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INSTITUTE FOR CLIMATE CHANGE AND ADAPTATION

THE POTENTIAL FOR BIOETHANOL FUELS TO REDUCE GREENHOUSE GAS EMISSIONS FROM HOUSEHOLD COOKING IN URBAN INFORMAL SETTLEMENTS: A CASE STUDY OF KIBERA, KENYA

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DEDICATION

To my beloved sister Lydia - for the all fun times we had in Kibera, and for her selfless and endless support: *Deus Vobiscum!*

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ABSTRACT

This thesis explores the potential for increased adoption of clean and sustainable domestic cooking fuels in urban informal settlements to reduce pollution and greenhouse gas emissions. It also highlights the impact of continued charcoal and kerosene fuels use in Kibera and the overall implications to sustainable development frameworks such as the National Determined Contributions and Sustainable Energy for All Action Agenda. In this regard, the thesis focuses on assessing the potential and feasibility of using bioethanol fuels for domestic cooking to reduce greenhouse gas emissions in Kibera, one of Nairobi's largest urban informal settlements. Past research often depicted economically marginalized households in informal settlements and in rural areas as negligible contributors of greenhouse gas emissions, owing to their modest consumption and dependence on wood fuels as the main source of household energy. This thesis challenges the notion that the transition to clean and sustainable energy in urban informal settlements should not be prioritized by policy makers. By applying a mixed-method approach, a series of qualitative and quantitative results from 400 randomly-selected households in Kibera provide a framework for understanding the core factors responsible for household cooking energy choice. Analysis of the quantitative findings showed that charcoal and kerosene were the main cooking fuels available in Kibera, used by 76% and 81% of surveyed households respectively, typically in combination with each other. Only 10% of the surveyed households reported using bioethanol fuels for domestic cooking. It was estimated that approximately $3{,}764.39\ t\,CO_2e$ emissions will be generated annually as a direct result of the combustion of the current mix of cooking fuels, on the other hand, the study estimated that 98% of annual emissions from household cooking would be avoided if all households in Kibera were to completely switch to bioethanol fuel as the only means of domestic cooking. Analysis of qualitative information collected through triangulation of various information collection strategies, including surveys, semi-structured interviews with key experts and targeted focus groups, illuminated the key roles of the government and the private sector in reducing the costs of bioethanol fuels and stoves making them affordable to Kibera families. By providing empirical evidence, the study argues that greenhouse gas and black carbon emissions as a result of reliance on unsustainable and heavily-polluting fuels for domestic cooking are not only negatively impacting on the environment and human health but could also be dramatically reduced by transitioning to simple, low-tech alternative cooking technologies such as bioethanol. In this respect, the study concludes by providing specific policy and technology recommendations to overcome key barriers of adoption of bioethanol fuels which are discussed at length in chapter 6.

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LIST OF ABBREVIATIONS AND ACRONYMNS

AFI	Analysis of Fuel Input
ASAL	Arid and Semi-Arid Lands
BAU	Business as Usual
CBA	Cost Benefit Analysis
CCAK	Clean Cookstoves Association of Kenya
CEM	Continuous Emissions Monitoring
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	CO_2 equivalent
EF	Emission Factors
EPA	United States Environmental Protection Agency
ERC	Energy Regulatory Commission
FAO	Food Agriculture Organisation
FBO	Faith-Based Organisation
FGDs	Focus Group Discussions
Gg	Gigagrams
GHGs	Greenhouse gases
GoK	Government of Kenya
HAPs	Households Air Pollutants
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICS	Improved Cook Stoves
KBS	Kenya Bureau of Standards
KCJ	Kenya Ceramic Jiko
KII	Key Informant Interviews
KIRDI	Kenya Industrial Research and Development Institute
KNBS	Kenya National Bureau of Statistics
KSB	Kenya Sugar Boars
N_2O	Nitrous Oxide
NDCs	National Determined Contributions
PM	Particulate Matter
SE4ALL AA	Action Agenda Sustainable Energy for All
SFC	Specific Fuel Consumption
SLCPs	Short Lived Climate Pollutants
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention for Climate Change
UNSD	United Nations Statistics Division
VAT	Value Added Tax
WHO	World Health Organization

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1. INTRODUCTION

1.1. Background

Incomplete combustion of fuelwood and the use of inefficient, polluting cookstoves in low-income households contribute significant quantities of greenhouse gases (GHGs) (Ndolo, 2017; Ramanathan & Carmichael, 2008; Yonezumi, 2015). Similarly, key data inventories carried out in Kenya in the year 2000 indicate that the energy sector contributed 1,932 Gg CO_2 equivalent of methane (CH_4) emissions and 601 Gg CO_2 equivalent (CO_2e) of Nitrous Oxide (N_2O) emissions, accounting for 18% of all GHGs generated in Kenya (Ministry of Environment Kenya, 2015). CH_4 and N_2O are major GHGs that absorb thermal radiation emitted by the earth's surface, thus triggering the global warming effect.

In addition, 44,000 people are reported to die annually in Kenya as direct result of Household Air Pollution (HAP), which includes short-lived climate pollutants such as black carbon, methane and tropospheric ozone (WHO, 2016). Specifically, these deaths are caused by ischaemic heart disease, strokes, lung cancer, chronic obstructive pulmonary diseases (18 years +) and acute lower respiratory infections (under 5 years).

As the population of Kenya's informal settlement continues to expand, there is an urgent need to provide households with clean and sustainable domestic cooking fuel sources to address these challenges. Concurrently, cases of deforestation and forest degradation continue to be reported countrywide, with especially high demand of forest products such as charcoal and fuelwood within low-income areas (Gitonga, 1999).

These negative impacts can be abated by cooking with bioethanol fuels, which produce lower GHG emissions, reduce premature deaths from HAPs and decelerate deforestation (Shi & Zhou, 2014). Recent policy documents indicate that the Government of Kenya (GoK) is committed to create both national and county-level cross-ministerial taskforces to increase the availability of more sustainable, less polluting alternatives to charcoal and fuelwood, including higher tier stoves and alternative fuels such as bioethanol (Ministry of Energy and Petroleum, 2015; Ministry of Energy and Petroleum SE4ALL, 2016). The Kenyan Government is also committed to promoting the use of fast maturing trees for energy production (State Law Office, 2012).

This thesis examines the current state of bioethanol fuel usage in informal settlements using a classic case study approach. It does so by using various scientific techniques such as household surveys, focus group discussions (FGDs), ethnographical observations and semi-structured interviews with key experts and informants. In doing so, the study builds upon a large body of knowledge on domestic cooking fuels that has been carried out by other researchers, both in Kenya and in other developing economies across Africa. Much of the recent work has focused on bioethanol fuel use in middle-income urban areas – see Machandi et al., (2013), as well as low-income rural areas (UNDP, 2012).

The motivation for this study is to support evidence-based policy reforms in the energy sector by providing timely and up-to-date data on domestic fuel dynamics in informal settlements. The implications of fuel choices in informal settlements for prospects of Kenya meeting its commitments for the United Nations Framework Convention for Climate Change (UNFCCC) is also addressed. Upon analysis, this paper recommends that the GoK must make substantial, targeted efforts to raise the profile of bioethanol fuels as more sustainable and environmentally-friendly substitutes for polluting fuels such as kerosene, charcoal and firewood.

The overall structure of the thesis comprises 6 Chapters, including this introductory Chapter 1. Chapter 2 begins by laying out the theoretical dimensions of the research and looks at previous work in relation to bioethanol fuels, while Chapter 3 introduces the research instruments and methodology used. Chapters 4 analyses the results of survey data, interviews and FGDs undertaken during the field work stage of this study. Chapter 5 begins by synthesising all the findings of the study, followed by an in-depth discussion of the key thematic areas. Concluding remarks and recommendations for future research are addressed in Chapter 6.

1.2. Problem Statement

According to Kenya's Second National Communication to the UNFCCC, the energy sector is the 3rd largest contributor to GHGs emissions, accounting for up to 18% of total emissions (Ministry of Environment Kenya, 2015). Substantial amounts of these emissions are generated as a direct result of domestic cooking, by burning wood-based and petroleum-based fuels.

Most households in informal settlements consist of small rooms that do not allow adequate ventilation when cooking indoors (Karekezi et al., 2008; Yonemitsu et al., 2014; Yonezumi, 2015). Furthermore, shelters in informal settlements such as Kibera are closely spaced as a result of extremely high population densities, which exposes large number of individuals to smoke and other adverse health effects from domestic cooking fuel combustion (Desgroppes & Taupin, 2011). *Figure 1.1.* shows exposure to smoke levels of women and children during the cooking process. Women and children are typically the most vulnerable, as these groups are often present within homesteads during cooking hours (Kosgey, 2015).

Figure 1.1. A picture indicating HAPs generated from domestic cooking fuels

Apart from the dangers of immediate inhalation of smoke, Short Lived Climate Pollutants (SLCP) such as CH_4 and black carbon have the ability to cause local warming and can cause changes to local rain and cloud patterns (Zaelke & Parnell-Borgford, 2013). Smog is also generated, which presents serious air quality and health challenges (United States EPA, 1999; WHO, 2014).

A number of studies conducted in slum establishments around the world indicate that during the cooking process, indoor and outdoor air contains high concentrations of health-damaging Particulate Matter (PM)—typically in the range 10 to 100 times higher than the levels recommended by the World Health Organisation (WHO) (Muindi et al., 2016; WHO, 2014). Other notable GHGs produced alongside PM during both wood fuel and kerosene combustion are CO_2, CH_4 and N_2O, which all have climate warming properties.

It is linkages like these between household energy technologies, HAP and GHGs emissions that highlight the need for simple and affordable alternative clean cooking technologies, such as smoke-free bioethanol fuels. Evidence-based knowledge is critically-important in triggering energy policy reforms that can effectively reduce residential air pollution as well as safeguarding the health of the urban poor.

1.3. Scope of the Study

The study used a case study approach, which as a research strategy aims at bringing depth to specific phenomena by studying the relationships and processes that define them (Denscombe, 2010). The research focused on surveys administered to 400 households randomly selected across all of the villages that make up Kibera, i.e. a sample representing 0.04% of the total Kibera population— calculated by using formulae available online such as survey system—with a confidence interval of 4.85. The informal urban settlement of Kibera was selected as it is the largest not only in Nairobi but also in the country, with an estimated population of 950,000 people (Umande Trust, 2010 as cited by Mutisya & Yarime, 2011).

During the field study, two key parameters were considered: the total number of people inhabiting a given household, and the average consumption rate of fuel per day for a given fuel and stove type. These parameters were used to calculate the amount of GHGs produced in Kibera within specified time intervals. The GHGs that were considered for the study were only CH_4 and N_2O since Kenya is considered to be a carbon neutral country on the global scale (Ministry of Environment Kenya, 2015). Other parameters considered during the study were socio-cultural dynamics driving cooking fuel choices in Kibera as well as the current state of bioethanol fuels as a cooking technology. Though there were a wide variety of commonly used cooking fuels in Kibera, the study gave particular attention to charcoal and kerosene since they were the major sources of domestic energy for these households.

Some of the key challenges experienced during the study were related to obtaining up-to-date population data for Kibera. Available GoK census data as of 2009 indicated Kibera to have a total population of 355,188 people (see APPENDIX VI), which is widely considered to be a major underestimate. To overcome this challenge, the study used additional sources of data as provided by Umande Trust (as cited by Mutisya 2011) and the UN projection estimates. In doing so, a range of population data estimates representing all scenarios of the total population of Kibera were considered.

1.4. Research Questions

This research sought to address the following questions:

1. What are the available cooking technology options in Kibera?
2. What is the current state of bioethanol usage by households in Kibera?
3. What are the total GHG emissions currently produced in Kibera by burning cooking fuels?
4. What is the quantity of GHGs (CO_2e) emissions that would be avoided if households in Kibera switched to bioethanol fuels?
5. What factors are responsible for the observed trends and patterns in available cooking technologies?
6. What factors are responsible for the observed trends and patterns in available bioethanol fuel technologies?
7. What policy and technological options can accelerate the adoption rate and sustained use of this fuel in Kibera?
8. What are the roles of the public and private sectors in advancing the use of bioethanol fuels in Kibera?

1.5. Research Objectives

1.5.1. Overall Objective

To access the potential for bioethanol fuels to reduce GHGs emissions from household cooking in the urban informal settlement of Kibera

1.5.2. Specific Objectives

1. To analyse the cooking technologies and household energy sources available in Kibera.

2. To determine the quantity of GHGs (CO_2e) emissions that would be avoided in Kibera if households were to switch to bioethanol fuels.
3. To identify key factors determining bioethanol fuel adoption in Kibera.
4. To propose policy measures and technological options based on empirical evidence that could facilitate adoption and sustained use of bioethanol fuel in Kibera.

1.6. Justification and Significance

In order to map the critical areas for bioethanol fuel adoption in Kibera, there is an urgent need for the Kenyan government to rely on timely data to advance decision-making capacity on household energy options at national and subnational levels (Ministry of Environment and Natural Resources, 2017). In both Kenya's NDC document to the UNFCCC and its SE4ALL report, access to affordable clean energy technologies is one of the priority areas identified as necessary to achieve sustainable development (Ministry of Energy and Petroleum, 2016; Republic of Kenya, 2017) . Despite these initial steps, the potential for a shift towards the adoption of bioethanol fuels among informal settlement households has been marred by various technical, logistical and economic challenges, as described in the following sections (Jackson, 2007; Landfried et al., 2015). Ideally, however, such a market shift would not only create business opportunities and jobs but will also transform the lives of informal settlement dwellers from lives of hardship, want and ill-health, to greater comfort and well-being.

This study seeks to close some of the knowledge gaps with regard to the impact of continued use of charcoal and kerosene fuels in Kibera by estimating the total amount of GHGs produced under a Business as Usual (BAU) scenario. This study also builds on the works of Bailis et al., (2004); Ndolo, (2017); Ngeywo, (2009); and Nyambane, (2016) to provide a standard methodology that can be adapted and used to estimate the amount of GHGs emissions in other informal settlements in Kenya. This study lays a foundation for advancing the use of bioethanol fuels to address many government policy priorities, including energy access, energy security, saving on foreign exchange on petroleum imports, rural development, urban job creation, environment and climate objectives.

2. LITERATURE REVIEW

This section provides an overview of the key literature that has been produced on the topic of using bioethanol as a domestic cooking fuel. It seeks to outline key theories and concepts underpinning international efforts to promote the use of alternative cooking fuels for households cooking, and where possible, provides a critique of previous research findings in this field. The issues covered are guided by the research questions described in Chapter 1. It is often argued by energy planners and policy makers that emissions associated with traditional fuels in the developing world are minimal owing to their modest consumption and dependence on wood fuels as the main source of energy (Ministry of Environment Kenya, 2015). However, if Kenya is to meet the development goals indicated in the NDCs and SE4ALL documents, the impact of emissions that are generated in low-income households cannot afford to be overlooked.

