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Research Article

Indoor Air Pollution from Cooking and its Effects on Households in Low Income Urban Areas in Developing Countries

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ABSTRACT

The purpose of this study was to carry out controlled cooking tests so as to evaluate the amount of Carbon Monoxide (CO), Carbon Dioxide (CO_2) and Particulate Matter ($PM_{2.5}$), the main causes of indoor air pollution released from incomplete combustion of cooking fuels used by the sampled households. The study was carried out in Kibera Constituency, Nairobi, Kenya. The study found that measuring these emission and highest temperature (˚C) reached in the house while cooking was quite important in understanding the extent of indoor air pollution among targeted households. The study further sought to analyze the amount and efficiency of fuel used when cooking a standard meal of breakfast and dinner in a typical household. The fuels evaluated in this study were Charcoal, Kerosene, Electricity and Liquefied Petroleum Gas. Four households were randomly selected from a sample size of 304 households to participate in the Controlled Cooking Tests. Participation in the study was voluntary. Participating household who signed consent forms containing information about the study, the procedure and the benefits of participating in the study was quite symmetrical but participants willingly.

Keywords: Charcoal; Controlled cooking tests; Household; Kibera; Indoor air pollution

ABBREVIATIONS: CCTs: Controlled Cooking Tests; CO2: Carbon Dioxide; ˚C: Temperature; GHG: Global Greenhouse Gas; LPG: Liquefied Petroleum Gas; PM: Community Particulate Matter; PPM: Parts per million

INTRODUCTION

Background of the Study

Provision of clean, affordable, safe and sustainable energy is important in poverty reduction, wellbeing of people and sustainable development. Many people worldwide have no access to most basic energy services [1]. Clean energy refers to energy types that create less or no pollution to the environment. There is no perfect environmentally friendly energy. Wind energy production for example may cause visual and noise pollution [2]. Hence this study applies the term cleaner cooking energy as opposed to clean which is in line with the Sustainable energy for all guidelines initiated by Ban Ki-Moon in 2011 [3]. As the Secretary-General of the United Nations, he emphasized that, "energy is the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive." Access to energy is a necessary precondition to achieving many development goals that extend far beyond the energy sector in eradicating poverty, increasing food production, providing clean water, improving public health, enhancing education, creating economic opportunity, and empowering women. Hence cleaner energy is needed to prevent climate change, reduce premature deaths and economic burden and provide energy security [3]. IEA and OECD (2004) report indicated that worldwide, 2.4 billion people continue to depend on biomass fuels like wood, dung and agricultural residues to be able to meet their basic energy needs for cooking, boiling water, and lighting and, depending on climatic conditions, space-heating.

Rehfuessetal. [4] noted that, from an environmental point of view, wide- spread use of solid fuels could mistakenly be interpreted as a positive development, given that most biomass fuels constitute a source of renewable energy. From a public health point of view, widespread use of solid fuels is, of course, interpreted as a negative development because of the health risks associated with indoor air pollution. The study further noted that, solid fuel use is a poor proxy for indoor air pollution levels as the concentrations of small particles, CO, and other pollutants vary markedly between different types of solid fuels and between the same fuels being burnt in open fire versus in a well-maintained improved stove. In light of population growth and given the current lack of political commitment, it seems unlikely that the coming decade will witness

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a large reduction in solid fuel use in most of the developing world. Owusu andAsumadu[5] stated that,renewable energy sources replenish themselves naturally without being depleted in the earth; they include bioenergy, hydropower, geothermal energy, solar energy, wind energy and ocean (tide and wave) energy.

Zheng et al.[6] in a study in four neighborhoods in Accra, the capital of Ghana found that household and community biomass fuel use were important predictors of household PM pollution in Accra neighborhoods. The study further noted that, community biomass use had a stronger effect on cooking area Particulate (PM) than a household's own fuel in crude and adjusted estimates. At the household level, fuel use for both own and small-commercial cooking seemed to be associated with PM pollution. We also considered associations by PM size fraction and found that cooking area $PM_{2.5}$ concentrations consistently exceeded corresponding ambient levels, suggesting the presence of household sources for coarse particles, such as sweeping and resuspension; the pattern for ambient and household $PM_{2.5}$ was more mixed, According to Energy Technology Perspectives [7].

'*Climate scientists agree that there is a strong and incontrovertible link between global GHG emissions caused by human activity, their concentration in the atmosphere and average global air and sea temperatures. The global average annual concentration in the atmosphere of* CO_2*– the most important anthropogenic greenhouse gas – reached 410 parts per million (ppm) in 2019, up 3 ppm (0.6%) on the previous year. This is a major increase from pre-industrial levels, which ranged between 180 and 280 ppm. These higher concentrations are responsible for increasing the global average temperature of the planet by about 1 degree Celsius, leading to an increase in global sea levels of about 20 centimeters, the melting of glaciers and reduced sea ice, along with broader changes in weather patterns. Increased* CO_2 *levels in the atmosphere dissolve into the upper ocean waters and are also causing the world's oceans to become more acidic*'.

