Variability of domestic burning habits in the South African Highveld: A case study in the KwaDela Township (April 2017)

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Abstract— Air quality in the South African low-income residential areas is poor due to gaseous and particulate emissions from a range of sources including domestic burning. The absence of data on fuel use and variability in low-income residential areas introduces uncertainties when quantifying total emissions from the township. The aim is to characterise KwaDela resident's fuel use, and stove operation behaviour. Data-sets used to meet the objectives of the paper were both qualitative and quantitative. These include detailed fuel use survey responses, two-week first person observations, and stove temperature data collected from KwaDela. The observations were made during winter (2016) to capture the residents' fuel use behaviour when ambient concentrations are at their peak. Residents use modern and traditional energy sources. Coal is the primary fuel while wood and dung are mostly used to start coal fires. The most common burning appliance in KwaDela is cast-iron coal stove. Inter- and intra-variability of fuel use, burning patterns and stove operations were recorded during observations. The majority of the residents have two burning events per day, a morning burning events starts between 06h00-08h00 end 11:00-12:30, and the evening fire events starts between 16h00 up to 17h30 end 21:30-22:00. Factors determining household energy profile are (I) fuel availability (II) demographics and (III) seasons.

***Index Terms*— Cast-iron coal stoves, PM, solid fuels, variability. For enquiries and suggestion send an email to, nomhawunkosi93@gmail.com**

1 INTRODUCTION: FUEL USE IN LOW-INCOME RESIDENTIAL AREAS

Air quality in the South African low-income residential areas is poor due to emissions of gases and particles from domestic burning of solid fuels (Makonese et al., 2016, Kimemia & Annergan, 2011). Energy is regarded as a basic human need, and can be categorized as either modern (Electricity, Liquefied Petroleum gas, biogas) or traditional (coal, wood, and dung). In South African townships, energy is primarily used for cooking, space heating and entertainment (Aitken, 2007; Kimemia & Annergan., 2011). The use of energy varies significantly in time and space depending on factors such as (I) Income (II) fuel availability (III) cultural preferences (IV) social class (V) demographic (VI) seasonality and (VII) location (Davis, 1998 & Barnett, 2000; Heltberg., 2004). In most cases, traditional fuels are readily available or cheaper than modern fuel, and for that reason they are regarded as the most convenient energy source in low-income residential areas. At a household scale, costs associated with solid fuel use include time, money (fuel price and transportation) and labour while for electricity it is fuel price and electrical appliances. Low-income households perceive electricity costs high when compared to solid fuel costs combined. Using fuel that requires time and labour costs than high purchase costs is convenient for low-income residents. In most cases, low-income residents have large families with only one or two breadwinners therefore have a large source of labour and time. While electricity requires a sustainable source of income, of which most income residents do not have (Goldenberg, 2000). Therefore, they will continue to use traditional fuel sources even when they have access to electricity. Burning of solid fuels under poor combustion conditions, using inefficient stoves causes high emission of gases and fine particulates. These emissions degrade ambient and indoor air quality, which has a negative impact on human health (Annergan et al., 1995 Seaton et al., 1995). Studies have found that the concentration of fine particulate matter in townships is 51% higher than in urban residential areas and 78% higher when compared to industrial areas (Hersey et al., 2015). This makes low-income residential areas one of the priority areas to target for air pollution mitigation in the country.

It is stated in the National Environmental Management Act, 2004 that every South African citizen has a constitutional right to a clean environment, which includes clean air. The government has tried to address this issue by prioritizing accessibility of electricity in low-income residential areas. The anticipation was that giving access to electricity to the residents would completely shift them from using solid or bio fuels. To account for the high cost of electricity the government has given a portion of the electricity free to low-income residents (Howells et al., 2005). However, electrification intervention alone does not remove the need to burn solid fuels in low-income residential areas. Even with electricity subsidies low-income residents live in deep poverty therefore cannot afford to buy electricity that would sustain them and meet all their energy needs (Matinga et al., 2014, Makonese et al., 2016).