2.1. Typology of Cooking Fuels in Informal Settlements

Previous studies have reported on the practice of using a combination of fuels, otherwise known as fuel stacking in informal settlements in Kenya (Karekezi et al., 2008; Lambe & Senyagwa, 2015; Ndolo, 2017; Yonemitsu et al., 2014). Factors found to influence cooking fuel choice in informal settlement households have been explored in several studies, and income has been quoted to be one of the key determinants of fuel choice within households (Lambe & Senyagwa, 2015; Toole, 2015; Yonemitsu et al., 2014). Various surveys focused on cooking fuels in low-income households have demonstrated that charcoal and kerosene are the main fuels used for cooking in urban poor households (Karekezi et al., 2008; Ndolo, 2017). This could be attributed to the fact that these fuels are readily available and affordable within slums. The same applies to their accompanying stoves.

Table 2.1 presents a summary of the common types of cooking fuels available within informal settlements and their market costs per unit. The values indicated have been obtained from the field data. Despite the availability of modern cooking fuels such as bioethanol, charcoal briquettes among others, it seems they have not been able to overcome consumer awareness, affordability and accessibility adoption barriers.

Table 2.1 *Common Cooking Fuels and their Average Costs in Kibera*

Fuel Type	**Market Cost (USD) per Unit Measurement**
Charcoal	0.3 – 0.6 per tin (~1.2 Kg standard measurement)
Kerosene	0.6 – 0.8 per litre (measured using 1 litre bottles)
LPG	6 – 10 for 6 Kgs cylinder
Electricity	3 per month (average cost including all electric appliances used in household)
Traditional wood	0.15 – 0.5 per bundle (~1.2kg *weight varies depending on vendor's measuring criteria, wood type, water content in wood etc.)

2.2. Determinants of Cooking Fuel Choice in Informal Settlements

Ahiekpor et al*.*, (2015) discuss the view that low incomes and large household sizes within informal settlements prevent these communities from shifting to cleaner fuels ultimately due to high average costs. Yonemitsu et al., (2014) further present the view that education level, income, preferences in taste and consumption habits are among the key determinant factors behind fuel choice in Kibera. They further provide evidence that households tend to stack fuels and devices as their incomes increase instead of completely switching to cleaner cooking options. This transition theory as well as other energy transition theories such as the "energy ladder model" underpin most energy policies and development initiatives in Kenya.

While most studies have generally reinforced the prevalent energy transition theories, one study by Jackson (2007) reached different conclusions. While citing Ross (1993), Jackson (2007) highlights how fuel choice is inextricably linked to availability and cost. He warns that "*transition models created by developers are often based on modernist linear progression models that predict increased development and that due to unpredictability of circumstances, insecurity of tenure and irregular income patterns*". He argues that households will adopt a fuel, with its accompanying appliances, if both the fuel itself and the related cooking tools are readily available and less expensive than the alternatives. This provides an important insight on why households would continue to use dirty, polluting fuels even with the knowledge of all the health and environment challenges posed by these fuels.

Cultural factors as a determinant of cooking fuel choice are also discussed by various scholars (Atanassov, 2010; Doro, 2016; Omar, 2012). Doro (2016) in particular demonstrated that there is a relationship between fuel choice and misconceptions that are not necessarily always backed by evidence. In this regard, Doro (2016) presents findings that indicate households will shy away from buying cleaner cooking options such as LPG for fear of being perceived or labelled as 'rich', with the argument that a sign of a richer home would attract criminals. It is important to consider the peculiarities and perceptions that characterise individual informal settlements while mapping policy design. Indeed, cultural factors that may influence choice of fuel in one geographical area may not work for a different neighbouring area.

2.3. Bioethanol as a Cooking Fuel

There has been an increasing amount of attention focused on ethanol as a fuel of the future and various studies have been conducted to assess the applicability of bioethanol as a kerosene and charcoal substitute (Dioha et al., 2012; Utria, 2004). Stokes (2005) as cited by Oketch (2013) compares ethanol to LPG in terms of cooking efficiency and greenhouse gas emission reduction capabilities.

Bioethanol is an alcohol fuel produced from a wide variety of plant-based materials (Balat & Balat, 2009). It is a renewable fuel made by the fermentation process of carbohydrates produced in sugar, starch crops and cellulosic material (Rajvanshi et al., 2007; Thomas & Kwong, 2001). The molasses from one tonne of sugar through this pathway is estimated to yield about 7 litres of ethanol (Eshton et al., 2011). Chemically, bioethanol is identical to ethanol and can be represented by either the formula C_2H_6O or C_2H_5OH.

All domestic fuels generate emissions upon combustions that can potentially cause global warming. However, the burning of bioethanol fuel has far fewer emissions than charcoal or kerosene fuels (Oketch, 2013).

$$\underset{(Ethyl\ Alcohol)}{C_2H_5OH} + \underset{(Oxygen)}{3O_2} \longrightarrow \underset{(Carbon\ Dioxide)}{2CO_2} + \underset{(Water)}{3H_2O} + Heat$$

Table 2.2 presents a breakdown of the energy densities of the two commonly used cooking fuels in urban informal settlements and compares them against bioethanol fuel. It typically illustrates the potential of bioethanol fuel to produce sufficient heat to prepare a meal.

Table 2.2 *Energy [a]Densities Across Fuels*

Fuel Type	**Charcoal**	**Kerosene**	**Bioethanol (100%)**
Gross Calorific Value $(MJ\ Kg^{-1})$	29.6	43	29.7
Net Calorific Value $(MJ\ Kg^{-1})$	28.4	43	26.7

2.3.1. The International Bioethanol Fuel Scene

The United States, Brazil and the European Union are currently leading in the usage, production and consumption of approximately 80% of the world's total biofuels (World Bank, 2011). In the Global South, the use of bioethanol fuels has been tested with considerable success in Madagascar, Ethiopia, Thailand, Haiti, India and Nigeria (Lambe et al., 2015; Ohimain, 2012; Rajvanshi et al., 2007). *Figure 2.1.* presents some bioethanol fuel pilot projects around the around the world including Kenya, as compiled by Puzzolo Elisa, 2013.

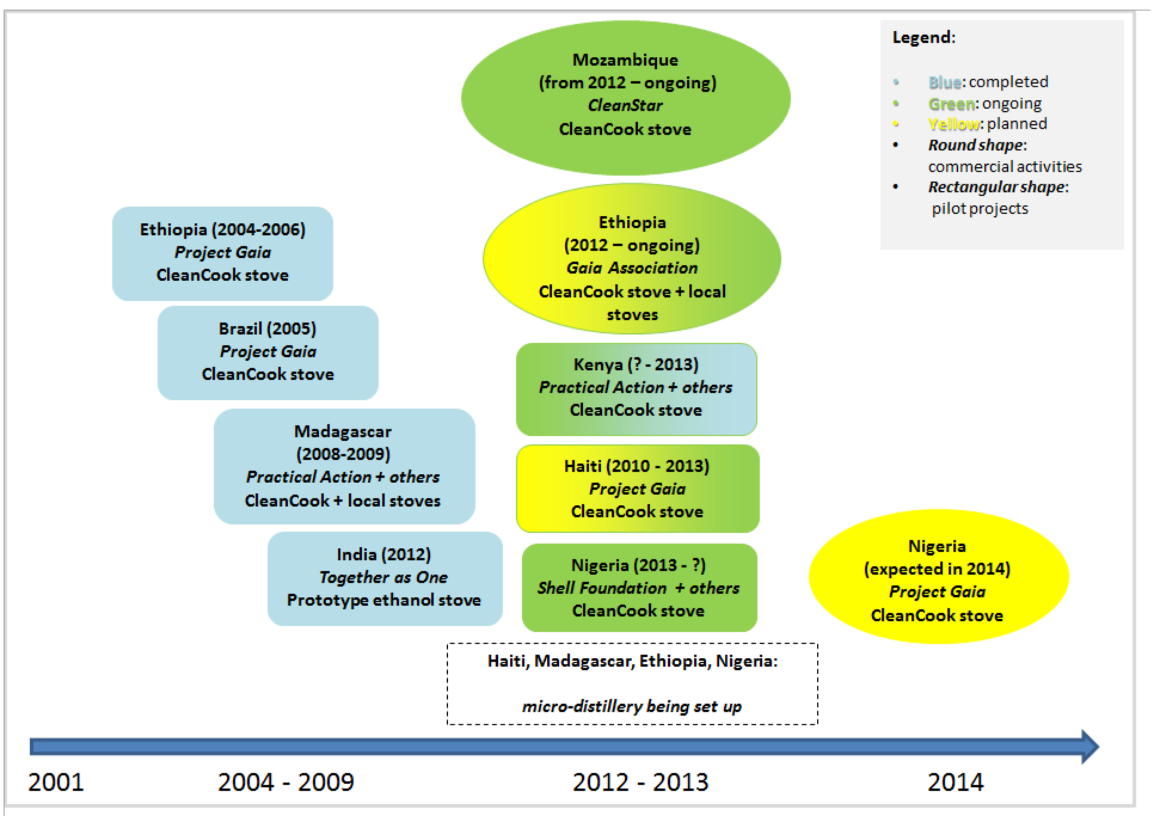

Figure 2.1. Bioethanol fuel pilot projects conducted around the world.

[a] https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

Worldwide, there has been an increased demand to use bioethanol fuels particularly due to the unpredictable petroleum prices and climate change mitigation targets. The success stories in Brazil and USA can be attributed to the dedication of the government to provide support for the sugar industries and/or for fuel blending programmes, including the establishment of institutional frameworks and formulation of favourable policies.

Table 2.3 illustrates some of the factors that have accelerated bioethanol fuel use around the world, and also presents some of the barriers that have limited the consumption of bioethanol fuels.

Table 2.3 *Enablers and Barriers of Scaling the use of Bioethanol Cooking Fuels*

Enablers	**Barriers**
• Energy security: reduced reliance on petroleum imports	• High transportation costs of fuel to markets
• Cultivation of feedstock agriculture	• Competition with other fuel types such as kerosene
• Sufficient quantities of feedstock	• Threatened the national food security
• Increased demand from the domestic fuel sector	• Taxation policies and land policy ownership challenges
• Government support including setting up institutions and policy frameworks	• [b]Social cultural factors such as religion and cuisine
• Infrastructure: such as micro distilleries, reliable distribution networks	• Insufficient contributions from the private sector

2.3.2. Bioethanol Fuels in Kenya

Preliminary studies on the sustainability of ethanol production and use as a cooking fuel in Kenya have been undertaken as early as 2005 (Dalberg, 2018; Eshton et al., 2011; Machandi et al., 2013; Ndegwa et al., 2011; Oketch, 2013; Wanambwa & Ness, 2005). Various programs on ethanol fuels for cooking have been implemented by civil society organisations, and some have been run jointly by the Kenyan government and the United Nations. Currently, there are various designs of the ethanol cookstoves present in the Kenyan market. These include Moto Poa and Moto

[b] Adapted from various studies including Chantawong *et. al.* 2016, WB 2011, Balat *et.al*.2009.

Safi Cookstoves produced by Consumer Choice Limited, Smart Cook Stove by KOKO Networks, Ethanol Safi Cooker by Safi International, CLEANCOOK stove by DOMETIC AB and Samsung Electronics ethanol stoves.

Bioethanol is currently produced through the distillation process of molasses by Agro Chemical and Food Company Limited and Spectre International Limited companies (GTZ, 2008). In terms of feedstock supply, *Jatropha* was initially ruled out as a viable source of bioethanol production owing to the fact that it was not economically viable (Landfried et al., 2015). Subsequent research by Machandi et al*.,* (2013) further demonstrated that high yielding varieties of sugarcane and sweet sorghum, developed through the efforts of Kenya Sugar Board and ICRISAT, were ideal crops to be cultivated to produce bagasse for bioethanol feedstock. They argued that this production framework was behind Brazil's success stories in bioethanol production.

2.3.3. Policy on Bioethanol in Kenya

Currently, bioethanol manufactured and marketed for cooking is taxed in the same way as alcoholic beverages, i.e. at 16% in VAT and 25% in duties compared to 0% for most other fuels (apart from kerosene, which faces a 9% excise duty) (Dalberg, 2018). Tax exemption on alternative cooking fuels and technologies is one of the strongest incentives to stimulate demand and markets (GTZ, 2008). Table 2.4 compares the taxation frameworks of bioethanol fuels against other commonly-used fuels in Kenya. It highlights the importance of securing tax exemptions for bioethanol, for example by means of a reclassification of the product from beverage to a domestic fuel within revenue generation frameworks.

Table 2.4 *Common Cooking Fuels in Kenya Against Their Applied Tax | Source Dahlberg Analysis*

Cooking Fuel	**Effective Duty**	**Effective VAT**
Charcoal	N/A	N/A
LPG	0%	0%
Kerosene	9%	0%
Denatured technical ethanol	25%	16%

2.4. Calculating Emissions

Several attempts have been made to quantify total GHG emissions from the household energy sectors (Bailis et al., 2003; Lin et al, 2013; Naidoo et al., 2014). GHG emissions usually can be calculated by using two methods; the Continuous Emissions Monitoring (CEMS) systems – which involve direct measurement of emissions, and the Analysis of Fuel Input (AFI) – a method that involves measurement of emissions by determining the carbon content of a fuel combusted using either fuel-specific information or default Emission Factors (EF) (USEPA, 2016). The fuel analysis method is usually recommended where fuel consumption is known by mass or volume units.

Various methodologies and tools have been developed to quantify GHG emissions based on the fuel analysis method (Lin et al., 2013; Ngeywo, 2009; Nyambane, 2016). Typically, these methodologies will use EF to quantify the amount of CO_2 that will be released when the fuel is combusted. These methodologies are all deemed appropriate as long as adjustments are considered to the available inputs while carrying out the estimates. This study uses the fuel analysis method to calculate total amount of GHG emissions generated in Kibera by considering the volume and mass of the fuels consumed by the sample population. Further discussions of the methodology are described in Section 3.

2.5. Literature Gaps

Over the years, domestic energy mapping in Kenya has been constrained by inadequate and unreliable data at both national and sub-national levels. This is evident based on the last comprehensive household energy survey that was conducted by the GoK during the national census in 2009 (Ministry of Finance and Planning, 2000). The census took place almost a decade ago, yet domestic energy planning requires quality and up-to-date data to be effective. A clear understanding of the current household energy dynamics is essential to advance policies in the energy, environment and health sectors.

Current data on domestic household energy agrees on the major fuel sources of GHGs emissions and points out the different emissions levels of commonly-used stove technologies, but significant uncertainties still remain. There is lack of empirical evidence on the full implications of the continued use of charcoal and kerosene fuels, especially within informal urban settlements.

Information gaps include the amount of charcoal and kerosene consumed on average per capita, and the total GHG emissions generated by the combustion of these fuels, which are the most commonly used in Kenyan informal urban settlements. The availability of this knowledge is critical for policy makers and other stakeholders planning mitigation strategies for the domestic energy sector in Kenya.

3. STUDY AREA AND RESEARCH METHODS

When considering the potential of bioethanol fuels use, energy planners need to first consider the current typology of cooking technologies and clearly define the added value that bioethanol fuel technologies may bring if they were used instead. While the acclaimed regional success in terms of acceptance of bioethanol as a primary fuel for domestic cooking in Ethiopia (Kassa, 2007) is encouraging, it should be noted that the socio-cultural and political context of low-income communities in Addis Ababa may vary significantly from that of low-income communities in Nairobi. It is therefore a major aim of this research to assess the conditions for bioethanol fuel adoption in the Kenya context, based on an effective and clearly formulates methodology. Eight key research questions as described in the introduction have led to the formulation of the methodology outlined below.