In most households in Africa south of Sahara, 700 million depend on biomass for cooking energy. Whereas biomass use is on the decline in other parts of the world, its use in SSA is increasing. Biomass energy production requires a lot of labor and employs many people. Charcoal contributes around Ks.35 billion to the economy and the industry employs 200,000 people [8]. Charcoal is preferred because it is relatively clean compared to firewood, charcoal produces less smoke in terms of fine particulate matter though with higher concentration of carbon monoxide compared to firewood and is readily available [9]. It is estimated that 900 million people will use biomass as cooking energy by 2020. Access to clean energy services remains limited [10]. This may be due to many factors which could be affordability of cooking fuel, convenience of cooking fuel [11].

The current trends in biomass cooking energy production and use are unsustainable and inefficient. Charcoal production process involves burning wood in traditional earth kilns which are inefficient and efficiency range of 10-20%, 9% of charcoal produced in Kenya is done by this method which wastes wood and emits large volumes of greenhouse gases. The use of traditional kiln produces 0.77- 1.63 kg of carbon dioxide per kg of charcoal [12]. Environmental impacts include depletion of forests and climate change. Firewood is mainly used by rural households in Kenya who collect it from , public or private farms, branches of pruned tress and dead fallen tree parts. Firewood may also be collected from gazette forest where there is danger of cutting young trees illegally preventing regeneration thereby reducing forest cover. Firewood collection can interfere with fragile ecosystems. The imbalance between firewood supply and demand was 57.2% in 2002 and was expected to rise to 63.4% by 2015 [13]. In firewood collection women travel long distances, spend a lot of time and risks their lives to attacks by human or wild animals and injuries of head, back and legs.

About 82% of urban households in Kenya and 34% of rural households use charcoal [14,15] an inefficient biomass energy which has many negative impacts such as fuel wastage and indoor air pollution. For instance, 600,000 people die every year as a result of smoke inhalation and economic costs are considered in relation to the best case scenario of full adoption of higher performing biomass stoves by households and it is as high as US $36.9 billion per year [10]. There is need to adopt cleaner cooking energy which is more efficient and sustainable.

Alternative sources of cooking energy are available and their implication on livelihoods and environment needs to be understood as well as strategies for enhanced adoption and scaling up. These alternative sources of cooking energy include the following and their average national proportional use; Biogas (0.7%), electricity.0.8%, LPG 5.1% Kerosene 11% [16].

The aim of this study was to investigate indoor air pollution as a result of cooking fuel (Charcoal, LPG, Kerosene and Electricity) under actual conditions prevailing in the kitchens in the selected households. Participatory research method was used with four households volunteering to participate in cooking using charcoal , LPG, kerosene and electricity. Time taken to light the stove, time taken to cook, amount of fuel used were recorded. Changes in concentrations of Carbo dioxide, carbon monoxide and $PM_{2.5}$ were recorded. Temperature was also recorded.

Research Methodology

The study was carried out in Kibera (Laini Saba village) an informal settlement in Nairobi with a population of 170170 people according to the 2009 Kenya Population and Housing Census Report.

Four households were randomly selected from a sample size of 304 households to participate in the Controlled Cooking Tests. Participation in the study was voluntary. Participating householdssigned consent forms containing information about the study, the procedure and the benefits of participating in the study.

Out of the 4 households selected, 3 households typically used Charcoal, Kerosene or Electricity as cooking fuels at different times of the day while thefourth householdwas selected to join the three household and cook with Liquefied Petroleum Gas (LPG).

Cooking Process Procedure

Eight controlled cooking tests were carried out to cook breakfast and dinner using thefour different fuel types. A total of 32 tests were carried out by the end of this study.

The cooking tests were done between6am-9am for breakfast and 3pm-6pm for supper.Before the cooking begun, ingredients for the meals were sourced from a local shop and weighed using an electric scale.

For breakfast 2000g water, 1000gmilk, 20g tealeavesand 80g sugars were weighed. After weighing, the ingredients were all mixed in a medium sized pot.

The ingredients for dinner, which consisted of two dishes,were 2000g Water, 1000g Maize flour for cooking the first meal and kale, tomatoes,onions, salt and oil all precisely weighed to a total weight of 1100g for the second meal.

Charcoal was weighed in a separate container and put in the stove. When cooking with kerosene, the fuel was poured into the kerosene stove and the weight taken. The whole cylinder was weighed when LPG was used. After weighing the stove was lit with the time taken for it to be fully lit recorded. Cooking began when the stove was fully lit and ended when the meal was fully cooked depending on the household cooking style.