The rate of electrification in low-income residential areas is about 50% and in other townships it is none existence while in urban areas it is about 80% (Ismail & Khembo, 2015). Approximately 80% of residents that have access to electricity in low-income residential areas continue to use solid fuels (Mdluli & Vogel. 2010). Studies conducted in Eastern Cape and Limpopo provinces on the use of coal reported that 95% and 40% households living at QwaQwa

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and Lebowa depend on coal respectively (Ward, 1995). Another study by Aitken (2007) in Eastern Cape, KwaZulu-Natal, and North West showed that between 76-98% of residents continue to use wood for domestic energy.

There is an inter and intra-variability of solid fuel use and burning habits. The type, quantity, burning device and the manner in which the fuel is burned varies between and within the townships depending mainly on fuel availability, cost, and seasonality (Aitken, 2007; Kimemia and Annergan. 2011; Makonese et al., 2016; Lloyd, 2014). The use of fuel varies with time; that is from seasonally and daily. In low-income residential areas, more solid fuels are burned in winter when compared to other season (Smith, 1988; Smith et al., 1994). Burning during summer is done for cooking purposes whereas in winter it is for both cooking and space heating. Space heating needs increase the duration and number of burning events, thus; resulting in more fuel use, and consequently more emissions.

Assessing and documenting the variation of fuel use in low-income residential areas provides an understanding of how fuel use patterns change in time and space (Madubansi & Shackleton, 2005). This has raised a need to collect reliable solid fuel use data in townships and can be used to determine the best affordable intervention. The gathered data will be used to identify and understand factors that govern use and variability of solid fuel and emissions of fine particulate matter. The aim of the study, therefore, is to characterize burning habits and stove operation behavior of KwaDela residents. The study will highlight how stove operation behavior and fuel use varies in KwaDela.

KwaDela is a township located on the Highveld section of Mpumalanga in the Gert-Sibande district at the latitude of 26° 27' 44.64" S and longitude of 29° 39' 39.96" E (Figure 1). Mpumalanga is the second smallest province after Gauteng and rich in natural minerals such as coal (Nuwarinda, 2007). The township covers a total area of 19600 km^2 and is home to a total population of 3777 residents (StatsSA, 2011). Household's average monthly income in the township is R1500. About 97.10% of the township is electrified however, 76% of the population continue to use solid fuels (Wernecke et al., 2015). Minimum temperatures night time (-5°C) are experienced in winter between May and July while maximum day time temperatures (37°C) are experienced in summer between November and January. KwaDela is situated in a grassland biome, this makes wood a scares resource for the residents. The common agricultural activity in the township is keeping livestock domestic animals (Cows, Goats, Sheep and Horses). The common houses are reconstruction development programme (RDP) government structures with two-bed rooms and a kitchen area. The house is built using concrete bricks and the roof covered with corrugated iron with no ceiling or any insulation material. It has 2 exit doors and 3 windows. The life style in the township is almost rural with young boys herding livestock, girls collect wood from the fields while grandparents prepare afternoon and evening meals. This township was chosen for the study because it is a perfect example of a typical low-income settlement in South Africa, and located in the Highveld region priority area.

2. Methodology

2.1 Study Area

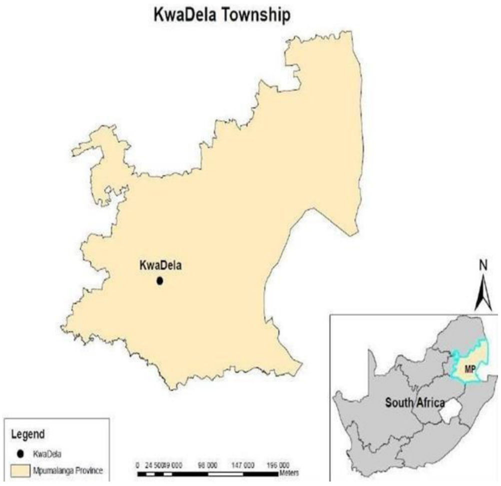

Figure 1. Location of the KwaDela Township in Mpumalanga

2.2 Qualitative and quantitative data was used to meet the objectives of the study. Fuel use responses and first person observation findings were used to determine the (I) a total number of residents burning solid fuels in KwaDela (II) dominant and type of fuel used (III) factors governing the governing household energy profiles (IV) sources of fuel and lastly (V) stove operation behaviour.