3.1. Study Site

The study was conducted in the Kibera informal settlement that lies within Kibra constituency in Nairobi County between the months of August and October 2017. Kibera lies approximately between geographical coordinates 1° 19' 14" South and 36° 47' 34" East (see *Figure 3.1* over page). Kibera is the largest urban informal settlement in Nairobi and one of the largest in Africa, comprising a population of approximately 950,000 people (UmandeTrust, COHRE, & Hakijamii, 2007). It spans an area of 2.5 square kilometres on land entirely owned by the Kenyan government (Mutisya & Yarime, 2011), and is divided into 14 villages with varying populations: Kianda, Olympic, Soweto West, Gatwekera, Raila, Karanja, Kisumu Ndogo, Makina, Kambi Muru, Mashimoni, Lindi, Laini Saba, Silanga and Soweto East.

Communities found within Kibera vary in their social, economic, cultural and political composition, with key interest groups aggregating around structure ownership and tenancy, religion, welfare groups, business and occupation, education, political interest, age and gender (UmandeTrust et al., 2007). Much the same as Nairobi's other informal settlements, Kibera is characterized by dire deprivation of basic services and infrastructure. Local facilities such as schools and hospitals are unable to cope with the population pressure. Housing units are typically semi-permanent, consisting mainly of mud-walled huts with corrugated iron sheets (ICCA, 2016).

Kibera was chosen as an ideal study location for the following key reasons:

1. It is the largest urban informal settlement in Kenya. As such, research findings would be in various respects indicative of the household energy situation among Kenya's urban poor.
2. Its distinctive setting, accessible location, and clearly-defined territory facilitates sampling of individual villages based on their population as a proportion of the total Kibera population. Denscombe, 2010 argues that individual villages permit the use of ethnography studies, which are traditionally restrictive to smaller sample sizes.
3. A rich history of activities by various Non-Governmental Organizations (NGOs) including Safi International, Moto Safi Cooker and Bio-Moto Cooker, all running cooking bioethanol fuel projects.

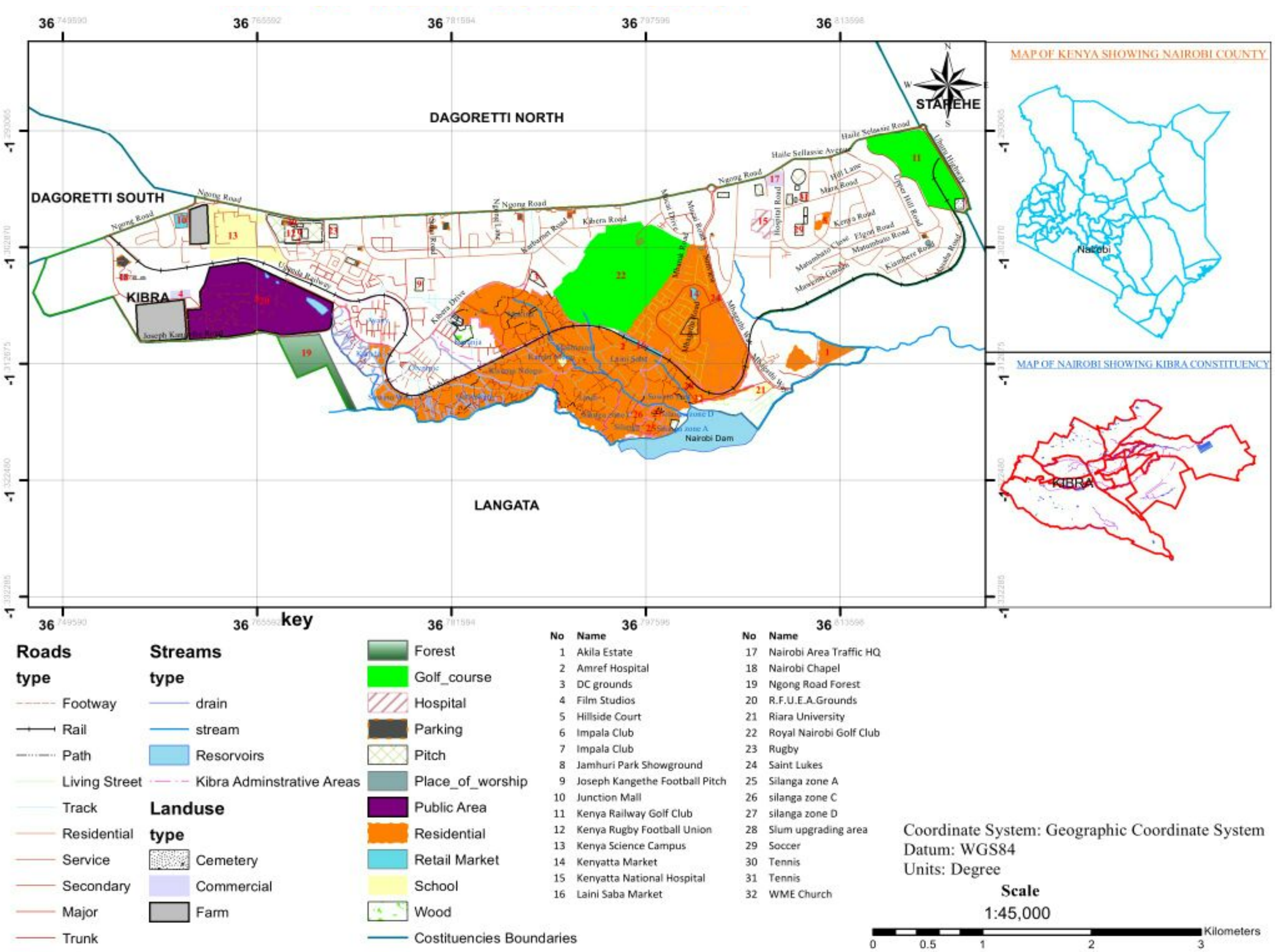

Figure 3.1. Map showing the geographical location of Kibera

3.2. Conceptual Framework

A conceptual framework for this study provided in *Figure 3.2*. to give a visual illustration of the core ideas on which this review is based. This study focuses on the potential of simple and affordable alternative cooking methods that can help in achieving three key development goals:

1. Improved health of Kibera residents
2. Enhanced environmental sustainability in and around Kibera
3. Socio-economic development for Kibera residents

To address the development goals outlined above, the study relies on a mixed-method research design that makes use of data obtained from multiple sources. The study will map the current cooking technologies in Kibera by conducting household surveys and using ethnographic observations. Field data will provide additional information on current energy dynamics in Kibera. The study will depend on survey data to estimate total GHG emissions generated from the combustion of cooking fuels in Kibera. By using available published literature on emission factors for CH_4 and N_2O, it is possible to calculate GHG emissions over a specific time period by multiplying these factors by the consumption rate of the fuel in question.

Given the nature and size of the dataset on which this study is based, Microsoft Excel was identified as the most effective and appropriate data analysis tool, owing to the relative simplicity of the data. Apart from FGDs, various interviews were conducted with key informants and experts in Nairobi. Information obtained in this manner was used to provide insights on best practices that can help facilitate the adoption of bioethanol fuel technologies in low-income areas.

Successful implementation of bioethanol fuel initiatives will pave the way to multiple benefits such as time savings in cooking for the Kibera residents, income savings from the effective utilization of available and affordable fuels, decreased pressure on forests and forest products, improved ambient air within Kibera and the neighboring suburbs, socio-economic empowerment of women and other marginalized groups, etc. Overall, pointing out opportunities for upscaling bioethanol fuels will also support existing frameworks for reducing GHG emissions at the local and national levels.

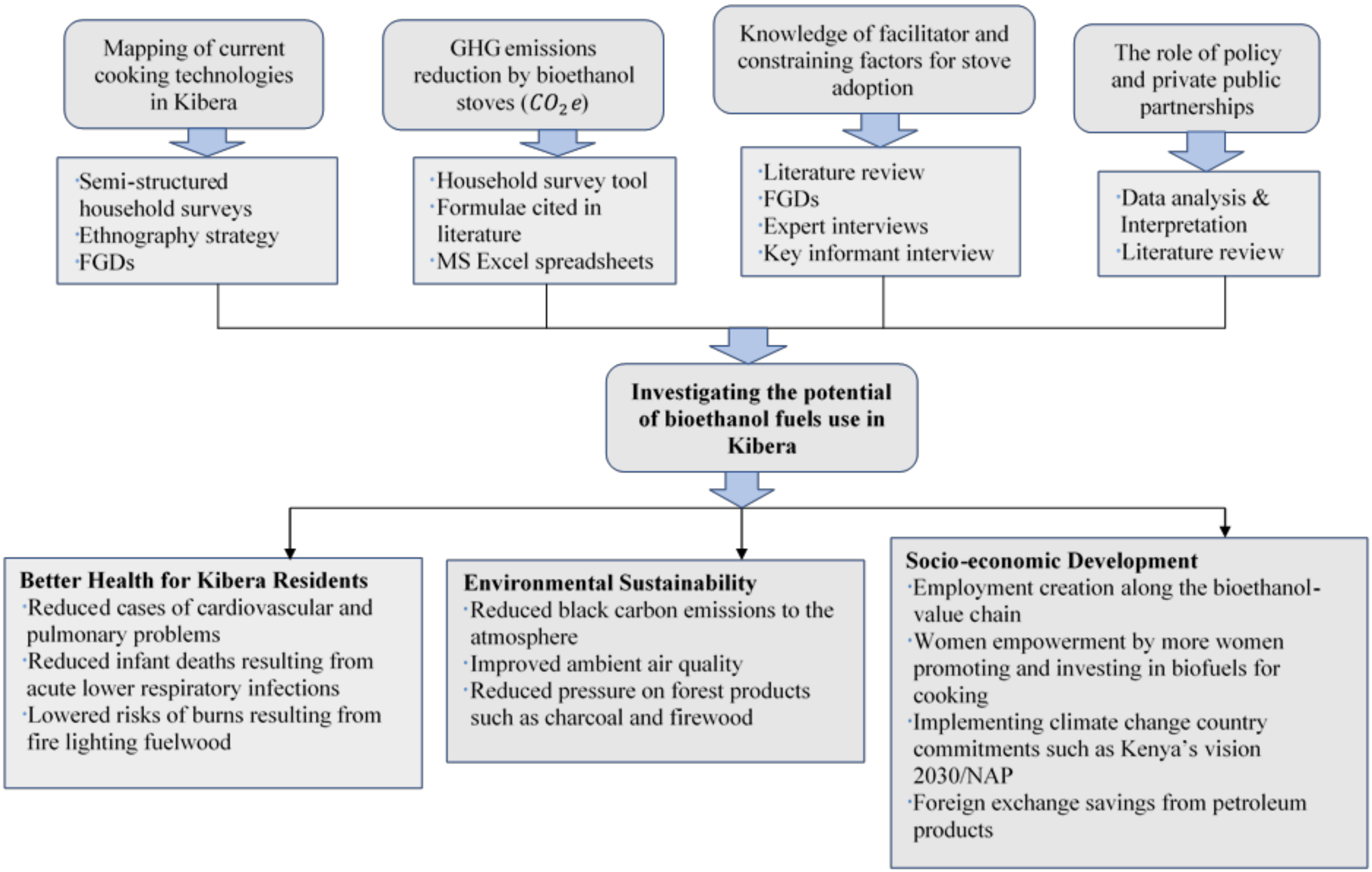

Figure 3.2. Conceptual model for investigating the adoption potential of bioethanol fuels in low-income areas.

3.3. Site Stratification and Sampling Design

This research adopted a case study approach to investigate the potential of bioethanol fuel as cooking fuel to reduce GHGs emissions by Kibera households. As a research strategy, case studies aim to bring depth to particular phenomena by studying the relationships and processes that define the case (Denscombe, 2010). In order to provide an in-depth account of fuel consumption dynamics in Kibera, the study relied on a multi-method data collection technique, commonly referred to as triangulation. Denscombe (2010) argues that besides allowing for an understanding of the study area in a more rounded and complete way, triangulation also allows for the validity of data to be tested, as findings from one method are checked against another.

Household surveys were conducted in 400 households that lie within Kibera area. In order to ensure a sound statistical representation of respondents, the study area was stratified using both the cluster and random probability techniques. The 14 Kibera villages—Makina, Mashimoni, Lindi, Gatwekera, Laini Saba, Kianda, Silanga, Kambi Muru, Kisumu Ndogo, Olympic, Soweto West, Soweto East, Raila and Karanja—formed part of the cluster groups to be used by the study. Cluster sampling was ideal as it allowed the study design to proceed along pre-existing naturally occurring boundaries and allowed the study to make use of the heterogeneity composition of the total population in Kibera. It is by these criteria that cluster sampling was deemed the most appropriate technique selected for this type of study (Denscombe, 2010).

Sampling units were selected within each of the village boundaries by use of random probability technique. To determine the number of respondents per village to participate in the study, ratios and proportions mathematical principles were applied.

The following formula was adopted:

$n: 400 = N1: Nt$ .... Equation 1

$$\frac{n}{400} = \frac{N1}{Nt}$$

Where:

n is the desired sample size

$N1$is the population within each of the individual villages and

Nt is the total population for Kibera

Therefore, the value of n is:

$$n = \frac{N1}{Nt} \times 400$$

The results obtained from the application of the formulae are summarized in Table 3.1. It was possible to calculate a range of total GHGs emissions generated in Kibera due to availability of different sources of data on the number of people in Kibera. Additional data was obtained from Kenya National Bureau of Statistics (KNBS) and United Nations Statistics Division (UNDS) Statistical Databases.

Table 3.1 *Sample Size Distribution Within Each of the Cluster Boundaries*

Village	**Population Estimate ($N1$)**	**Population Sample (n)**	**KNBS[c] Data ($N2$)**
1. Makina	135,000	57	25,242
2. Mashimoni	105,000	44	n/a[d]
3. Lindi	85,000	36	35,158
4. Gatwekera	90,000	38	24,991
5. Laini Saba	80,000	34	52,373
6. Kianda	85,000	36	29,356
7. Silanga	70,000	29	17,363
8. Kambi Muru	65,000	27	n/a
9. Kisumu Ndogo	60,000	25	n/a
10. Olympic	45,000	19	29,356
11. Soweto West	40,000	17	n/a
12. Soweto East	30,000	13	n/a
13. Raila	30,000	13	n/a
14. Karanja	30,000	13	n/a
Total (Nt)[e]	**950,000**	**401**	**355,188**
UNDS[f]	**3, 019,098**		

[c] Data obtained from the Kenya National Bureau of Statistics (KNBS) 2009, indicating population per the then assigned administration units.

[d] Not available

[e] Data obtained from Yarime & Mutisya 2011, citing Umande Trust, 2007.

[f] UN Statistic of exponential growth formulae $P_t = P_0(e^{rt})$

3.4. Research Instruments and Methods

The study employed a combination of both quantitative and qualitative data collection techniques to address the research questions. The data collection tools adopted are comparable to those used in previous research of Atanassov & Kinlund (2010) and Puzzolo Elisa (2013), both of which dissected distinct elements of ethanol as a domestic cooking fuel. The key research instruments selected for this study included Key Informant Interviews (KII), semi-structured household surveys, Focus Group Discussions (FGDs), expert interviews, and ethnography. Desktop studies as a research tool was also used in the study.