After removing the food from the charcoal stove remaining fuel was placed in a separate container and weighed so as to ascertain the amount of the fuel used in the cooking session. For kerosene the stove with the fuel were weighed to get the weight remaining fuel. When cooking with LPG, the whole cylinder was weighed again to determine the amount of fuel used.

Emission Monitoring

The dimensions of the houses with all the ventilations were measuredat the beginning of the study.The equipment wasplaced at least 1.5m away from any ventilation in the house.

The equipment was hanged 1m away from the stove and 1.5m high in the house using a wire. The distance from the stove emulated the distance from which a person operating the stove sits and the height simulated a person standing in the house.

Carbon Monoxide (CO) data was measured at an interval of 10seconds using EL-USB-CO Carbon Monoxide data logger.

Carbon Dioxide and Temperature data were logged at an interval of 1 minute using HOBO Telaire 7001 TEMP/RH/CO_2 data logger combined with the HOBO U12 to record and download the data.

Particulate Matter was also measured at an interval of 1 minute using the University of California, Berkeley Particulate Matter Monitor (UCB-PM Monitor).

The process of measuring the concentration of CO, CO_2, Particulate Matter and Temperature changeswhile cooking,begun an hour before lighting of the stove. The equipment waslaunched and set to zero (warm up) for 30 minutes inside zip lock bags. Afterwards the equipment was hanged and left for 30 minutes to monitor ambient CO, CO_2, Particulate Matter and Temperature data inside the room where the cooking test took place. After monitoring ambient air data for 30 minutes the stove was brought in the room and cooking started.

After the whole cooking was done, the equipment was again left for another 30 minutes to capture the background air data so as to evaluate the process of returning back to the ambient conditions before any cooking in the room. Data was then downloaded after the final ambient air data logging.

Emission Data Analysis

Raw CO, CO_2, Particulate Matter ($PM_{2.5}$) and Temperature (°C) data captured during the whole indoor air concentration monitoring was analyzed using the MS Excel Descriptive Statistics Function to determine Mean, Median, Mode and Standard Error.

RESULTS AND DISCUSSION

Combustion properties of cooking fuels used in Kbera informal settlements

Charcoal used for cooking was analyzed by KEFRI (Kenya Forestry Research Institute) and the following results (Table 1) were obtained.

Combustion test for sample of charcoal was done by Kenya Forestry Research Institute (KEFRI) using the standard procedure to analyses combustion properties of charcoal sample used in cooking tests by households in Kibera. Bomb calorimeter was used to determine the calorific value of charcoal sample. Moisture content was determined by heating a sample of charcoal to 103°C in an oven for duration of 12 hours and expressed as % decrease of weight of initial sample of charcoal. Volatile matter was determined by incinerating the dried charcoal sample in a muffle furnace at atemperature of 900°C for 7 minutes and taking weights. Fixed carbon is the combustible portion that is left as a residue after volatile matter has distilled off. Fixed carbon is determined by subtracting the sum of moisture and ash content from the original sample (Tables 2 and 3).

LPG has good combustion properties compared to Charcoal and kerosene. It has higher calorific value,hot flame and leaves no unburnt residue (Table 4).

The dimensions of the kitchens in Kibera were measured and recorded in the table above. There was no partition between the kitchen and the living room. The bedroom and the living room were separated with a piece of cloth. Emissions from the kitchen could circulate in the whole house since the rooms were not fully partition. A plastic sheet separated the roof and the rooms in all households sampled for cooking test.

Bar graph shows time taken to light and cook breakfast using the four types of cooking energies (Kerosene,LPG ,Charcoal and Electricity). LPG took the shortest time to cook followed by Charcoal Electricity and kerosene respectively. Concerning time taken to light , LPG was instant followed by Kerosene Electricity

Table 1: Combustion test on charcoal sample.

M.C(%)-Moisture Content	V.M(%)-Volatile matter	F.C(%)-Fixed Carbon	A.C(%)-Ash Content	C.V (k.cal/g)–Calorific Value
3.93	15.6	77.9	2.54	6.9431

Table 2: Combustion properties Kerosene.

Viscosity	Density	Solubility	Flashpoint	Heat of combustion
Low viscosity	0.78-0.81gm/cm³	Insoluble in water	37-65°C (100& 150° F)	43.1/mJ/kg

Table 3: Combustion properties of Kerosene.

Flash point	Melting point/Boiling poit	Highest temperature when burned	Calorific value (MJ/kg
-104°C/156° F	-188°C/-306.4°C	1967°C/3573°F	46.1

Table 4: Kitchen characteristics.