2.2.1. Fuel use survey

KwaDela households participated in a fuel use questionnaire conducted by NOVA institute in 2013 and 2014. The 2014 fuel use responses were used to characterise KwaDela burning habits. A total of 207 residents participated in the fuel use survey. Examples of the questions that were asked as part of the fuel use questionnaire included; (I) which solid fuels the residents use (II) how much fuel KwaDela households use (III) the type of medium they use to burn the fuel, (IV) how they start the fire, and (V) the type of medium they use to burn the fuel. The fuel survey was divided in into 19 sections: these included (1) Household identification, (2) Respondents details (3) House information (4) Living standards, (5) coal (6) coal ignition time in winter (7) coal ignition time in summer (8) electricity usage (9) wood section (10) paraffin (11) Animal dung (12) lighting (13) utility preference (14) household utility (15) garden rubbish (16) other combustion (17) domestic safety (18) perception about house (19) end of survey. To reduce the effect of human factor on the data, only household's fire makers were interviewed and the people conducting the interviews received a 5 days training.

2.2.3 Two-week first person observations

First person winter observations methodology

Ten houses in KwaDela were randomly selected. Residents were asked to participate in the observation study and not to change their burning patterns or habits during observations.

Each house picked a day from the given 14 observation days. Observations were done twice a day in each house to capture burning events in the morning and evening. Some households mentioned that burning only occurred once a day, for the purpose of the study they were asked to burn twice for the day when observations will take place in their house. The burning starting time varied from house to house. The study was done during school holidays therefore, most of the households were not obliged to burn in early morning hours therefore chose 8h00 am as burning event starting time. The starting time for evening burning event ranged between 16h30 and 17h00. Other residents mentioned that they only burn during weekends since they are working and in those houses, observations took place on a Saturday or Sunday. Before any burning event, the amount of fuel to be used for ignition and refueling was weighed and recorded. During observations, stove operation behaviour was recorded and images were captured after obtaining verbal consent from the households.

3. RESULTS

3.1 Types of fuel used in KwaDela

There are currently 6 known types of fuel used in KwaDela, electricity, coal, wood, dung, paraffin, and LPG (Table I). Coal is the most used solid fuel in the township. Wood and dung are used as primary solid fuels in the absence of coal. Paper and wood are used as secondary fuels to start the fire. Most residents use both modern (electricity) and traditional fuel for cooking, space heating, boiling water and lighting. This can be seen by the percentage imbalance between solid fuel and electricity use. Table II shows that more than 90% of KwaDela residents use solid fuels for cooking, space heating and boiling water during winter. The use of these fuels for cooking and space heating decreased by less than 30% and by 57% respectively in summer. This means that more than 50% of the population continue to use solid fuels for cooking, boiling water and about 43% for space heating during summer. Electricity is used for cooking predominantly in summer and for lighting throughout the seasons (Table II). The number of residents using electricity for space heating in summer decreased to 23.9% while it remained high (96%) in both seasons for lighting. Therefore, it can be concluded that electricity is used mainly for lighting in KwaDela. A small population of about 6.6% use other fuel (candles) for lighting purposes.

Table I. Different energy sources and consumption percentages in KwaDela

Sources of energy in KwaDela	% of households using type of fuel
Electricity	97.1
Coal	74.9
Wood	63.3
Dung	28.0
Paraffin	3.4
Liquefied petroleum gas (LPG)	2.4
Total number of residents who participated in the survey:207	

Table II. Comparison of seasonal energy use (solid fuels and electricity) for different mode of usage

End use Function	Solid fuels Winter	Solid fuels Summer	Electricity Winter	Electricity Summer
	%of households			
Cooking	91.84	61.9	57.02	74.79
Space heating	91.8	43.54	32.64	23.96
Boiling water	95.23	61.9	38.01	50.41
Lighting	6.6		96	
Number of residents who participated on the survey :207				

KwaDela has a well-established coal and wood supply network. There are currently two known official points in KwaDela where households can purchase coal. According to the residents, coal from the two purchasing outlets differ in quality. Point A sells low ash coal at R110 per container (85 L) and offers delivery services. Point B sells high and low ash coal at a cheaper price of R100 without delivery.

