disease, low birthweight, cataracts, cardiovascular events and a variety of mortality cases in both children and adults. If the effect from decreasing PM10 by $10\mu g/m^3$ is as positive as postulated then there is scope for much more that can be done to reduce indoor air pollution, particularly in rural areas. Increasing FBE is only one way in which this can be done. Improving education, increasing ventilation, introducing renewable energy, incentivising shifts to cleaner fuels or improved stoves can help to achieve this effectively.

Chapter 6

Conclusion and suggestions for future work

One of the key motivations for undertaking this study was the lack of literature on the costs and benefits of affordable electrification in Khayelitsha. There have been several studies that have researched fuel-use in Khayelitsha as well as some studies that have recorded the PM10 measurements for domestic fuel use. The primary aim of this dissertation was to gauge the potential welfare implications of an increase in the Free Basic Allowance scheme implemented in South Africa in the year 2000. While FBE is an extremely relevant and beneficial government subsidy there has been no attempt to adjust it despite the fact that electricity prices have risen above inflation rates every year for over a decade. Another shortfall within government capacity is that while Khayelitsha is almost entirely electrified, only 63.4 per cent of households actually benefit from the scheme. This can largely be attributed to illegal connections which can damage connections, as well as increase the regularity of power outages.

Data collection saw that a dependence on dirty fuels such as wood and paraffin correlates with a higher prevalence of PM10 in the immediate atmosphere than households that depended more on gas and electricity. An overall average of the data samples that were collected showed that the annual average limit of 60 micrograms per cubic metre would be exceeded should the trend of such PM10 readings continue. The suggestion that this dissertation proposed was that FBE should be doubled from the monthly allowance of 50kWh to 100kWh. It was calculated that this change could decrease domestic PM10 emissions by over half of the current amount (see Chapter 5, section 5.3) which would not only bring down the average domestic PM10 emissions to below the allowable standard, but would also have improved impacts on health.

Research has shown that significant PM10 prevalence can have adverse health effects in the form of respiratory infections, cardiovascular disease, asthma, pneumonia and so on. While PM10 may not be the sole cause of hospitalisations and deaths in each case it is certainly a significant contributor. Dose-response functions were adopted from international studies and the relevant welfare implications were estimated in accordance with a 10 microgram decrease in PM10. The result was that illnesses among children could be alleviated and hospital and day care visits could be reduced significantly. The conclusion drawn was that an increase in

FBE would result in far less dependence on solid fuels and the prevalence of domestic air pollution would decrease, keeping in line with legal standards as well as contributing to improved health in Khayelitsha.

There are several foci where basic research has to be conducted in order to better understand air pollution in dense, low-income communities such as Khayelitsha, where possible intervention options can be formulated. There is also research potential in terms of health risks that pertain to indoor air pollution that need to be updated and further developed.

More data needs to be collected for air quality in rural areas in South Africa. While townships such as Khayelitsha do have stationary ambient air quality monitors in position there are many rural areas in South Africa that have no record of atmospheric air pollution levels. Accordingly, it is impossible to give a plausible overview of the national situation of ambient air pollution in South Africa. Ambient air quality monitors should also be more robust, so as to avoid gaps in data as has been seen in this dissertation. In addition to this, more reliable information regarding actual levels of indoor air pollution across different areas, household types and fuel types would enable a better estimation of the situation.

To further this, there is also very little information regarding wood use in South Africa despite the fact that it is the country's second most prevalent source of domestic heating. There is a significant amount of data that is missing and that needs to be investigated, such as the number of households that use wood as a primary source, the number of households that use wood as a secondary or supplementary source, the types of wood that are commonly used and the adverse health effects that arise from the resulting emissions. Considering the fact that wood is lowest on the 'energy ladder' and produces the highest emissions, resulting in a high number of health adversities it becomes apparent that more information is needed regarding this matter.

There is also much more information regarding social factors that needs to be researched in order to understand the problem of indoor air pollution from an integrated and holistic perspective. Pollution is often viewed as a technical problem that only has to be solved by technical means. Various efforts that have been made to solve the problem of ambient and indoor air pollution have failed as a result of the fact that they were not based on a thorough understanding of the social dynamics involved. The quality of life of low-income households will only be enhanced if residents are engaged in the process of interventions that are functionally integrated within their social dynamics.

There are a number of research gaps that are evident in relation to household energy, indoor air pollution and health in South Africa. In particular, there is a need for larger and more detailed studies regarding indoor air pollution, interventions and health impacts. Future studies need to monitor indoor air pollution and exposure for longer periods of time so that there are large enough samples that health impacts can be significantly accounted for.

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