Household	Length (cm)	Width (cm)	Height (cm)	Distance between partion and roof (cm)	Size of door (The only opening)	Window size
Household 1	355	240	355	40	70 cm by 160 cm	0
Household 2	386	375	235	50	69 by 171 cm	0
Household3	350	344	305	42	74 by 172 cm	49 cm by 43 cm

and lastly Electricity. For electricity, the time taken to light was the duration from switching the coil on to when it turns red hot (Figure 1).

Bar graph showing the quantities of different fuel types used to cook the same amount of breakfast and dinner.A comparison revealed that kerosene took the smallest quantity to cook dinner followed by LPG and lastly Charcoal. Electricity could not be compared with other cooking energies because households had direct connections to the mains with no meters (Figure 2).

A comparison of amounts of fuel used to cook breakfast revealed a tie between LPG and Kerosene which took the smallest quantity followed by Charcoal which took more than three times the amount of Kerosene or LPG used.

Bar graph showing the amounts of CO release when cooking a standard breakfast meal with the four different types of fuel (Kerosene, LPG ,Charcoal and Electricity). Cooking with Charcoal results in more emission of CO followed by kerosene, Charcoal and electricity respectively (Figure 3).

Bar graph showing the amounts of CO release when cooking a standard dinner meal with the four different types of fuel (Kerosene, LPG ,Charcoal and Electricity). Cooking Charcoal results in more emission of CO followed by kerosene, Charcoal and electricity respectively (Figure 4).

Bar graph showing the amounts of CO_2 release when cooking a standard breakfast meal with the four different types of fuel (Kerosene, LPG ,Charcoal and Electricity). Cooking with Charcoal results in more emission of CO_2 followed by kerosene, Charcoal and electricity respectively (Figure 5).

Bar graph showing the amounts of CO_2 release when cooking a standard breakfast meal with the four different types of fuel (Kerosene, LPG ,Charcoal and Electricity). Cooking with Charcoal results in more emission of CO_2 followed by kerosene, Charcoal and electricity respectively (Figure 6).

Bar graph showing the amounts of $PM_{2.5}$ release when cooking a standard breakfast meal with the four different types of fuel (Kerosene,LPG,Charcoal and Electricity). Cooking with Charcoal results in more emission of $PM_{2.5}$) followed by kerosene, electricity and Charcoal respectively (Figure 7).

Bar graph showing the amounts of $PM_{2.5}$ release when cooking a standard dinner meal with the four different types of fuel (Kerosene,LPG,Charcoal and Electricity). Cooking with Charcoal results in more emission of $PM_{2.5}$) followed by kerosene, electricity and charcoal respectively (Figure 8).

Times taken to cook using different types of cooking energy

Time taken to cook a meal was determined by including the time taken to light cooking stove, time taken to prepare and cook all dishes. LPG was found take the shortest time to cook dinner and breakfast (19.20 minutes and 32 minutes respectively), followed by Charcoal (26 minutes, 50 minutes for breakfast and dinner respectively), Kerosene took the third shortest time (40 minutes for breakfast and 51 for dinner) followed by electricity which was last (37minutes for breakfast and 1 hour five minutes for dinner).

Anova results to compare the cooking times found that there is a significant ($p<0.05$) difference in cooking times.

Cooking with LPG reduced the cooking time by almost half compared to electricity. LPG reduced the cooking time of dinner by 1.56 times compared to charcoal. This makes LPG good for cooking during hours when people are time constrained. Cooking with charcoal increased cooking time because of the long time taken to light it.

Fuel use

Charcoal took the largest amount of fuel to cook food followed by LPG and Kerosene took the least. Electricity could not be compared because all houses using electricity had no meters.

Cooking with LPG and Kerosene reduced the amount of fuel used to cook. LPG was found to reduce the amount of energy by 2.9 times compared to charcoal. Kerosene reduced the quantity of cooking energy four times compared to charcoal.

An Anova test was done to investigate if there is significant difference in quantity of fuel used. Anova test found out $P < 0.05$ which confirms that there is a significant difference in the quantity of fuel used.

Cooking with LPG or Kerosene can reduce thequantity of charcoal consumed.Switching to LPG or fuel stalking if practiced by households can help reduce the demand for charcoal and this can reduce deforestation.

Emmissions from different cooking fuels

Carbomonoxide (CO)

Electricity had the least emission compared to other cooking fuels followed LPG then Kerosene and charcoal had the highest.

Anova test was done to test if there is a significant difference in emmission between different types of cooking fuels. An ANOVA test revealed $p<0.05$ which comfirms a significant difference in emmission between the different types of coooking energy.

Households cooking with LPG reduced emmission of CO by 6 times compared to charcoal. Cooking with Kerosene reduced CO Emmission by 3 times.