Most of the residents who participated in the observations reported purchasing coal from point A due to the guarantee of high-quality coal all the time. Residents who purchased Point B coal reported knowing the difference between high and low-quality coal, and therefore, choose high quality coal at a relatively cheaper price compared to point A and do not have to worry about transportation cost due to its proximity to their residents. Another informal source of coal in KwaDela is the residents smoking Nyaope known as “Nyaope guys”, Nyaope is a local cheap addictive drug that is smoked. They collect coal from the train railway that passes through to the township. As the train passes, they get on the train, remove large quantities of coal from the train, and sell it at very low prices: usually at, R50 per container (85L). Some residents who live close to the railway also collect coal from the train instead of buying. Wood is either collected from the fields, bought from a local merchant or from the local residents selling at a very low price. The fields where the residents collect wood is an hour walk away from the township and it was observed that children play a role in collecting wood from the field in the morning around 9:00 am. The general dealer sells a pack of 10 kg wood at R45. The “Nyaope guys” sell wood at a varying price depending on negotiating ability of the buyer.

3.2 Relationship between household demographics and solid fuel use

The observation data direct link between households’ demographics and burning patterns. The age distribution, distance from the workplace and family size has an effect on the number and length of the burning events. One of the residents; mentioned that she has to cook twice every day to save money spent on bread because she has four male grandchildren between the ages of 10-15 years; During school holidays however, burning in the morning is inconsistent. During school holidays, burning is still done in the morning and evening however, the time for morning burning events shift from 06h00am to 08h00. The only reason for burning during winter school holidays is to boil water for cleaning and washing dishes. In one of the houses, observations were made around 16h00 due to the early commencement of burning activity for boiling water for bathing a three-year-old girl. One of the residents lives alone, is at home only during weekends, and so burns only during that time.

3.3 Solid fuel burning patterns

There are two burning events in winter (morning and evening) while in most cases there is only one in summer (morning). The morning burning events start about the same time 6h00; regardless of the season, evening event starts at about 17h00. There is variation of the burning starting time and burning period within the township for both morning and evening events. The morning burning events are longer with an average of 4 hours and evening with 3 hours. Traditional cast iron stoves have a burning chamber, cooking plates, a baking area and a chimney extending outside through the roof Figure 4. Inside the chamber just below the fire bed are openings that allow ash from burned coal to be transferred to the ash-tray. The plates are also used as openings where the fuel is loaded. Supply of wood is controlled by the fire marker and is determined mainly by the size of the chamber. The bigger the chamber the more fuel can be loaded in the stove. The stoves are sold with a steel extension used to reshuffle the fire or remove ash that falls on the sides of the ash-tray. The height of the chimney varies from house to house but is generally longer from the stove to the roof and shorter from the roof to outside ranging between 150 cm to 287 cm. This design results in emission of particulate at breathing level where it can have significant impact on human health. Most of the stoves are placed in the kitchen; other residents have a room separate from the house where they keep the stove. Almost all the stoves were bought when the first child of the house was born. The stoves are either union seven or eight with an average age of 25 years. Most of the stoves are broken and have leak points since they have been passed on from generations. One of the residents mentioned that she got her stove as a gift from her late great gran mother before she passed. Thus, she will continue to use the stove in her honor.

3.4 Stove operation behaviour

All the residents who participated in the observations remove ash from the stove before a burning event. They stated that if they do not remove the ash it takes longer for the fire to be established and results in thicker smoke emission than usual. The residents mentioned that they clean the stove once a week or after every two weeks. The "cleaning" of the stoves includes removing the plates, cleaning of the chimney and the combustion chamber. Chimney blockage inhibits smoke from being emitted outside thus, resulting in indoor air pollution. From the observation results, the bottom lit-updraft is the commonest ignition method used in the township. Two bottom lit ignition methods used differ in the way that the fuel is loaded in the stove. Other residents first load paper-wood-coal at once then light the fuel while others prefer to load paper-wood light the fuel, and then add coal once the fire is fully established. About 60% of the residents used the first (load paper-wood-coal at once) bottom lit-updraft while 40% used the second method. After ignition, the residents' close openings on the stove, and open the kitchen door as well as windows. When the fire is fully established, the doors and windows are closed, while the stoves combustion chamber is opened to allow heat to warm up the house. Based on the observation results it takes about 5 to 8 minutes for the fire to be fully established.