3.4.1. Desktop Studies

In order to calculate GHG emissions generated from cooking fuels in Kibera, the Analysis of Fuel Input (AFI) method discussed in Section 2.4 was applied. Emission Factor (EF) values for different fuel types were identified from IPCC inventory guidelines and emission databases available online. Various published studies were used to guide and verify the mass or (volume) of fuel combusted in informal settlements per capita (Kituyi, Marufu, et al., 2001; Ngeywo, 2009; Nyambane, 2016). To measure the fuel economy of different cooking fuel, standard conceptual models developed by the Food Agriculture Organisation (FAO) were applied (Geller & Dutt, 1981). It was necessary to use the per capita fuel daily rate consumption variable as it is a more accurate and normalizing technique that enables the study to obtain a range of emission scenarios given that three divergent population estimates for Kibera were available. Final values were subsequently converted to annual values to allow comparison with pre-existing literature values.

3.4.2. Key Informant and Expert Interviews

The underlying reason to conduct semi-structured interviews with selected key informants and experts was to capture stakeholders' insights with regard to the research topic and to obtain valuable first-hand information based on their own direct experiences in the field and professional competences. This approach is in line with Denscombe (2010) who argues that for purposive non-probability sampling techniques, the best information is obtained by focusing on a small number of instances (or informants) that are deliberately 'hand-picked' on the basis of their known attributes. A purposive sample of informant and expert groups was based upon two broad categories:

1. Stakeholders involved in implementation of bioethanol projects/initiatives. For example, those from NGOs, business companies, stove manufacturers etc., who can provide informed views and opinions on issues faced in practice, including specific barriers and enablers to bioethanol fuel uptake.
2. Stakeholders involved in promotion and research activities such as members of international organizations such as the United Nations Development Programme (UNDP) and the Clean Cookstoves Association of Kenya (CCAK), who will serve as experts to provide deeper understanding and strategic views on bioethanol fuels.

Their specific role was to enhance the understanding of the potential of bioethanol as a domestic cooking fuel in urban informal settlements. The diagram reflects the difficulty experienced in accessing the participants in terms of availability. A full participant information list is illustrated in APPENDIX VII. *Figure 3.3*. maps out the two tiers of the stakeholders who considered in the study.

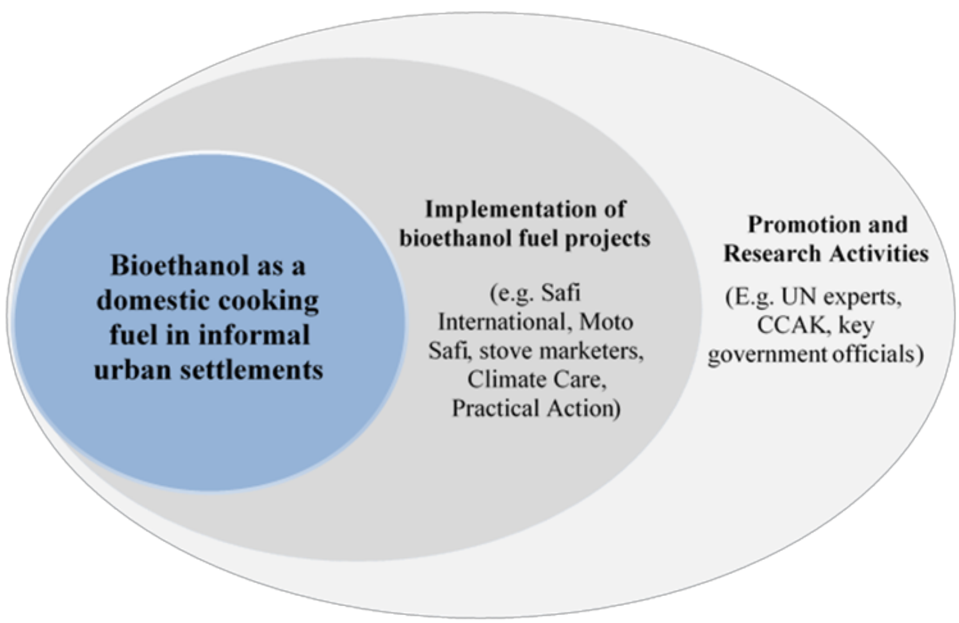

Figure 3.3. Stakeholder groups hand-picked for the study.

Five interviews were conducted between August and September 2017 upon completion of the expert recruitment processes. The participants were identified through both published and grey literature, via online professional platforms, and through referrals by other experts (i.e. through a snowballing process). Snowballing is a concept where the sample emerges through the process of reference from one person to the next — in this case, asking initial informants to suggest possible participants with the biofuels background (Denscombe, 2010). Some interviews sessions were face-to-face interactions while others were conducted via Skype for convenience purposes.

Semi-structured interviews were the preferred tool for this type of data collection, as they allowed for flexible and dynamic conversations. Raw data was audio recorded and transcribed *verbatim* on the following day. Questions covered during the interviews were based on six key domains relevant for bioethanol fuels in Kenya. Questions covered the political, social, economic, environmental, legal, technological aspects of factors that influenced adoption of bioethanol fuels within informal settlements (see APPENDIX I). The sessions typically lasted 30 - 40 minutes.

3.4.3. Semi-Structured Household Surveys

For this study, pretested sets of semi-structured questionnaires were administered to 400 households in all the 14 villages of Kibera; Makina, Mashimoni, Lindi, Gatwekera, Laini Saba, Kianda, Silanga, Kambi Muru, Kisumu Ndogo, Olympic, Soweto West, Soweto East, Raila and Karanja. A sample size of 400 was ideal as it represented about 0.04% of Kibera population. Furthermore, this figure presented the required 95% confidence level with a 5% margin of error arrived at by calculation using available online sample size calculator engines such as survey system. Semi-structured questionnaires were the preferred tool for data collection, as they allowed for flexible and dynamic conversations with participants (see APPENDIX II) for the attached questionnaire). Additionally, the researcher was able to gain in-depth understanding of the motivations, thoughts, feelings and reasoning behind domestic fuel choice among surveyed residents.

Surveys took place between 11 and 20 September 2017. Questionnaires were divided into five sections, designed to cover a broad range of issues such as cooking fuel choice, quantity of fuel used, fuel costs, household composition, perceptions of bioethanol fuels, perception of health and environmental matters with regard to fuel used, etc. While questions were printed in English and Kiswahili, interactions were based on the language participants were most comfortable with. Interviews typically lasted 10 – 15 minutes.

3.4.3.1. Calculating fuel consumption rates

Simple statistical analyses were used to determine the consumption rates of cooking fuels within Kibera. Fuel types considered for the study included charcoal, kerosene, LPG and bioethanol. Electricity as a cooking fuel was omitted on the grounds that a negligible number of people reported using electricity for cooking, hence its exclusion cannot in any way compromise the overall result. Firewood was also excluded because it was primarily used as a cooking fuel by small businesses rather than households (e.g. by the numerous food kiosks that exist in Kibera). However, since most of the food kiosks were an extension of the respondents' households, some respondents reported using the remnant embers of burnt firewood for household cooking. Weight (kg) as a unit of measurement was used for charcoal and LPG, while volume (L) as a unit of measurement was restricted to liquid fuels such as kerosene and bioethanol.

The first step in calculating fuel consumption rates involved determining the daily total fuel consumption of the surveyed sample. Eligible survey participants were asked to indicate their consumption habits for the different fuel types within their households. The questionnaire tool was designed to allow participants to express how long it took before replenishing a specific quantity of fuel within their households. To increase the reliability of data, each participant was requested to show the researcher the fuel being discussed, with its associated packaging. The fuels were then measured using a digital weighing scale for charcoal and LPG and using a graduated 1 L cylinder for kerosene and bioethanol fuels. This method was advantageous as it allowed for all data to be converted from the 'local packaging units' to scientific measurements. The total daily fuel consumption of the surveyed sample was then determined by the following expression:

$Consumption = Cw/n$ .... Equation 2

Where Cw is the total fuel consumed daily in kg or L and n is the total sample population. This expression was adapted by applying the procedure used by Kituyi et. al., (2001b).

The second step involved determining the consumption rates for the different fuel types, based on average family sizes estimated via the survey, and expressed as kg/cap/day or L/cap/day. For this particular study, an individual household's fuel consumption was calculated for a full day of preparation of meals. The formula in Equation 3 was applied as it ultimately represents fuel consumed per person per day and was used in a similar manner as detailed by scholars Kituyi et al., (2001b). The final values that were obtained were then converted to annual values to enable comparison with available literature. A systematic literature review was conducted in advance to identify reliable and published literature values.

$Consumption\ rate\ per\ capita\ =\ Kg\ or\ L\ /person/day$ .... Equation 3

<u>3.4.3.2. Calculating total emissions</u>

Data was obtained by considering the quantity of cooking fuels per day per household under typical conditions of actual use. CH_4 and N_2O emissions were calculated by multiplying their emission factors, which are available in published literature, with the consumption rates per capita of each of the various cooking fuels available in Kibera for the sample population. Mass and volume were the units considered to quantify the fuel types considered in this study. This method is based on the Analysis of Fuel Input (AFI) model discussed in Section 2.4. The findings were then extrapolated to indicate total emissions generated in an annual timeframe for Kibera households in BAU scenario. This methodology has been adapted from the works of Kituyi *et. al*. (2001b), Nyambane (2016) and Ngeywo (2009) to meet the study objectives.

As discussed in Section 2.4, the fuel analysis method was used to calculate average total emissions per person per day for the different fuel types in Kibera. Only CH_4 and N_2O gases were considered with the assumption that emissions from CO_2 gas are assimilated by available vegetation in the country (Ministry of Environment Kenya, 2015). However, it is worth mentioning that during the study there was no apparent vegetation in Kibera. It is possible that vegetation had been cleared to create space for the construction of the very densely placed housing structures. In order to estimate the amount of emissions from cooking fuels, the following formula as cited by USEPA, (2016) was adapted:

$Emissions\ =\ SFC\ (\text{kg}\ or\ \text{l}\ /cap/day)\ x\ EF$ .... Equation 4

Where:

SFC is the fuel consumed per person per day as indicated in Table 4.1 in Section *4.1.4*

EF are emission factor values obtained from literature as indicated in Table 4.2 in Section *4.2.1*

3.4.3.3. Calculating averted emissions

The bioethanol flame burns to entirety to produce CO_2 and water vapor as by-products. The emissions are so minimal in the sense that bioethanol fuels are excellent fuels and can be used to reduce emissions such as N_2O and CH_4 in the domestic energy sector. The GHG savings effect is calculated by taking the difference between total emissions in business as usual scenarios for combusting kerosene and charcoal fuels and deducting emissions from bioethanol fuels, in a scenario where all of the households in Kibera would completely switch to using bioethanol fuels.

The formula used in this research has been adapted to suit the study objectives from the work of Nyambane (2016) as follows:

$(CO_2e)\ E_{avoided} = E_{bau} - E_{bioe}$ .... Equation 5

Where:

CO_2e is the GHG emissions unit

E_{bau} are GHG emissions in business as usual scenario

E_{bioe} are GHG emissions resulting from combustion of bioethanol fuels

3.4.3.4. Evaluating bioethanol fuel and stove applicability

Semi-structured questionnaires were the main tool used to map the level of awareness of bioethanol fuels in Kibera, as they offered an effective way to collect insights into how Kibera residents experienced or perceived bioethanol. Respondents were asked to indicate whether they were bioethanol fuel users, or if not, if they had ever heard of this cooking technology. The awareness of bioethanol as a household cooking fuel was high, reported to be just over 57% of the sampled population. On the other hand, only 10% of surveyed households reported that they regularly used bioethanol fuels and stoves (see *Figure 4.1.*). In order to reduce errors in reporting results, the participants were requested to show the researcher a bioethanol cook stove and a fuel canister within their households whenever they reported it.

3.4.4. Focus Group Discussions

Focus Group Discussions (FGDs) were used primarily to complement, verify and validate household survey results. Denscombe (2013) highlights the unique features provided by the FDG data collection tool, especially for its role in gaging the extent of shared views among a group of people towards a specific topic. Discussions covered the following key topics: cooking fuel types in Kibera, factors influencing decisions on household stove and fuel type, experiences with bioethanol fuels, barriers and enablers of bioethanol fuel adoption, user willingness to adopt the bioethanol fuel, kerosene and charcoal impacts on health and environment (see APPENDIX III for list of questions covered).

A total of 3 focus group sessions were conducted on 27, 30 and 31 October 2017 within 3 different villages in Kibera; Olympic, Laini Saba and Makina respectively. These locations were deemed suitable because they had communal biocentres, which were relatively well-known landmarks to most Kibera residents. The biocentres also offered meeting spaces at a relatively affordable fee. A total of 30 Kibera residents were recruited based on their respective residences and divided into 3 groups each of 10 participants, with careful consideration of the gender distribution. The discussions took place within the Umande Trust Biocentre facilities, which were strategically positioned allowing the ease of transportation for all participants. In as much as the discussions only lasted 60 minutes, overall response rate to the topics of discussion was high. Participation was purely on a voluntary basis and all discussions were conducted in Kiswahili.

3.4.5. Ethnography Strategy

According to Denscombe (2010) "*As a topic, ethnography refers to the study of cultures and groups – their lifestyle, understandings and beliefs*." Thus, ethnography as a data collection strategy is both important and appropriate in investigating the suitability of bioethanol fuel technology as related to the key social and cultural aspects that characterise Kibera residents.

A set of guidelines were used to evaluate the suitability of the bioethanol cook stove design and the fuel performance in relation to existing cooking options, local culture and lifestyle within households. These guidelines consisted; 1) Income levels, 2) Taste preferences, 3) Religious practices, 4) Ease of lighting fire, 5) Ease to extinguish fire, 6) Household size, 7) Storage space, 8) Cooking practices e.g. cooking outside a house, storage of stove outside the house, 9) Cuisine type, 10) versatility of cooking technologies (e.g. smoke drying of food, smoke as mosquito repellent, 11) Cooking time, 12) Cooking utensils and 13) Safety precautions.

3.5. Dependability of Data

Denscombe (2010) presents the view that in order for research to achieve credibility, it needs to demonstrate in some way or other that the findings are based on practices deemed to be bases on good research. Data reliability is an important aspect to consider when the researcher's aim is to limit biases and report correct results. To obtain an acceptable level of reliability, research instruments used must produce the same data time after time when tested, and that if there are any variations in data obtained through using the instrument, it is then entirely due to variations in the variables being measured.

The methodologies used in this research were adopted from previous reports of Kituyi et. al (2001), Atanassov & Kinlund (2010) and Puzzolo Elisa (2013) and modified to suit the study's objectives. Before the beginning of the fieldwork, two enumerators were trained, and important emphasis was placed on looking out for ways of reducing bias. To ensure accuracy and precision of data, care was taken to prevent the interviewee bias effect by taking an objective stance and refraining from making strong opinions on topics. Various quantities of cooking fuels were measured using a weighing scale to ensure accuracy, while extra care was taken to avoid manipulation or misrepresentation of data. Triangulations were used to test data validity by checking and comparing findings across methods.