Shifting from cooking with charcoal a traditional cooking energy by majority of people in Kenya to LPG or Kerosene can help reduce health impacts as a result of CO and reduce many premature deaths.

Carbondixideemmissions (CO_2)

Electricity had the least emission of CO_2 followed by LPG then Kerosene and charcoal had the highest emission of CO_2.

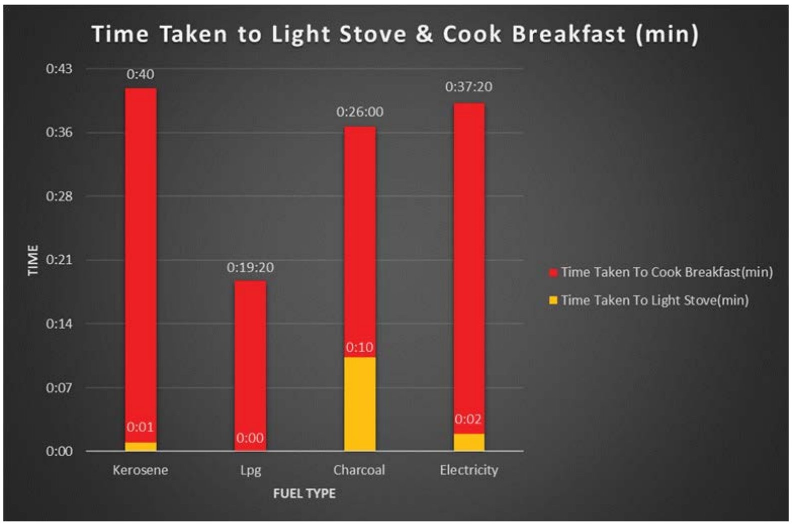

Figure 1: Time taken to light stove and cook breakfast.

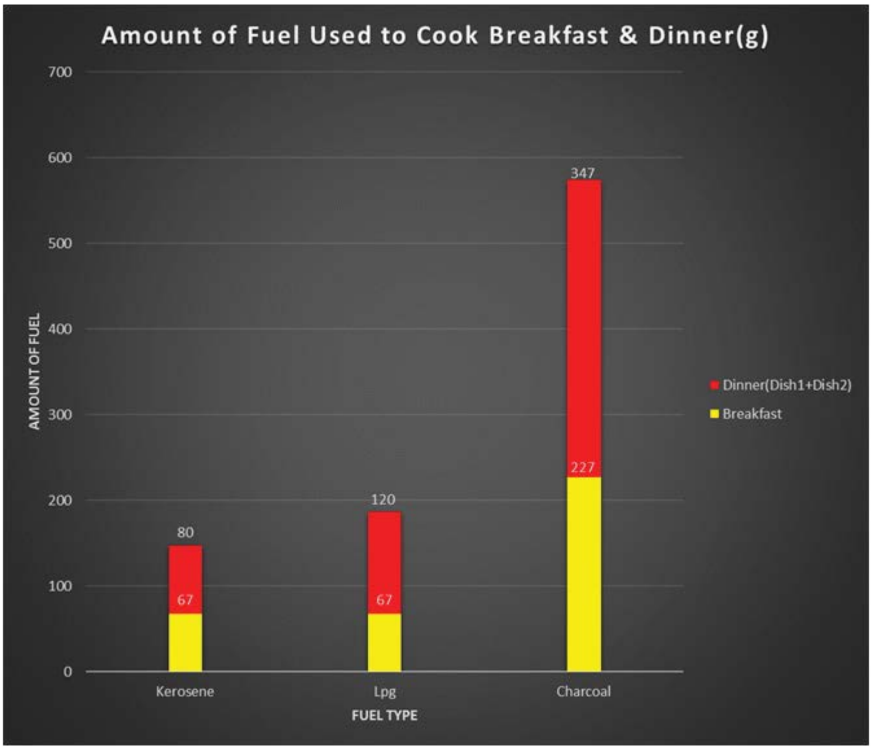

Figure 2: Time taken to light stove and cook dinner.