The average amount of paper, dung, wood, coal used for ignition is 0.01, 1.6, 1.4, and 4.5 kg with a sample standard deviation of 0.003, 0.5, 0.4 and 0.43 respectively. The amount of fuel used for ignition varies from house to house but the variation is not significant. Each household has a container they use to control and keep coal consumption constant. This variation also exists within a household and is depended on the fire maker. One of the residents mentioned that if it is the kids burning they put more coal on the stove at once because they are rushing to watch Television and play. Most of the households use 1 dustbin for a week and for the whole month they use 3 to 4 dustbins of coal. Households who burn twice every day are most likely to use four dustbins and those that work far from home burn only during weekends. The residents do not refuel after cooking they just poke the fire to keep it alive until they go to sleep.

3.5 Fuel use variability in South African low-income residential areas

Findings from this study have similarities and differences when compared to local or international studies. The role for different energy sources remain the same in the Highveld townships but differ in other regions. Studies by Makonese et al., 2015, Scorgie et al., 2013 and Naidoo et al., 2014 in Tembisa, Vaal triangle and Zenzele showed that coal remains the predominant fuel used for cooking and space heating. To start the fire, the residents also use paper and wood. About 90% of the 52 residents who took part in the fuel use survey in Tembisa use coal for cooking and space heating (Makonese et al., 2015). However, Tembisa and Zenzele residents use Kerosene as a secondary fuel instead of Dung. Residents often use solid fuels simultaneously; or use another when the predominant is unavailable (Naidoo etal., 2007, Mdluli and Vogel., 2010 &Ludwig et al., 2003). About 98% of the residents who participated in the fuel use observation in KwaDela use coal, wood, dung and paper in a single burning event. Hence introducing another form of fuel "clean fuel" while there is still a vast amount of coal in the local area may not be a solution. Rather, the introduced clean fuel will add to the multiple fuel choices the residents already have. Residents shift between clean and dirty fuels as a strategy to avoid high-energy costs. Residents (42%) at KwaGuqa and Doornkop shift from burning coal to burning paraffin in summer because of less space heating needs (Mdluli and Vogel. 2010).

While most townships in the Highveld region use coal as their primary source of energy (Makonese et al., 2015 and Naidoo et al. Mdluli and Vogel. 2010,), low-income residents in the Eastern Cape, KwaZulu-Natal, and North West use wood as their primary energy resource (Aitken 2007). The most used burning devices in Tembisa and Zenzele are Braziers, traditional cast iron or handmade coal stoves and PandaTM wick paraffin stoves. Over 50% of Zenzele residents who participated in the fuel use survey use handmade stoves. The most important factors governing fuel use in Tembisa are like the ones in KwaDela. This includes fuel availability, fuel cost, seasonality and cultural factors such as family diet.

The role of culture or generational instilled behaviour on fuel use and stove operational behaviour is not considered when designing interventions for improving air quality in low-income residential areas. KwaDela residents prefer to cook samp, traditional beans, and tribe using solid fuels because they take long to cook and have a different taste when cooked using electrical stoves. Residents in Thailand's rural, semi-urban and urban areas prefer to cook a specific rice (Glutinouse rice) using wood or coal and another (non-sticky) using electricity (Nansaior et al., 2011). According to Nansaior et al., 2011 coal can preserve the traditional cultural taste residents prefer when cooking certain dish. Therefore, despite having access and affording electricity residents will continue to use the preferred fuel for certain food they eat (traditional food). Therefore, fuel preference for cooking is one of the important factors for the continuous use of solid fuels in townships and urban areas (Nansaior et al., 2011).

4. DISCUSSION

Fuel use for domestic purposes is a complex activity governed by interlinked factors that vary in space and time (Thorn, 1994). Factors such (I) Income (II) Fuel availability (III) Fuel prices (IV) seasonality and (V) household demographics have the most impact on the choice of fuel used (David, 1998). The effect of household income on fuel choice explained by the energy ladder theory. The theory suggests that there is a one-way linear transition between the use of traditional and modern fuels, and household economic status is the only driving factor (Davis, 1998). Household financial status either restrict or allows the households to choose from different energy sources (Xiaohua & Zhenmin, 2003). In low-income residential areas like KwaDela, a linear transition from traditional to modern fuel use in not always evident as household income increases. Also in low-income residents in Zimbabwe, do not follow a one-way linear progression as anticipated by the energy ladder theory (Hosier& Dowg, 1987).