3.6. Data Analysis and Interpretation

Quantitative data was analysed using Microsoft Excel spreadsheets, a Microsoft Office-based data analysis tool owing to the simplicity of the final data set. By relying on published literature on GHG emission factors for cooking fuels, the study calculated daily GHGs emissions (CO_2e) generated when cooking fuels are combusted in Kibera. To enable comparison with published literature, total GHG emissions values standardized to reflect annual emissions in Kibera. The study calculated averted emissions, for the case if bioethanol fuels were used entirely in place of charcoal and kerosene fuels, by deducting emission values of bioethanol fuels from the total emission values of both charcoal and kerosene fuels.

FGDs and expert interviews were transcribed *verbatim* to maintain integrity and discussion detail. Transcripts were analysed using a thematic analysis, by taking an inductive and interpretative approach (Denscombe, 2010). Key issues were identified by listening to the audio records and taking notes. Conversations were coded into categories to enable organization of texts and to enable pattern recognition.

3.6.1. Interview and FGD Data Analysis

Audio recordings were transcribed and annotated for identification of themes and comparison of data from published literature. Grounded theory design by way of using an inductive approach was the preferred method for qualitative data analysis. Conversations were coded into categories to enable organization of texts and pattern recognition. Key themes were identified, compared with the available data set and discussed.

4. RESULTS

Chapter 4 presents a summary of the study's key findings. An in-depth analysis and discussion of the results is presented in Chapter 5. As described in detail in the following sections, the study finds that bioethanol is a comparatively recent addition to Kenya's household cooking landscape, which has the potential to significantly help reduce air pollution from domestic emissions. However, as discussed below, the adoption rate of bioethanol remains low.

4.1. Analysis of Cooking Technologies in Kibera

4.1.1. Sample Population Characteristics

A total of 400 households representing 0.042% of Kibera´s estimated population of 950,000 were surveyed. It can be said with a 95% level of confidence that the sampled households are representative of the population due to the use of a purposive random sampling technique. This technique ensured that households within all the individual villages in Kibera were considered proportionately in order to achieve the objectives of the study.

The data collected indicates that the average Kibera household consists of 5.92 persons in total, including an average of 2.53 children. These figures differ significantly from the 3.27 persons per household statistic recorded in the most recent KNBS (Kenya National Bureau of Statistics) data. This inconsistency may be partly due to the high annual urban population growth rate of 4.4% in Nairobi, which is significantly higher than the average national annual population growth rate of 3.3% (Wairagu, 2006). These family dynamics could also be explained by the fact that by the time of the study, Kenya was going through a national election period that lasted from August to October 2017. During the period in question, many Kibera residents reportedly boycotted the voting exercise and families stayed within their homes for fear of election violence.

4.1.2. Patterns of Household Fuels Kibera

Sixty-nine percent of the surveyed households owned more than one stove type, while only 31% of the surveyed households reported using only a single type of fuel. Charcoal and kerosene fuels were by far the most common cooking fuels used within households, being used by 76.27% and 81.71% of surveyed households respectively and were mostly used in combination of each other. All of the surveyed households that reported using bioethanol as a cooking fuel used it in combination with other fuels. Other cooking fuel types that were commonly used by Kibera residents included LPG, electricity and – to a lesser extent – firewood. The chart in *Figure 4.1.* illustrates key cooking fuel types recorded within surveyed households across Kibera.

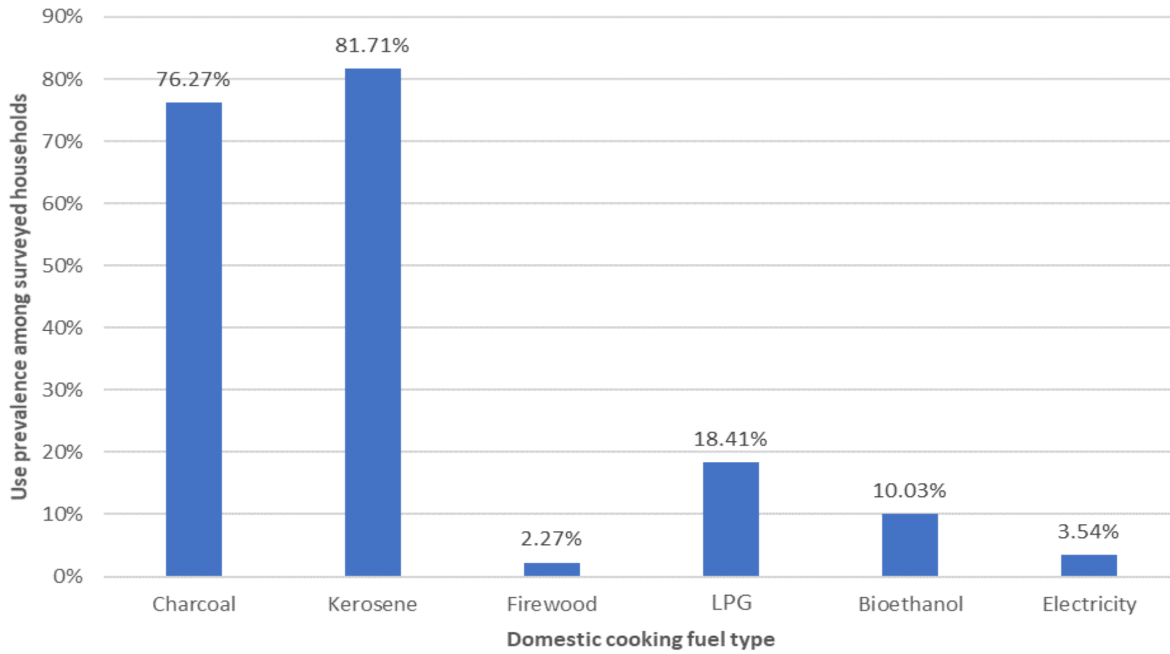

Figure 4.1. Prevalence of domestic cooking fuel types in Kibera among surveyed households

Households alternated between fuel types depending on various factors such as affordability of fuel, socio-cultural needs such as food type, etc., and did not particularly stick to using a particular preferred cooking fuel. For example, a household would prefer to use charcoal fuel to prepare *Ugali* at night when the whole family was at home. On the other hand, kerosene fuel would be used to prepare a 'quick' meal during the day when the housewife was at home alone with an infant. These findings further strengthen the Multiple Fuel Use Strategy model discussed in Section 2.1, as opposed to the Energy Ladder theory of fuel use. These findings are also consistent with domestic energy mapping in informal settlements by (Karekezi et al., 2008; Ndolo, 2017).

4.1.3. Cooking Fuels Usage by Village

There was a high variation in cooking-fuel dynamics across individual villages in Kibera, as illustrated in *Figure 4.2*. The chart shows that all surveyed households in Olympic used charcoal as their preferred cooking fuel, while all of the households surveyed in Kisumu Ndogo and Soweto West used kerosene as their preferred fuel option. At just over 50%, the use of LPG as a cooking fuel was recorded to be most prevalent in Karanja village. Just under 5% of households in Kianda used firewood fuel as a cooking fuel source, but most paired it as a cooking fuel for cooking *mandazis*, *samosas* and other 'fast foods' as part of the business activities around Kibera. Bioethanol fuels can be introduced to target specific villages such as Kisumu Ndogo and Soweto West where most residents prefer to use liquid fuels such as kerosene.

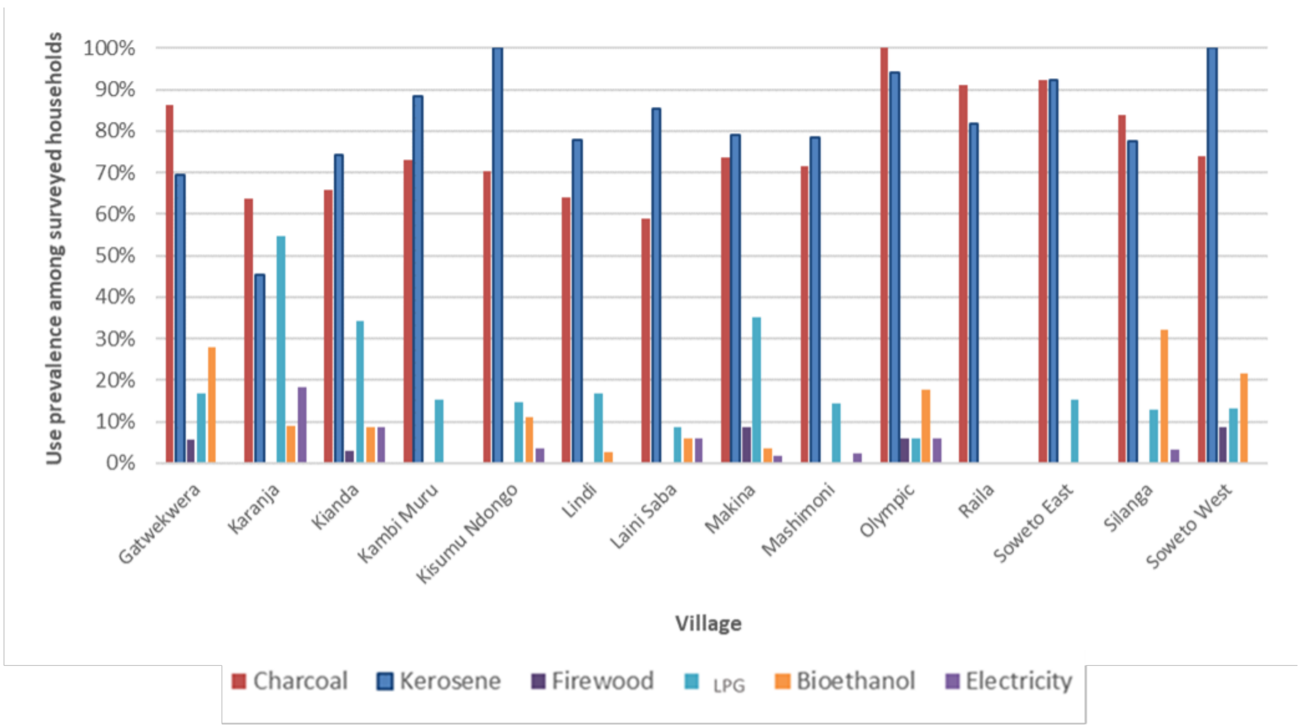

Figure 4.2. A variation of cooking fuel use across villages in Kibera.

Although bioethanol fuel usage was recorded in various households across Kibera villages, households in Mashimoni, Kambi Muru, Raila and Soweto East villages did not report any usage of bioethanol fuels at all. It is possible that the absence of bioethanol fuels in these villages was a result of a lack of introduction of these fuels in those specific areas by the various NGOs that have been promoting bioethanol fuels in Kibera. Silanga and Gatwekera villages had the highest number of households using bioethanol fuels, with an overall prevalence of 30% among surveyed households. Makina and Lindi villages, on the other hand, have 5% of households using bioethanol fuels.

4.1.4. Fuel Consumption Rates

The daily charcoal consumption rate for the surveyed sample $(n = 400)$ was $510.73\ \text{kg}/day$ with an average per person consumption rate of $0.37\ \text{kg}/cap/day$. The daily consumption rate for kerosene for the surveyed sample was $226.01\ \text{L}/day$ with an average daily per person consumption rate of $0.16\ \text{L}/cap/day$. The bioethanol fuel consumption rate was very low at only $3.95\ \text{L}/day$ with a daily average per person consumption rate of $0.11\ \text{L}/cap/day$. Table 4.1 presents the daily and annual consumption rates for different fuel types in Kibera. Literature figures are also indicated to compare the study's findings with existing published values.

Table 4.1 *A Comparison of Reported Fuel Consumption Rate Values for the Surveyed Sample in Kibera*

Fuel		**Daily total consumption rate (n) kg or L /day**	**Daily consumption rate per capita kg or L /cap/day**	**Annual consumption rate per capita kg or l /cap/yr**
Charcoal	This study	510.73	0.37	135.05
	Literature[g]		0.18 – 0.69	67–252
Kerosene	This study	226.01	0.16	58.40
	Literature		0.06	
LPG	This study	14.09	0.05	18.25
	Literature		0.007	
Bioethanol	This study	3.95	0.11	40.15

[g] The literature values reported for this study are obtained from Kituyi, Marufu, et al. (2001b) who conducted studies on biofuel consumption patterns in Kenya.

4.1.5. Bioethanol Fuel and Cookstove Applicability

The pie chart in *Figure 4.3.* shows the breakdown of the awareness levels of bioethanol as a cooking fuel among surveyed households. Based on the information collected from the sample population, it is likely that more than half of Kibera's total population had heard of bioethanol or tested it as a cooking fuel. With more awareness campaigns supported by the government and its partners, bioethanol fuels can gain leverage in the market leading to an increase in demand among households as a preferred household fuel

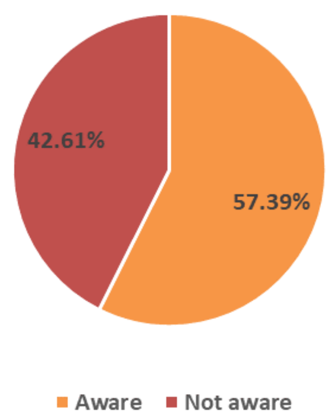

Figure 4.3. Awareness of levels on bioethanol as a cooking fuel among survey respondents.

A large portion of the survey participants explained the lack of adoption of bioethanol fuels to be as a result of the high initial cost of obtaining bioethanol cookstoves and the cumulative costs incurred when replenishing bioethanol fuel on a daily basis, when compared to other locally available cooking fuels. The average cost for a double burner bioethanol stove was reported to be Ksh 4800 (USD 48), with bioethanol fuel going at a retail price of Ksh 150 per litre (USD 1.5), compared to kerosene which was significantly cheaper at Ksh 600 (USD 6) for the stove price, and about Ksh 60 (USD 0.6) for the fuel price per litre. Determinants of Bioethanol Fuels Adoption in Kibera discusses in further detail factors that hinder the adoption of bioethanol fuels among Kibera residents.

4.2. GHG Emissions from Cooking Fuels in Kibera

4.2.1. Emission Factors for Fuels Types

Table 4.2 indicates the Emission Factor (EF) values that were used to calculate GHG emissions from domestic cooking fuels in Kibera. In order to obtain reliable data sets on the state of domestic combustion of cooking fuels in urban informal settlements in Kenya, reference was made to a number of reliable sources and appropriate adjustments were made to give correct data and units (EPA, 2014; USEPA, 2016). In order to convert to CO_2e units, gases were multiplied by their respective Global Warming Potentials (GWPs).

Table 4.2 *GHG Emission Factors for Different Fuels*

GHGs	GWP – 100 years	Kerosene $g/$Kg	Charcoal $g/$Kg	LPG$g/$Kg	Bioethanol (100%) $g/$Kg
CH_4 Gas	25	0.1083	0.1389	0.0740	0.0238
N_2O Gas	298[h]	0.0211	0.0694	0.0159	0.0026

4.2.2. Total Emissions from Cooking Fuels in Kibera

Table 4.3 presents the findings of the average total emissions per person per day when a kilogram unit of fuel was combusted in Kibera. Please note that the values in this table have not been reported in CO_2e but rather in grams.