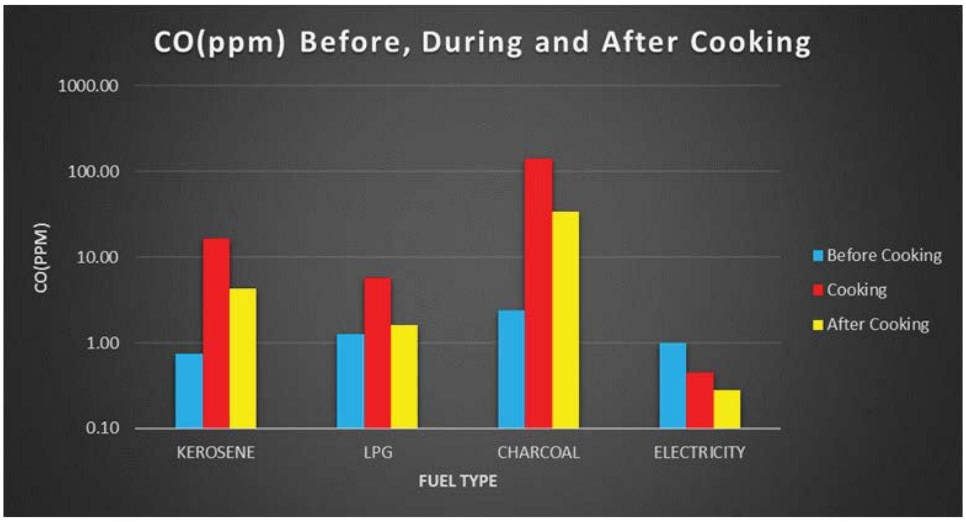

Figure 3: CO emission before, during and after cooking breakfast using different types of fuel.

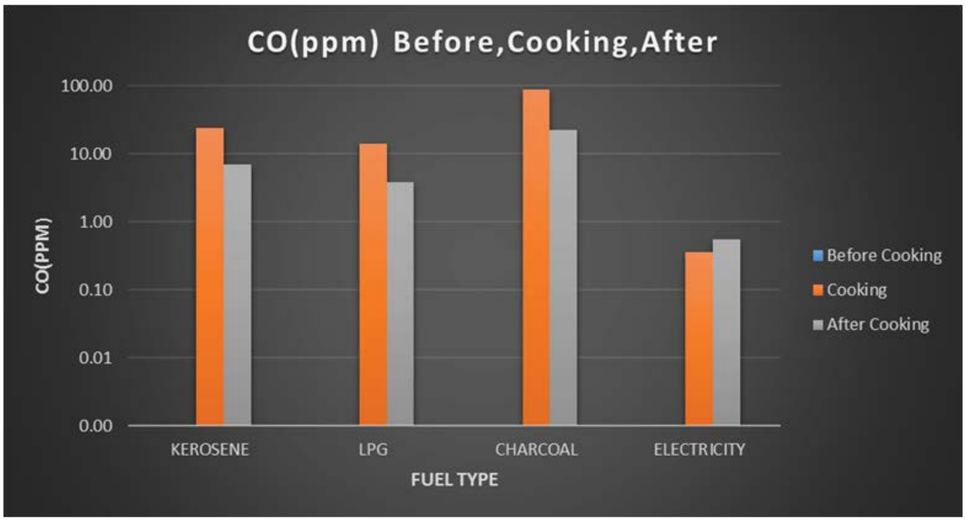

Figure 4: Bar graph showing CO Emissions before, during and after cooking dinner.

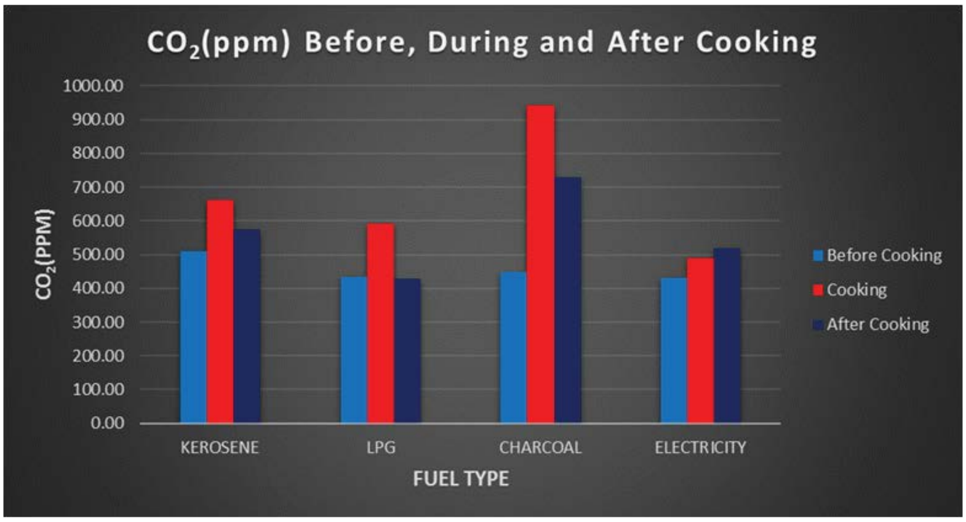

Figure 5: Bar graph showing the amounts of CO_2 released before, during and after cooking breakfast.