In cases where transition occurs, it is not linear or rapid. Linear transition may occur when the household monthly income increase significantly (Cheng& Yang., 2014). Fillipini, 2006 argues that not all households completely switch from one fuel to another but partially switch between modern (electricity) and traditional fuels (coal, wood). Improvement of a household economic status leads to diversification of fuel use (Davis, 1998). As economic status improves, most households gradually change from using only traditional fuel to using both traditional and modern for fuel security purposes until they can afford to use electricity for all household purposes (cooking, lighting, and space heating). Same conclusions were drawn from the current study, KwaDela residents tend to use both modern and traditional fuel at the same time. Within the township traditional fuels are dominant in winter while modern are dominant in summer. The residents use low cost fuel (wood, coal, dung) for is used for space heating, cooking and boiling water because they consume large amount of energy while electricity is used for lighting and electrical appliances (refrigerator). This finding is in-line with results made by Mdluli and Vogel. 2010 at KwaGuqa and Doornkoop.

Seasonal variability and fluctuation of fuel costs lead to continuous switching between use of traditional fuel and electricity (Davis, 1998). Households that have shifted from using traditional fuel tend to rely on coal for space heating during winter. However, during summer, these households rely on electricity for most household activities that require energy. This explains the decrease and increase in number of residents using solid fuels for boiling water, cooking and space heating in KwaDela during summer and winter respectively. The residents tend to use both fuels for energy security purposes, which is why the percentage of fuel use does not add up to 100%.

The economic status of a household does not always have an impact on fuel use. In cases where fuel is collected, either from bush or mine dump; other factors such as distance between the household and source of fuel and availability of alternative fuel impact on fuel use (Heltberg, 2004). Residents that live close to the railway mentioned that they collect coal from there and they are close to the wood fields. This removes the need to save coal; therefore, they are most likely to use more fuel when compared to a household that has to buy coal. KwaDela Township has a well-connected coal supply network, with two coal sites within the township that offers delivery, wood is collected and delivered door to door by local residents. This removes the time consuming and labour intensive factors attributed to collection and transportation of solid fuels. Therefore, residents that live distant from the local coal merchant or wood fields can buy large quantities of coal or wood at an affordable price range (Mdluli and Vogel 2010). The proximity between the residential area and the mine in the vaal triangle and a well- established local coal network are the reasons coal remains cheap and easily accessible to the residents (Scorgie etal., 2013). This means that if there were to be another clean fuel suggested to replace solid fuels should be affordable, easily accessible and available in large quantities. The variability, complexity and interlinked relationship of the factors implies that factors governing fuel use in other settings may not be generalised.

Poor stove operation causes high emission of incomplete combustion products and thick smoke. This includes parameters such as (I) method used to start the fire (II) refueling patterns (III) fuel load mass (IV) stove cleaning. Results from the observations showed that most KwaDela residents use the bottom lit updraft (BLUD) ignition method. There are two known Ignition methods used, the TLUD (Top-Lit Up -Draft) or BLUD (Bottom-Lit Up-Draft). BLUD has a fuel consumption rate is approximately 20% lower compared with TLUD. This means that BLUD ignition stage is longer when burning thus, results in high emissions of smoke and incomplete combustion products. This method produces about 10-30% of tar while TLUD method produces about 1-5% (Saravanakumar et al., 2007). TLUD reduces emissions of fine PM by up to 80% and smoke by 60% (Makonese et al., 2015). This ignition method also produces less ash compared with convention method (Saravanakumar et al., 2007). Changing the residents stove operation behaviour could reduce fine particulate emissions in the township.

During combustion, ash is deposited inside the combustion tray. After every burning event, KwaDela residents empty the ash-tray to avoid the ash from pilling up inside the combustion chamber. High ash content from previous burning events blocks air from entering the combustion chamber and inhibits smokes from escaping thus results to indoor air pollution (Maraver, 2014). The ash also makes it difficult to light and for fuel to catch the fire thus results in combustion in low temperatures. Other factors such as age of the stove, combustion chamber size, airflow openings, length and size of the chimney affect the combustion conditions. The older the stove is, the higher the chances of it being broken beyond repair thus, more leakage points. Most of the stoves in the township are old, have leakage points that cause indoor air pollution. The leakage point allows emissions of flue gas that is not completely burn thus, lead to release of incomplete combusted products and particles leading to indoor air pollution. Air also enters through the openings into parts of the combustion zone cooling it down, resulting in loss of heat and combustion at low temperatures.