Table 4.3 *Total Daily Emissions in Grams Generated Per Person When Cooking Fuels Were Combusted*

Fuel type	Kerosene	Charcoal	LPG	Bioethanol 100%
CH_4 Gas	0.01733	0.05139	0.00370	0.00262
N_2O Gas	0.00338	0.02568	0.00080	0.00029

The findings are based on a sampling design aligned with Kibera's population data as provided by Umande Trust (2011) and cited by Mutisya & Yarime (2011). In order to calculate the total daily emissions generated by the entire Kibera population, the values in Table 4.3 were multiplied by 950,000 people and presented in Table 4.4 as follows.

[h] GWP100 values and emission factors adapted from U.S. EPA 1995. Compilation of Air Pollutant Emission Factors, Vol. 1: Stationary Point and Area Sources, 5th edition.

Table 4.4 *Total Daily Emissions in Grams Generated When Cooking Fuels are Combusted in Kibera*

Fuel Type	Kerosene	Charcoal	LPG	Bioethanol 100%	Total Emissions	CO2e
CH_4 Gas	16,461.60	48,823.35	3,515.00	2,487.10	71,287.05	1782176.25
N_2O Gas	3,207.20	24,394.10	755.25	271.70	28,628.25	8531218.5

The total daily emissions generated when cooking fuels are combusted in Kibera is $10.31\ \text{t}\ CO_2\text{e}$. This figure is obtained as follows:

Step 1: Total individual fuel emission values for CH_4 and N_2O gases are added across the table to give a total of $71{,}287.05$ g CH_4 and $28{,}628.25$ g N_2O respectively.

Step 2: Both total CH_4 emissions and N_2O emissions were converted to $CO_2\text{e}$ by multiplying with their respective GWP values as indicated in Table 4.2 to obtain $1782176.25\text{g}\ CO_2\text{e}$ for the CH_4 gas and $8531218.5\ CO_2\text{e}$ for the N_2O gas.

Step 3: The CDE values are added and converted to tons by multiplying by $1/100{,}0000$

If $10.31\ \text{t}\ CO_2\text{e}$ emissions are generated in Kibera at BAU, then in one year:

$10.31\ \text{t}\ CO_2\text{e}\ X\ 365\ days\ =\ 3{,}764.39\ \text{t}\ CO_2\text{e}$ will be generated.

4.2.3. Emission Scenarios for Kibera

Since the study used a sampling design based on Kibera's population estimate of 950,000 residents, it was important to give a range of emissions based on both government statistics and UNDS statistics. The study deemed this approach appropriate as there have been debates by interest groups, including the national government, on the actual total population of Kibera (Desgroppes & Taupin, 2011) . The methodology above was repeated, where daily per capita emission values as indicated in Table 4.3 were multiplied by government and UNDS data respectively. The total emissions across fuels were totaled and then converted to $\text{t}\ CO_2\text{e}$. It was assumed that the consumption rate would remain the same in each of the scenarios.

Table 4.5 *Total GHGS Emission Scenarios in $t\ CO_2e$ Generated in Kibera*

	Daily total emissions	**Annual total emissions**
Government data $P = 355{,}188$	$3.86\ \mathrm{t\ CO_2e}$	$1,408.02\ \mathrm{t\ CO_2e}$
This study (Umande Trust) $P = 950{,}000$	$10.31\ \mathrm{t\ CO_2e}$	$3,764.39\ \mathrm{t\ CO_2e}$
UNDS $P = 3{,}019{,}098$	$32.79\ \mathrm{t\ CO_2e}$	$11,968.17\ \mathrm{t\ CO_2e}$

From Table 4.5, it is apparent that focusing on the government data would give a gross underestimate of the total GHG emissions. Government data represent the lowest emissions scenarios while UNDS data represents the highest emissions scenarios of total emissions generated from combustion of cooking fuels in Kibera.

4.2.4. Annual Emissions Mitigation Potential by use of Bioethanol Fuels

Equation 3 as discussed in Section *3.4.3.1* was used to calculate averted emissions in scenarios where bioethanol fuels would be used by all families in Kibera. The total annual emissions generated in Kibera are approximately $3{,}764.39\ \mathrm{t\ CO_2e}$ as indicated in Table 4.5. In order to determine the mitigation potential of bioethanol fuels, it was necessary to calculate the total emissions that would be generated if all families in Kibera were to completely switch to bioethanol fuels. A wide range of feasibility studies on bioethanol stoves reported that one litre of bioethanol was sufficient for a full day's cooking based on three meals for a family of five (Benka-Coker et. al., 2018; Murren, 2006; Puzzolo Elisa, 2013).

Table 4.6 *Total Emissions Generated if all Households Completely Switched to Bioethanol Fuels.*

Consumption rate	Corrected Value	EF	Per person per day emissions (g)	Total Pop. daily emissions (g)	CO_2e
l/day/cap	kg/cap/day	g CH_4 /kg	0.00375564	3567.858	89196.45
0.2	0.1578	0.0238			
		g N_2O/kg	0.00041028	389.766	116150.268
		0.0026			

The consumption rate of 0.2 $l/day/cap$ has been considered because 1 family = 5 people (average Kibera family from this study) = 1 litre of bioethanol fuel /day. The total annual GHG emissions generated if all households in Kibera were to switch to bioethanol fuels would be $74.95 \text{ t } CO_2e$. The value is arrived at by adding the total CDE emissions, which is then converted to annual emissions by multiplying by 365 and converted to tons by multiplying by 1/1,000,000. By applying Equation 5 as described in Section *3.4.3.3.,* the total emissions that would be averted if Kibera households were to completely switch to bioethanol fuels would be as follows:

$$(CO_2e)\ E_{avoided} = E_{bau} - E_{bioe} \quad \text{.................................... Equation 5}$$

$$3,764.39 \text{ t } CO_2e - 74.95 \text{ t } CO_2e = 3689.44 \text{ t } CO_2e$$

Therefore, if all households in Kibera were to use exclusively bioethanol fuels for domestic cooking, 98% of local GHG emissions from household cooking would be avoided. However, since households within a low-income bracket typically prefer to use multiple fuels in combination, this ideal scenario seems to be unrealistic. On the other hand, if only 50% of the entire population were to be convinced to completely switch to bioethanol fuels in place of kerosene and use it in combination with other available fuel types such as charcoal, significant annual GHG emissions would be averted.

4.3. Determinants of Bioethanol Fuels Adoption in Kibera

This section presents findings that illuminate the factors responsible for the uptake of bioethanol fuel technologies in Kibera. To assess these factors in detail, only current and former users of bioethanol fuels were engaged in the semi-structured survey exercise. FGDs, expert and key informant interviews were also conducted to meet the objectives of the study. Survey results demonstrate that bioethanol fuels were considered desirable cooking fuels due to the following key attributes: smoke-free homes, clean cooking pots, clean furniture, smoke-free stoves, easy to light, cooks fast, and easy to store. Users who had tested using bioethanol gel fuels further explained that they had the added advantage of not spilling easily when accidentally overturned. On the other hand, bioethanol fuels were viewed unfavourably in terms of the high costs involved in purchasing both the fuels and associated stoves, the time and distance it takes to obtain replenishment fuel, their lack of versatility, and their suitability to prepare meals for large families.

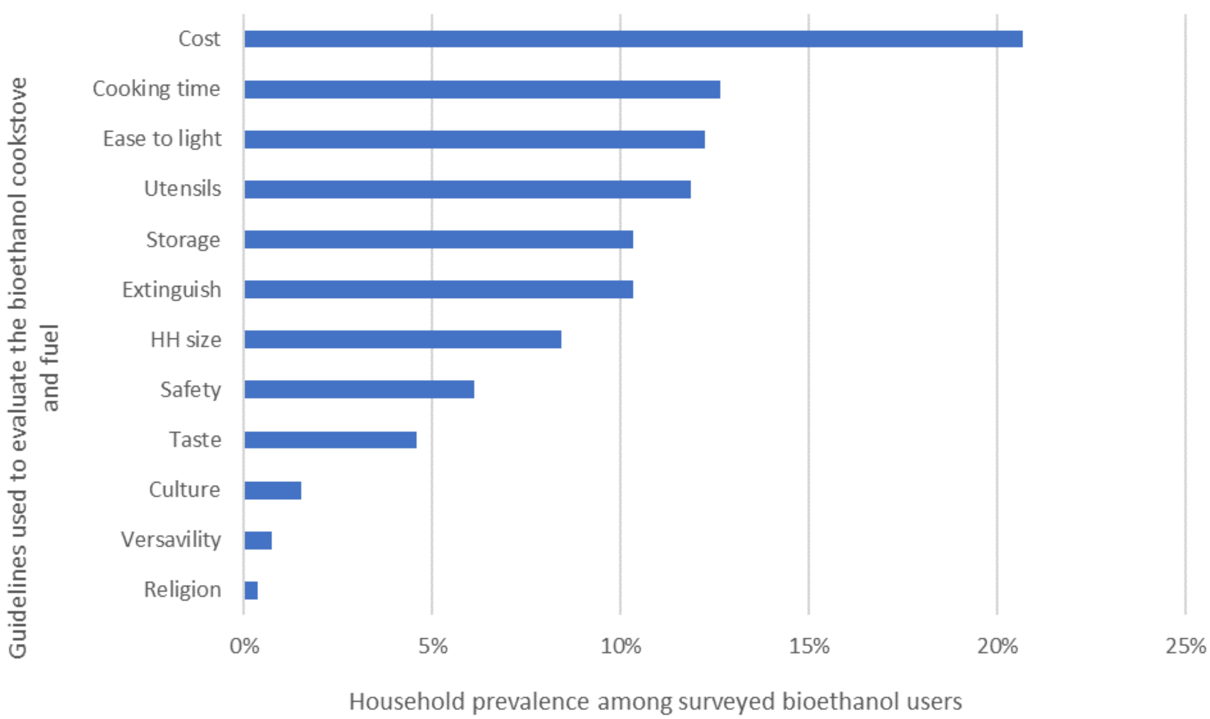

Figure 4.4. An evaluation of the bioethanol cookstove and fuel characteristics.

4.3.1. *Health and the Environment*

When participants were asked to indicate whether both charcoal and kerosene stoves posed any health and environmental challenges, a majority of those who responded could not clearly distinguish between the human health and the environmental domains. Muindi, (2017) provides in-depth analysis of air pollution in Nairobi's urban informal settlements and finds that most households had mixed perceptions on the health impacts of air pollution, with respiratory illnesses perceived as the main consequence. About 55% of the participants as indicated in *Figure 4.5.* were positive that charcoal and kerosene fuels were bad for the environment, while about 45% of respondents did not necessarily view burning charcoal and kerosene fuels as harmful to the environment. Several women explained that smoke from charcoal and kerosene stoves frequently caused them headaches, coughs, chest pains and asthma conditions. They further explained that these ailments also could affect infant children since they were usually at home during the cooking process. The overall response to the question on the environment was that cutting down trees was bad.

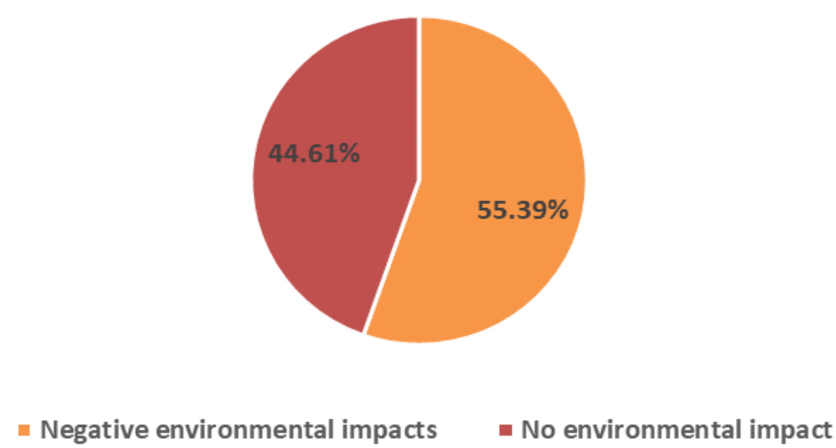

Figure 4.5. Pie-chart representing users' perceptions on the negative impacts of continued use of charcoal and kerosene fuels to the environment.

Generally, about half of the respondents believed smoke emissions from charcoal and kerosene fuels were bad for the environment, while the other half considered cooking with charcoal and kerosene fuels to be okay.

4.3.2. Stove and Fuel Characteristics

4.3.2.1. Cost of cookstove and fuel

Residents in low-income communities will generally prefer to spend as little money as possible on daily livelihood commodities in order to get by. Most Kibera residents would still opt for a cheaper charcoal and kerosene fuels because they are relatively cheaper and readily available. This phenomenon was explicitly addressed during the survey exercise as indicated by a former bioethanol fuel user in the following words:

> *"I cannot continue to use bioethanol because the fuel is expensive. If kerosene is going for 65 shillings per litre and bioethanol is going for 120 kes shillings per litre, why should I continue to waste my money? I have many other problems and bioethanol is not on the list. I was given the stove and the fuel long time ago, but I don't use it anymore."*

This perspective is recurrent among all former bioethanol fuel users that reverted to using kerosene and charcoal fuels. Taken all into account, these cases confirm that pricing matters most when introducing a new technology of any kind to low-income earning communities. The pricing of the bioethanol cookstove for example should be ideally placed within the same price range as the cooking technology it is designed to substitute.

Just as with fuels, low-income earners will prefer to purchase cheaper cookstoves even if they were considered dirty and polluting, rather than pay extra for cleaner cooking stoves because it is what they can afford. The pie-chart in *Figure 4.6*. illustrates that approximately 70% of surveyed residents were aware of the negative impacts on their health that arose from cooking with charcoal and kerosene fuels, yet families continued to use these fuels as the norm.

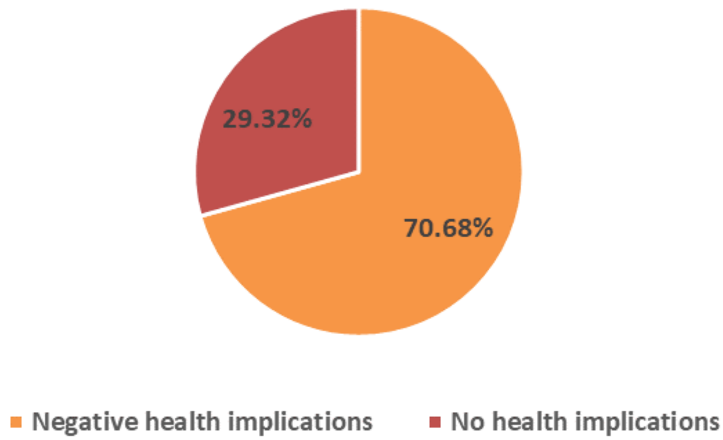

Figure 4.6. Pie-chart representing users' perception on negative health impacts by continued use of charcoal and kerosene stoves.

Another survey participant gave the following statement:

> *"The (bioethanol) stove is quite expensive if you compare it with both charcoal and kerosene stoves. While a single bioethanol cookstove plate goes for 2500 shillings, you will find that a charcoal stove will go for only 300 shillings and a kerosene stove will be sold in kiosks all over for only 600 shillings*."

In their accounts, a majority of the surveyed participants seemed to agree that they would not buy bioethanol cookstoves as they were so expensive. In general, low-income earners will typically opt for a cheaper fuel, even in cases where a more expensive fuel would have health benefits (Toole, 2015).