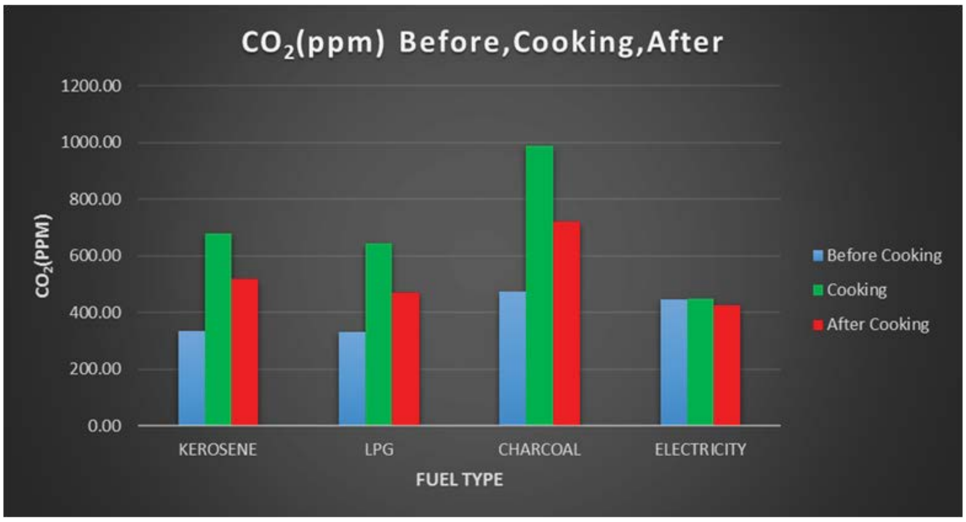

Figure 6: Bar graph shows CO2 Emissions before during and after preparation of dinner.

Household's cooking breakfast with charcoal released 1.7 times more CO_2 thanthose cooking with LPG and 1.2 times with Kerosene.

Using charcoal as a cooking fuel release more CO_2 a greenhouse gas than other sources of cooking energy.

A shift from charcoal to LPG may reduce greenhouse gas emission by a great margin

Particulate matter $PM_{2.5}$.

Electricity had the lowest emission of $PM_{2.5}$ followed by LPG then

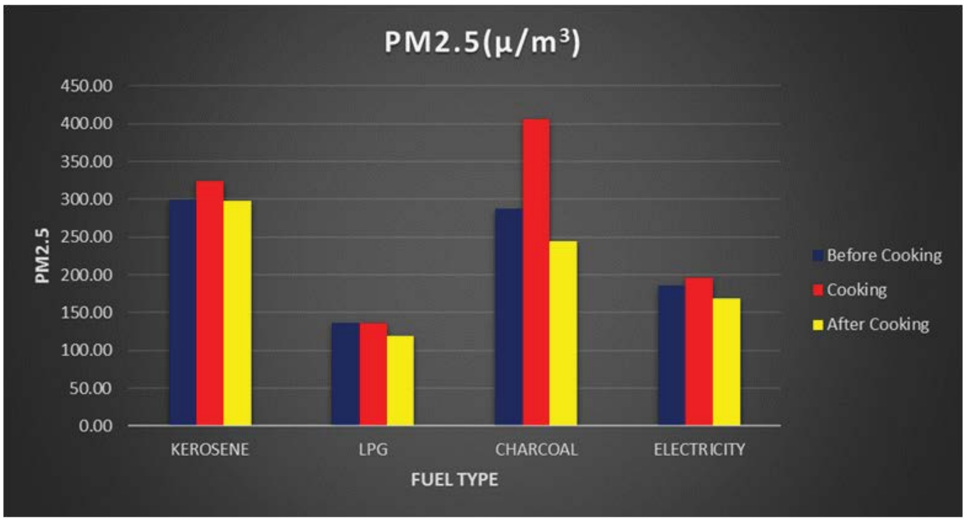

Figure 7: Bar graph showing particulate matter (PM2.5) concentrations, before, during and after cooking breakfast.