5 CONCLUSION

The goal of the National Air Quality Act, 2004 is to improve air quality in the country at a local and national scale. Attaining this goal may not be easy due to the complexity and variability of fuel use within and between the townships. This raises a need for detailed fuel use data to get the best applicable intervention methods for the specific township. The study findings affirm that KwaDela residents do not follow the energy ladder energy transitions, rather they partially or temporary move between modern and tradition fuel "fuel diversification or stacking" as an adaptation to avoid high fuel costs. The shift to using modern fuel in the township is restricted by household financial status, increasing electricity prices, unreliable supply of electricity and sentimental attachment on the traditional stoves. Factors governing household's energy profiles and consumption in the township include fuel availability, seasonality, household demographics, and fuel cost. The key to eliminating or reducing coal use in low-income residential areas is integrating intervention methods that the residents can afford and not high maintenance. Continuous public awareness through local radio and newspapers on the results from all studies done in the township would be effective on changing the residents stove operation behaviour. If there is a proposed clean fuel that will replace solid fuels in low-income residential areas it should be affordable, easily accessible and available in large amount in the local area. Long term intervention may include providing stable, well-paying job opportunities for the residents so they can afford electricity.

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REFERENCES

H.J. Annegarn, M.R., Grant, M.A., Kneen and Y. Scorgie. (1998). Direct source apportionment of particulate pollution within a township. Low-Smoke Coal Programme: Draft of final report. Report No. AER98.117DME

H.J. Annegarn, M.R., Grant, M.A., Kneen and Y. Scorgie. (1995). Direct source apportionment of particulate pollution within a township. Report to the Department of Minerals and Energy. pp. 126.

R. Aitken. (2007). Household energy use: a comparison of household energy consumption and expenditure across three provinces. J Energy South Afr. 18, pp. 20-8.

A, Barnett. (2000). Energy and the fight against poverty. Department for International Development (Dfid).

M. Davis. (1998). Rural household energy consumption: The effects of access to electricity—Evidence from South Africa. Energy Policy. 26, pp. 207-217

M. Davis., S. Ward. (1995). Household energy-use patterns in rural areas: The effects of access to electricity. EDRC Report Series.

S.P. Hersey., R.M. Garland., E. Crosbie., T. Shingler., A. Sorooshian., S, Piketh., and R. Burger. (2014. An overview of regional and local characteristics of aerosols in South Africa using satellite, ground, and modeling data. Atmos. Chem. Phys. 14, pp. 24703.

R. Heltberg. (2004, month.). Fuel switching: evidence from eight developing countries. Energy Economics. 26(5): pp.869-887.

M.I. Howells., T. Alfstad., D.G. Victor., G. Goldstein and U. Remme. (2003.). An Energy Model for a Low Income Rural African Village. Energy Research Centre, University of Cape Town. Cape Town, South Africa. 18.

W. Humphrey. J. Stanislaw. (1979). Economic growth and energy consumption in the UK, 1700–1975. Energy Policy, 7 (1), pp.29–42.

Z. Ishmail.,P, Khembo. (2015). Determinants of energy poverty in South Africa. Journal of Energy in Southern Africa, 26 (3). pp. 2413-3051

M. Farsi., M.Filippini., S, Pachauri. (2007). Fuel choices in urban Indian households. Dev.Econ, 12, pp. 757–774

A.Garcia-Maraver., M. Zamorano., U. Fernandez., M. Rabacal. (2014) Relationship between fuel quality and gaseous and particulate matter emissions in a domestic pellet-fired boiler. Fuel, 119, pp. 141-152.

D.Kimemia. and H.J. Annegarn. (2011). Urban biomass energy economy in Johannesburg, South Africa, Energy for Sustainable Development, 15(4): pp 382–387.

T.B. Jordan. And A.J. Seen. (2005). Effects of Airflow Setting on the Organic Composition of Woodheater Emissions. Environmental Science and Technology, 39, pp.3601-3610.

G. Leah. (1992). The energy transition. Energy Policy, 20, pp. 116–123.

P. Lloyd. (2014, Aug.). The energy profile of a low-income urban community. Journal of Energy in Southern Africa, 25(3), pp. 80 – 85.