4.3.2.2. Thermal efficiency

In order for a cooking stove to be rated highly as a potential option by a target community, it has to be able to give high and consistent energy power during the entire cooking process. Literature points out that thermal efficiency is a key determinant of a good and quality cooking fuel (Jackson, 2007; Jan, 2012). Vincent Okello gave comments consistent with the fact that bioethanol fuels had enough power to cook a meal, as follows:

“Originally, the bioethanol technology was introduced by DOMETIC Group (a Swedish firm) that was developed mainly for the people going out on boats or camping since the cooker produced enough energy sufficient enough to cook. While I was on the project, the single burner was piloted in the Nyalenda urban informal settlement in Kisumu and results indicated that it took about 1 litre of ethanol fuel per day to cook for a household of 5 people. The fuel is usually diluted at 95% alcohol content which is relatively high energy and is able to meet the demands of a household for cooking for one day without having to top up.”

Unfortunately, most of the survey participants who responded to the question on this topic expressed deep frustration about the power of the bioethanol flame. It is possible that the fuels may have been adulterated once they entered the market. Generally, when consumers are frustrated by a technology, they are likely to revert to what worked best for them (Benka-Coker et al., 2018b).

4.3.2.3. Stove and fuel safety

While accidents associated with the use of bioethanol fuels and stoves have been reported elsewhere, risks associated with the use of the bioethanol cookstove did not come up as a key theme. Such accidents arose from the improper use of bioethanol fuels such as drinking it, mixing it with kerosene to light firewood which in turn created explosive blends etc. (Benka-Coker et al., 2018a; Puzzolo E., 2013). Although no incidents were reported by respondents, they placed high importance on safety as a key determinant of fuel choice, as they raised concerns with fuels such as LPG and kerosene. This may be because of a fire outbreak incident that occurred in the beginning of the year in the neighboring Kijiji informal settlement, that destroyed property leaving dozens of residents homeless. According to the investigations, it had been caused by LPG cylinder explosions (Kamau, 2007; Wanjala, 2018).

Safety features of the bioethanol cookstove were discussed as illuminated by the following excerpt from Vincent Okello.

“*Bioethanol has a number of safety features. The stove has a cannister that is used to hold the liquid fuel inside the stove receptacle. The key safety feature for this stove is that you can tip it upside down with a full load of fuel and the duel would not spill. That enabled safety in comparison to a kerosene stove because of no danger at all of spillage.”*

On the other hand, the alcoholic properties of bioethanol fuels are denatured by addition of compounds that make it unfavorable to ingest as illuminated by Vincent Okello in the following transcript:

> *"Another risk factor was of ingestion either by children and people who considered it to be a beverage and not a fuel. As such we supplied denatured alcohol to the households in the sense that it was added with Bitrex (denatonium benzoate), which is one of the most bitter substances known to man."*

Various laboratory experiments on the bioethanol cookstove have indicated that it is safe to use (Benka-Coker et al., 2018a; Oketch, 2013). It is on this premise that bioethanol fuels and stoves can be successfully promoted in Kibera.

4.3.2.4. Ease of storage

House sizes in urban informal settlements are usually very small to comfortably fit a family that averages approximately five members. Heads of households will take measures to maximize on the available space by finding alternative storage spaces for bulky items or investing in small-sized items within their living spaces. The bioethanol stove was evaluated to be attractive by a majority of Kibera residents who had tried using it before. Anne Nyambane, an expert in renewable energy technologies, shares her experience on the practicability of the bioethanol stove design for a household in an urban informal settlement in the following excerpt of her interview transcript.

> *"Some of the feedback I got from Mozambique as to why people liked the bioethanol stove was that it was efficient, user friendly and could be used inside the house. So actually, for an informal settlement it becomes a more practical option since most of the time one may leave their Jiko outside and find that someone has stolen it. But for bioethanol you can just use it inside the house then after you turn it off, you easily slip it under the table and you just go to sleep."*

It is common to find that most homes in informal settlements will use their one-roomed house as a sitting area during the day and as a sleeping area by night. Having bulky stove designs will therefore reduce the space available to have a good night rest.

4.3.2.5. Cultural factors

A select cook stove and fuel type must align with the intrinsic traditional beliefs of a community for it to be accepted (Atanassov, 2010). Unfortunately, the bioethanol cookstove did not match some of the users' culinary expectations. There was a sense of dissatisfaction among various participants in their accounts on the applicability of the bioethanol cookstove in preparing traditional meals. A survey resident in Mashimoni, Kibera commented as follows, "*how can I use bioethanol stove to cook certain meal types such as ugali, githeri, chapati and samaki? No way!"* She further explained her preference to using the charcoal stove to prepare certain meals because of the specificity in culinary method, for example, when cooking *Samaki wa kupaka*. It is possible that the bioethanol cookstove in most cases fell short in meeting the traditional values of a community depending on which part of Kenya they come from. In such cases however, it would be recommendable to use bioethanol fuels in combination with other traditional cooking methods.

4.3.2.6. Versatility

Stove versatility, among many other advantages is one of the reasons why biomass energy is deemed favourable in most African homes (Atieno, 2012; Ndolo, 2017). For two key reasons, stove versatility was an important aspect of consideration when choosing a fuel type to a majority of Kibera residents. Families that had young children were most likely to use a charcoal stove during the cold months of June, July and August. Cooking with charcoal indoors ensured homes remained warm so that children did not get *Pneumonia* infections and other cold-related ailments. A participant during the field exercise illuminated this aspect in the following comment: *"I mostly use charcoal during the rainy and cold seasons because it keeps the house dry and warm, day and night"*. The bioethanol cookstove produced heat that did not match that produced by the charcoal stove to warm houses during the cold seasons. This is a design aspect that makes the stove fall short as desirable to the peculiar needs of Kibera residents.

Another equally important reason was that the bioethanol cookstove could not be converted into a business cookstove for households that had daytime cooking businesses. It was apparent that most families had open-air roadside cooking businesses, where women would cook a wide range of delicacies such as *mandazis, chapatis, samosas* among other foodstuff, while the husbands were away at work. One Gatwekera participant highlighted this aspect as follows: *"How can bioethanol really replace charcoal, when charcoal can be used to do business such as the cooking mandazi,* *and githeri?"* In her account, bioethanol fuel was very volatile when left out in the open, and that the flame was not strong enough. It is in this sense that the bioethanol stove fell short in meeting the different needs of Kibera residents.

4.3.3. Aesthetic Value

Some survey participants evaluated the bioethanol stove design to be beautiful compared to the Kenya Ceramic Jiko (KCJ) and the kerosene stoves. A majority of participants who had used bioethanol even compared it to LPG stoves, because the flame produced resembled the LPG flame in colour and that it was also relatively easy to control. Vincent Okello highlights the bioethanol stove's aesthetic desirability in the following excerpt of his interview transcript:

> *"The appearance of the bioethanol stove in colour and shape, and its portability aspect is in a way that you just want to put it in the living space for guests to see it. Overall, the bioethanol cookstove has a beautiful design that is appealing to the consumer."*

Since Kibera families are persistently in dire deprivation of basic services and amenities, the bioethanol cookstove offered as sense of equity to the residents, more so because their neighbours comprised middle-high income earners who usually use LPG fuels (Machandi et al., 2013).

4.3.4. Gender

If a cooking technology is going to be developed for use by women, then they should be involved as decision makers within the production framework of the technology. A number of experts interviewed highlighted the important role of women in advancing the use of bioethanol fuels and stoves. Vincent Okello, an energy consultant presented the following view:

> *"Another key feature of low-income houses is that they are usually women-headed. Women should be involved as key advocates in all aspects of development from the production to the consumption. When I started promoting bioethanol fuels many years ago, we would primarily use pictures of rural women in their kitchens. I have noticed that the trend is changing slightly, where a picture of an old woman, who is worn out, not so nicely dressed, cheerful but obviously indicating poverty, promoting the clean cookstoves is being now replaced by nice looking young women in urban areas, some of them really nicely dressed, cheerful and looking modern.*"

Similarly, James Muyula, another key informant who participated in the interview segment provided deeper insights as indicated by the excerpt below:

> *"Women are the recipients of the technology and should definitely play a big role. They should be the change agent in the whole process of adoption as they understand their actual needs. Women also act as peer reviewers of the performance of the cookstove. One community member would imagine that if the cookstove is working perfectly for her neighbour, then it must also work for her."*

Figure 4.7. The distribution chain for bioethanol fuels creates jobs for women as entrepreneurs

All these results suggest that women should be included in championing for the bioethanol fuels and stoves and should not be merely seen as consumers.

4.3.5. Durability and Maintenance

A cookstove is typically considered favourable by community members if it can be used for a long time with minimal maintenance, and without it easily breaking down. Unfortunately, results obtained from the household surveys indicated that bioethanol stoves fell short in terms of their durability aspects compared to kerosene and charcoal stoves. The general agreed responses from both survey and FGDs participants, was that the interior of the bioethanol stoves would rust after a short period of time, eventually clogging the burner. Christine Wairimu, a resident of Karanja area expressed the following insight during the second FGD session: "*The thing with the bioethanol cookstove is that it rusted easily after consistently cooking with it for a month. I wanted to repair it but unfortunately, there are no repair centres in Kibera*". If one compared the reparability of charcoal and kerosene stoves with bioethanol stoves, it was apparent that they had multiple repair kiosks distributed all around Kibera, while there were no repair kiosks for bioethanol stoves. Stove manufacturers would therefore add value to the bioethanol cookstoves if they could also set up collection and repair centres for broken down stoves within Kibera (Landfried et al., 2015).

4.3.6. Availability of Fuels and Stoves

For a stove technology to be taken up by a specific community, it has to be affordable and accessible to the target users (Ramana et. al, 2015). The study found a number of challenges believed to hamper the supply chain of bioethanol fuels. All the experts and informants that participated in the interview segments expressed the view that bioethanol fuels were currently produced unsustainably, thus constraining the supply that is available. Apart from insufficient feedstock, experts and informants further explained that there were very few micro distilleries that produced bioethanol fuels. An excerpt from the interview transcript of Fenwicks Musonye elicited some of these facts as follows:

> *"The other major concern that I almost forgot was the source of feedstock. On the pilot project we conducted, we sourced the bioethanol feedstock from molasses, which is not sustainable. Most of those companies we worked with have presently closed down. This means that we have to either plant feedstock plants or maximise molasses production from the sugarcane sector. But then again, there will be the conflict of food security and bioethanol feedstock agriculture. There has been research done by GIZ on different potential plants that can be used for feedstock. Sweet sorghum is one of the recommended crops that can be cultivated."*

As a result, the lack of reliable infrastructure and the irregular supply of feedstock caused the local production of bioethanol fuels to be more expensive than it would be if imported instead. Unfortunately, the total additional cost was then translated to the customer.

Another key finding was that no local companies manufactured bioethanol stoves hence making importation the only option that retailers could use to obtain the stoves. Felix Okoth illuminated this perspective in the following comment: "*I import the bioethanol cookstove from China because it's cheaper"*. In addition, a common view that was held among the experts, survey and FGDs participants was that both the bioethanol stoves and fuels were mainly sold in supermarkets yet the common Kibera residents would obtain their day-to-day supplies in small vendors kiosks within Kibera. Consequently, measures should be taken to improve the distribution networks of the fuels and the stoves to ensure that they are near the end users.

4.3.7. Certification and Legislation

Mihucz & Záray, (2016) reported that the use of inefficient cookstoves and poor-quality fuels were the main cause of Household Air Pollution (HAP) in low-income homes. For the study, it was important to assess if available bioethanol fuels and cookstoves had passed the rigorous guidelines indicated by the Energy Regulatory Commission (ERC) before being allowed into the Kenyan market. In order to fully understand this topic, the researcher conducted interviews with key energy planners from the energy department. Two broad themes emerged upon data analysis that are discussed below in detail.

4.3.7.1. The Role of the Government

Every government has the responsibility to ensure that the citizens it governs are consuming quality, safe products and services. The Kenyan government has set in place institutional frameworks such as Kenya Industrial Research and Development Institute (KIRDI) and Kenya Bureau of Standards (KEBS) that ensure only quality bioethanol fuels and stoves are available to customers. Anne Nyambane highlighted this aspect as follows:

> *"Certification of quality standards is the one thing currently being done by KIRDI. Do you know about KIRDI? It is the Kenya Industrial Research and Development Institute. It is a parastatal that has been mandated to test stoves quality. At the University of Nairobi, there is professor Githinji who is working on this issue together with KEBS. They generally do the certification and quality measures of fuels. Maybe they are some of the people that you can also talk to*."

In as much as there are institutional frameworks set up to ensure that only quality stoves and fuels are available to consumers, the general account of the survey participants was that the bioethanol fuel was of low quality, and that the cookstoves rusted easily. It is important that the government reviews set quality frameworks specifically for bioethanol technologies to ensure that gaps are identified and filled. For example, there can be a mechanism that ensures that law offenders such as fuel adulterators are held accountable.

The shift in government resources to promote LPG in favour of bioethanol fuels in informal settlements came up as an important factor that was holding back the adoption of bioethanol fuels. Fenwicks Musonye illuminates this aspect in the following statement: "*The government has a plan for phasing out kerosene fuels and promote other efficient and sustainable fuel sources like LPG*." Consequently, this has caused stakeholders to shift resources and created policies favouring the investment in LPG fuels, deeming bioethanol as unfavourable. Rather than concentrating on only one method exclusively, energy planners need to be flexible in exploring other options that could be cheaper and beneficial to the target community.

4.3.7.2. The Role of the Private Sector

The private sector has a critical role in ensuring that clean cooking fuels are available at an affordable price to the consumers. James Muyula illustrates this aspect in his comment as follows:

> *"As long as the environment is conducive, the private sector will automatically come in to ensure that fuels are reaching customers. When you talk about private investment, there's also the Public Private Partnerships (PPPs). Kenya is among countries that has clear guidelines on how PPPs should operate. For example, we have talked about setting up bioethanol distilleries in one of each counties. In this case the public which is the county, may allocate a piece of land to the private sector who will come in and to set up a distillery and they can see how they can share the revenue."*

With this element in consideration, if the government ensured that the investment atmosphere is conducive, in terms of tax, red tape, and other key factors, then more PPPs would be proposed to ensure that investing in bioethanol fuels is was viable to both the sellers and buyers.

4.4. Opportunities for Bioethanol Cooking Fuels

Results from Key Informant Interviews (KIIs), expert interviews and Focus Group Discussions (FGDs) provide insights in terms of the opportunities for potentially scaling up the use of bioethanol fuels and stove technologies within urban informal settlements. Data was analysed using the coding method, by following a thematic analysis and an inductive approach. The discussion points below represent some of the key thematic areas that were elicited from the study. Generally, the following perspectives in favour of bioethanol fuels and stoves are addressed in detail: setting up supporting institutional frameworks, establishing favourable policies, use of financial mechanisms, making improvements of the stove design, and establishing quality standards for bioethanol fuels.