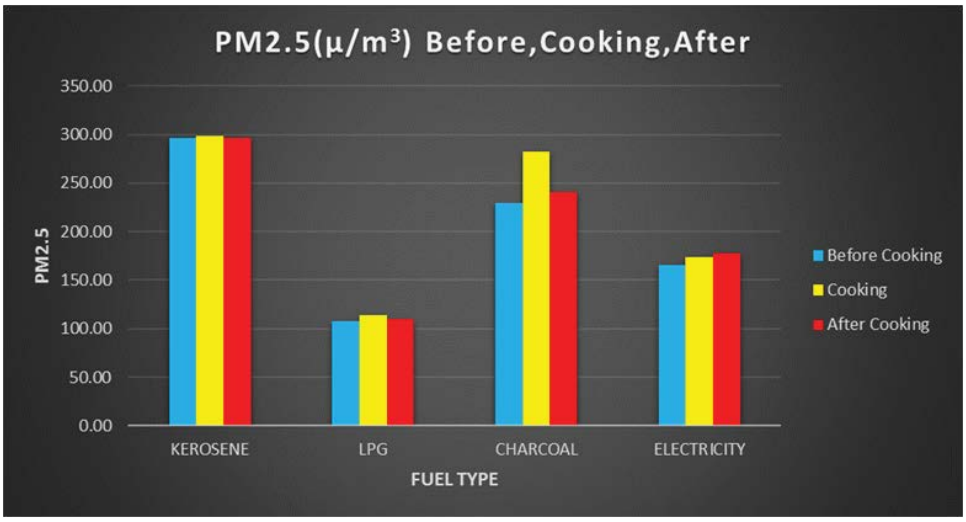

Figure 8: Bar graph showing particulate matter (PM2.5) concentrations, before, during and after cooking dinner.

Kerosene and charcoal had the highest emissions of $PM_{2.5}$compared to other cooking fuels. Kerosene had 1.23 time's higher emissions of $PM_{2.5}$than charcoal and 1.6 more than LPG.

Cooking with charcoal exposes the households especially the women to nearly three times the level of particulate matter than those cooking with LPG and 1.6times more than those cooking with kerosene.

Conclusion

The use of cleaner energy fuels such Biogas, electricity, LPG is still low in low income countries especially in slum areas. The implication of this on health and environment is quite severe and need to be addressed. This is quite dangerous as more household in the designated places are getting exposed to indoor pollution as a result of cooking fuel. Kerosene which is the most common cooking energy comes from fossils petroleum fuels that produces gaseous pollutants and particulate matter. Charcoal, a common cooking fuel in Kibera slums and many other low income households, come from carbonizing wood and this may lead to deforestation which also has its own consequences. Charcoal making is done in kilns that are highly inefficient leading to wanton destruction of forests. Charcoal cooking also produces harmful carbon monoxide and carbon dioxide gas. Researches indicate that inhaled carbon monoxide competes with oxygen to bind to hemoglobin, resulting in oxygen deprivation to the organs, which can lead to death. The current trends in cooking energy use in Kibera not sustainable and there is need for energy shift to cleaner sources of cooking energy.

References

1. International Energy Agency. Energy outlook 2014.
2. Haluzan N. Power gen Africa @ 2016 best power conference in Africa. 2016.
3. Sustainable Energy for All. Energy access committee report. 2014.
4. Rehfuess E, Mehta S, Prüss-Üstün A. Assessing household solid fuel use: Multiple implications for the millennium development goals. Environmental Health Perspectives,2006;114: 373-378.
5. Owusu PA, Asumadu S. A review of renewable energy sources, sustainability issues and climate change mitigation. Civil & Environmental Engineering, 2016;3: 1167990.
6. Zhou Z, Dionisio KL, Arku RE, Quaye A, Hughes AF, et al. Household and community poverty, biomass use, and air pollution in Accra, Ghana: Proceedings of the national academy of sciences of the United States of America. National Academy of Sciences,2011;108:11028-11033.
7. International Technology Agency. Paris: International Energy Agency and Organisation for Economic Co-operation and Development Energy Technology Perspectives (2020).

8. Mutimba S, Barasa M. (2005). National charcoal survey: Summary report. Exploring the potential for a sustainable charcoal industry in Kenya. Nairobi: Energy for Sustainable Development Africa (ESDA). 2005.

9. Njenga M, Yonemitsu A, Karanja N, Iiyama M, Kithinji J, Dubbeling M, et al. Implications of charcoal briquette produced by local communities on livelihoods and environment in Nairobi, Kenya. Int J Renew EnergDev 2013;2:19e29.

10. LambeF, Jürisoo M, Wanjiru H,Senyagwaet J. Bringing clean, safe, affordable cooking energy tohouseholds across Africa: An agenda for action. Background paper to the Africa Progress Panel 2015 report Power, People, Planet: Seizing Africa's Energy and Climate Opportunities. The New Climate Economy, 2015.

11. Njenga Y, Matsushita S. A choice of experiment study on fuel preference of Kibera slum households in Kenya. 2015.

12. Pennise DM, Smith KR, Kithinji JP, Rezende ME, Raad TJ, Zhang J, et al. Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. Jouranal ofGeophysical Research 2001;106: 241-243.

13. Ministry of Energy. Republic of Kenyastudy on Kenya's energy demand, supply and policy strategy for households, small scale industries and service establishments. 2002.

14. Karekezi S. Renewables in Africa—meeting the energy needs of the poor. Energy Policy 2002;30: 1059–1069.

15. Ministry of Energy. Study on Kenya's energy demand, supply and policy strategy for households, small scale industries and service establishments. 2002.

16. The Kenya Population and Housing Census. Counting our people for the implementation of vision 2030. volume population distribution by age, sex and administrative units,2009.