M. Madubansi. and C.M. Shackleton. (2007). Changes in fuelwood use and species selection following electrification in the Bushbuckridge lowveld, South Africa. Journal of Environmental Management, 83, pp. 416–426.

M. Madubansi. and C.M. Shackleton. (2006). Changing Energy Profiles and consumption patterns following electrification in five rural villages, South Africa. Energy Policy, 34, pp. 4081–4092.

T. Makonese., D. Masekameni., H. Annegarn. and P. Forbes. (2015). Influence of fire-ignition methods and stove ventilation rates on gaseous and particle emissions from residential coal braziers. Journal of Energy in Southern Africa, 26(4): pp.16-28.

T.Makonese., D.M. Masekameni. and H.J. Annegarn. (2016, Mar). Energy use scenarios in an informal urban settlement in Johannesburg, South Africa. In International Conference on the Domestic Use of Energy.

T.N. Mdluli. and C.H.Vogel. (2010). Challenges to achieving a successful transition to a low carbon economy in South Africa: examples from poor urban communities Mitigation and Adaptation Strategies for Global Change. 15: pp. 205 -222.

A. Nansaior, A. Patanothai, A. Rambo, and S. Simaraks, (2011). Climbing the energy ladder or diversifying energy sources? The continuing importance of household use of biomass energy in urbanizing communities in Northeast Thailand. Biomass and Bioenergy, 35(10): pp.4180-4188.

H. Nuwarinda, (2007). 'Air Pollution Study of a Highveld Township during a Basa ngengo Magogo Rollout'. Unpublished Masters Dissertation. Johannesburg: University of Johannesburg

South Africa. 2004. National Environmental Management Act.

C. Thorn. (1994) Energy for Rural Development, Paper 6 South African Energy Policy Research and Training Project, Energy for Development Research Centre, University of Cape Town, Cape Town.

A. Saravanakumar., T. M. Haridasan., T. B. Reed. and R. K. Baia. (2007). Experimental investigation and modeling study of long stick wood gasification in a top lit updraft fixed bed gasifier. Fuel, 86: pp.2846–2856.

Y. Scorgie., M.A. Kneen., H.J. Annegarn. and L.W. Burger. (2003). Air pollution in the Vaal Triangle - quantifying source contributions and identifying cost-effective solutions, Clean Air Journal, 13(2). pp. 5 – 18.

C.Schmidl., M. Luisser., E. Padouvas., L. Lasselsberger., M. Rzaca., C. Ramirez-Santa Cruz., M. Handler., G. Peng., H. Bauer.and H. Puxbaum. (2011). Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. Atmospheric Environment, 45: pp.7443–7454.

A.Seaton., W. MacNee., K. Donaldson. and G. Godden (1995) Particulate air pollution and acute health effects. The Lancet. 345, pp.176–178.

K.R. Smith., M.G., M. Yuquing., W. Wongsekiarttirat. And A. Kulkarni. (1994) Air pollution and the energy ladder in Asian cities. Energy. 19, pp.587–600.

K.R. Smith. (1988) Air Pollution: Assessing Total Exposure Developing Countries. Environment, 30, pp.16–34.

J. Soussan.,P. O'Keefe. And B. Munslow. (1990) Urban fuelwood challenges and dilemmas, Energy Policy, 18 (6), pp. 572- 582.

D.E. Ward., W.M. Hao., R.A. Susott., R.E. Babbitt., R.W. Shea., J.B. Kauffman. and C.O. Justice. (1996) Effect of fuel composition on combustion efficiency and emission factors for African savannah ecosystems, Journal of Geophysical Research-Atmospheres, 101: pp. 23569–23576.

B.Wernecke., B. Language., R.P. Piketh. And R. Burger. (2015) Indoor and outdoor particulate matter concentrations on the Mpumalanga highveld - A case study. Clean air journal. 25(2), pp. 12-16

W.Xiaohua. and F. Zhenmin. (2003) Common factors and major characteristics of household energy consumption in comparatively well-off rural China. Renewable and Sustainable Energy Reviews, 7. pp. 545-552.

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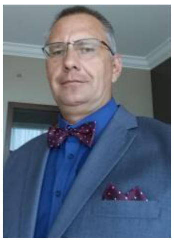

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