4.4.1. Fuel Infrastructure

4.4.1.1. Demonstration Centres

Demonstration centres offer an opportunity to educate a target group of consumers on how to use a new product. A majority of key informants pointed out to the need for establishing government sponsored programs that could actively promote and increase the awareness levels of bioethanol as a cooking fuel. *"There is a huge delink between the user and the product as most consumers do not understand it,"* commented James Muyula, reiterating the point on insufficient awareness of the technology by the end users. He further expressed that: *"The introduction of bioenergy centres in every village within informal settlements around the country will form an initial foundation of customers being able to access knowledge on what, and where the product is and how to use it*." All these factors considered, the government could for example facilitate the availability of public spaces within the designated counties to act as demonstration centres. These spaces would then exclusively be used to promote bioethanol, among other clean energy technologies, as an alternative to cooking fuel at subnational levels.

4.4.1.2. Distribution Networks

A well-established distribution network ensures that bioethanol fuels are available to the target consumers in close proximity within markets (EkouevI & Tuntivate, 2012; Julius, 2013). When questioned in separate occasions about the bioethanol fuel supply chain, both experts and key informants generally agreed that there should be active engagement of the state with the private sector to form extensive dissemination networks for both the fuels and the stoves. Felix Okoth illuminated this aspect in the following comment*: "Look at charcoal, it is everywhere. Look at kerosene, it is everywhere. Now you tell me why a Kibera resident should walk further in search of bioethanol?*" The overall response was that public-private partnerships could go a long way in strengthening the pre-existing bioethanol value chain.

Figure 4.8. Charcoal fuel at a charcoal kiosk in Kibera is commonly sold in 2 kg-sized reusable paint cans.

Certainly, during the study, what was apparent was that both kerosene and charcoal fuels had kiosks within less than twenty meters for every household. Unfortunately, this was not the case with bioethanol fuel at all. Family members had to travel to biocentres within Kibera to buy it. Indeed, A well-knit dissemination network would go a long way to ensure that bioethanol fuels were accessible to most families in Kibera.

4.4.1.3. Cross-Fertilization of Knowledge between Ministries

Investing in knowledge on bioethanol fuel technologies is an appropriate undertaking that elevates understanding on the potential of their use as alternative cooking fuels. The theme of investing in knowledge and research came up when a majority of experts pointed out the need for collaboration between the various involved government ministries. Edwin Nateminya elicited this perspective when he remarked the following statement:

> *"Ultimately, coordination between various ministries enhances knowledge sharing and reduces the chances for repeating errors from failed prior projects. It is very important to rely on quality science-based data to enable decision making by government practitioners, if bioethanol fuels are to be mainstreamed into national programs."*

For example, the Ministry of Agriculture Livestock and Fisheries, the Ministry of Finance and National Treasury, the Ministry of Energy and Petroleum, and the Ministry of Industry Trade and Cooperatives could open avenues for collaboration on cross-cutting projects on bioethanol technologies. Ideally, the government should at all costs venture into research on these technologies and assess their potential for use in the domestic cooking sector. A viable bioethanol fuels market will not only bring health and environment benefits to the Kibera residents but will save on importation costs from petroleum products.

4.4.1.4. Formalization of the Fuelwood Sector

In order for bioethanol fuels to stand a chance of making it in the domestic energy market, it has to compete on fair grounds with pre-existing fuels. Anne Nyambane illuminates the importance of this aspect in the following statement:

> *"If you look at the kind of fuels that bioethanol is trying to substitute such as charcoal and firewood, most of the time you will find that people are just picking firewood anywhere, and then the charcoal industry especially here in Kenya is not well regulated. Unless there are regulations in the charcoal sector, there are regulations in the firewood sector, it is only then that bioethanol fuels be well positioned to compete with these fuels."*

Therefore, fuel formalization policies have to be reviewed, gaps identified and filled accordingly in order to hoister bioethanol fuels and stoves a fair market share in the domestic energy sector.

4.4.2. *Financial Tools*

4.4.2.1. Incentives

Incentives are fiscal tools that can be used to ensure that both bioethanol fuels and stoves are affordable to the consumers (Quinn et al., 2018). The issue of financial incentives seemed to be a key conversation point for all experts when asked to comment on the costs on bioethanol fuels and the stoves. James Muyula clearly illuminates this aspect as follows:

> *"Incentives could play a major role in encouraging the adoption of bioethanol technologies and encourage the investment in this sector. Tax holidays can be granted to bioethanol fuel distillers and private sector investors for instance, where investors could enjoy Value Added Tax (VAT) exemption by way of an official order from the Ministry of Finance and Treasury."*

In his statement as follows, Edwin Nateminya highlighted the importance of offering incentives to farmers to encourage them to cultivate feedstock plants: *"Bioethanol feedstock, such as sweet sorghum, could be sold at relatively lower prices for farming in Arid and Semi-Arid Lands (ASALs) to encourage production and continued supply of the fuel within urban areas"*. The government needs to explore more domains under which incentives can be provided to ensure that bioethanol fuels are mainstream cooking fuels in informal settlements.

4.4.2.2. Tax Reforms

Tax reforms could go a long way in reducing overall costs that investors in bioethanol technologies experience. When experts were interviewed on the topic covering the taxation model of bioethanol fuels, currently attracting a 16% tax in VAT and 25% in duties compared to 0% for most other fuels, all agreed that effective tracking tools for cooking bioethanol fuel should be enacted to distinguish it from medical and recreational ethanol. "*Bioethanol can be used as a drink and there are no clear defining lines as to which bioethanol fuel can be used for recreational purposes or that can be used as a household fuel*", said Anne Nyambane. All of the experts interviewed had consensus on this topic that the current taxation scheme renders the product uncompetitive compared to charcoal and kerosene at current market prices.

4.4.2.3. Microfinance

Microfinance programs reduce the total cost impact experienced by consumers while purchasing bioethanol cookstoves and fuels. According to James Muyula, the private sector could capitalize on using pre-existing microfinance schemes to reduce overall costs directed to buyers when purchasing bioethanol fuels as well as the stoves. "*The private sector could engage target groups by selling and promoting the bioethanol stoves while ensuring that payments are done on a small-scale basis. Such groups include women chamas, cooperatives, church groups and so on".* He also suggested that the government could support the private sector by providing funding mechanisms aimed at reducing the total costs incurred when setting up bioethanol stove and fuel businesses. He warned that the high initial operational costs usually trickle down to the end users. It is therefore imperative that taxation guidelines are reviewed and amended as appropriate to grant bioethanol fuels a chance in the domestic energy sector.

4.4.2.4. Tariffs

Tariffs could play an important role in determining the competitiveness of bioethanol fuels in the free markets alongside pre-existing domestic cooking fuels within informal settlements. Vincent Okello illuminated this aspect as per his statement as follows: *"If the duty on kerosene imports was increased, since kerosene is the main fuel used in informal settlements, consumers will always tend to look for the next cheaper alternative commodity."* In order to successfully promote alternative cooking fuels such as bioethanol, the duty on imported kerosene fuels must be increased to make them unfavourable for investors. This in turn would favour locally produced bioethanol fuels.

4.4.2.5. Cost-Benefit Analyses

Cost-benefit analyses (CBA) aim at evaluating risks and rewards for projects that are under consideration. The view of conducting a country-wide CBA on bioethanol fuels and stoves surfaced when Edwin Nateminya suggested as follows: "*The government should evaluate the cost of foregoing bioethanol fuels on various sectors of the economy. At the end of the day, the socio-economic costs are higher in comparison to scenarios if bioethanol fuels would have been used*". Well conducted CBAs further understanding of the bioethanol value chain, and where knowledge gaps would be identified, they would be filled accordingly.

4.4.3. Stove Design and Fuel Type

4.4.3.1. Cultural Beliefs

Understanding the underlying cultural perceptions of a community with regard to cooking is critically important in order to develop cooking technologies that are both viable from a practical standpoint and culturally acceptable to the community in question (Atanassov, 2010). According to Sheth (1981), the strength of habit associated with existing practices is the most powerful determinant of resistance to change. Since literature points out that kerosene fuels are a widely used cooking fuels in urban informal settlements, bioethanol fuels could similarly become mainstream owing to the fact that they are also liquid fuels and can be used in a similar manner. Anne Nyambane illuminates this aspect by sharing the following opinion, "*the [bioethanol] fuel can actually be used to replace kerosene as people prefer a liquid fuel, which is much easier to use and is seen as the norm in these communities*". However, habits are hard to change, and substantial inertia must be overcome to convince Kibera residents to change their habits. This problem is exemplified by the comments of a local kerosene fuel user, Marylynn, who was asked if she may consider switching to bioethanol as a cooking fuel:

> *"I will not stop using kerosene for now because that is what I am used to. Perhaps one day I may try bioethanol but only if they can sell it in small plastic bags that can fit in my handbag, but not at the moment. I am very comfortable with kerosene.*"

Both of the above comments are supportive of existing studies on the significance of socio-cultural factors in determining adoption of a cooking technology (Atanassov, 2010; Omar, 2012). Marylynn's opinion elucidates how prevailing mindsets and habits can slow down change when it comes to technology substitution. However, her statement also highlights how informal settlement residents take practical consideration into account when making choices fuel type, as she explains that she will only switch to bioethanol fuels if they are packaged in a similar way to locally-available kerosene fuels.

Another important theme that came out during the study was the desire for households to be associated with prosperity and improved living standards, and in this regard modern stove types can be considered a status symbol in the Kibera context (see Section 4.3.3). It appears that this notion may have been considered at length by *Dometic AB*, the developers of the ethanol CLEAN

COOKSTOVE, which apart from being an effective cooking stove has a modern design that appeals to most users. Another user of bioethanol who only accepted to participate in the study on condition of anonymity said, "*the thing I like most about the bioethanol stove is that is works just like LPG, but luckily it is much cheaper*". All these comments complement previous studies done on socio-cultural factors and the extent to which they contribute to fuel choice among urban informal settlement residents (Atanassov, 2010; Omar, 2012).

4.4.3.2. Stove and Fuel Quality

A good cooking stove should be able to last for a considerable period without breaking down, should be easy to maintain and easy to repair if broken. All the experts who participated in the study all agreed on this important aspect of cooking stove technologies. Vincent Okello, who is a key informant in the study provides the following view:

> *"The life cycle of the ethanol stove is very long. It is a strong and robust stove that can be used for several years. Because of the durability aspect, maintenance requirements are minimal. A soft cloth with water is sufficient to wipe off the dirty surface of the stove*."

A stove with a relatively long-life yields benefits to low-income earners due to the foregone costs that would have otherwise been incurred in repairs and replacements. In contrast, however, the agreed consensus during the FDGs was far from Vincent's account. Participants felt that the bioethanol stoves would rust easily and that it was not easy to find repair kiosks in Kibera, as compared to the charcoal and kerosene stoves.

Figure 4.9. A single bioethanol fuel stove burner and a litre of bioethanol fuel

A good fuel should have a strong flame making it a favourable choice among end-users. Apart from its energy content, a good fuel should be relatively easy to control during the cooking process. At 95% concentration, bioethanol fuel should produce a flame sufficient to cook a meal for a household. However, most current and former bioethanol fuel users expressed that the fuel had a low energy content. Vincent Okello confirmed this aspect in the following clipping of his interview transcript.

> *"When it comes to low-quality fuel, usually you will find unscrupulous businessmen wanting to make more money than from what is available. The bioethanol is diluted with water to get an extra number of litres. The risk in that is that the concentration of the fuel is reduced from 95% to a lower percentage, therefore reducing the energy content of the fuel. I feel the risk of buying low quality fuel is frustrating customers, giving them a fuel that burns not as effectively as promised or that cooks as efficiently as promised. It is a commercial risk as the customers are not getting the value for their money. This therefore affects uptake especially when it comes to cooking certain local foods such as ugali."*

Therefore, in order for bioethanol fuels to be seen as a potential cooking fuel, there is a need for developing specific standards and laws that will ensure only quality fuels are available to customers.

4.4.3.3. Technology Awareness

In order to curb the HAP, GHG emissions and forest degradation challenges in Kenya, residents in urban informal settlements need to be aware of alternative fuels in the market, which can be used to substitute charcoal or kerosene. During the study, it was apparent that some participants had never heard of the bioethanol fuel technology. One participant mentioned the following during one of the FGD sessions: "*personally, I have never heard of bioethanol fuel. For me, I know that ethanol is used in Kinyozis*". Another important perspective was highlighted by another FGD participant in a different session, who claimed that he had never encountered the technology whatsoever. *"I have heard of the technology, but I do not know where to find it, or even how to use it*", he said. These comments highlight the need for relevant government agencies, partners and donors to effectively coordinate and implement initiatives aimed at increasing user knowledge on bioethanol stoves and fuels (see Section 6).

5. SYNTHESIS AND DISCUSSION

Chapter 5 aims to bring together all key findings discussed in the previous chapters to derive a higher order discussion on the potential of bioethanol fuels to help reduce greenhouse gas (GHGs) emissions from cooking fuels in urban informal settlements in Kenya. Table 5.1 over page summarizes all the key findings aggregated from the study, presented according to the qualitative and quantitative synthesis procedures used. These results provide a framework to discuss opportunities for scaling-up bioethanol fuels and stoves within low-income urban informal settlements across Kenya, and potentially across East Africa.

Table 5.1 *Summary Findings of the Kibera Household Surveys*

Study Objective	**Research Question**	**Methods**	**Quantitative Evidence (who, what, where and when)**	**Qualitative Evidence (how, why)**
To analyze the cooking technologies and household energy sources available in Kibera.	1. What are the available cooking technology options in Kibera?	• Semi-structured household surveys. • FGDs. • Ethnography.	• Kerosene users – 81.71% • Charcoal users – 76.28% • LPG users – 18.41% • Electricity users – 3.54% • Multiple stove users – 69% • Single stove users – 31%	• More than one stove type used per household on average. • Most families combined different fuel types depending on the cuisine and the cooking methods it required.
	2. What is the current state of bioethanol usage by households in Kibera?	• Semi-structured household surveys. • Experts and key informant interviews. • FGDs. • Ethnography.	• 35 stoves representing 10.03% of the sampled population.	• Most families were aware of bioethanol fuel but did not know where it is sold or how it is used. • The government is focused on phasing out kerosene and charcoal fuels by using LPG. • Insufficient research on bioethanol fuels.
To determine the quantity of GHGs (CO_2e) emissions that would be avoided in Kibera if households were to switch to bioethanol fuels.	3. What are the total GHG emissions currently produced in Kibera by burning cooking fuels?	• Desktop studies. • Semi-structured household surveys.	• 10.31 $t\ CO_2e$ emissions generated daily day from cooking technologies. • $3,764.39\ t\ CO_2e$ emissions generated annually from cooking fuels.	
	4. What is the quantity of GHGs (CO_2e) emissions that would be avoided if households in Kibera switched to bioethanol fuels?	• Desktop studies. • Semi-structured household surveys.	• 3689.44 $t\ CO_2e$ emissions would be avoided if Kibera families were to completely switch to bioethanol fuels. • 98% of total GHG emissions would be averted if all	

			households switched to bioethanol fuels.	
To identify key factors determining bioethanol fuel adoption in Kibera.	5. What factors are responsible for the observed trends and patterns in available cooking technologies?	• Desktop studies. • Semi-structured household surveys. • Experts and key informant interviews. • FGDs. • Ethnography.	• 44.61% of the sampled population believed cooking with charcoal and kerosene had no negative impacts to the environment • 70.68% of the surveyed households believed that cooking with charcoal and kerosene fuels had negative health impacts to their families	• Charcoal is reported to be a preferred substitute to kerosene depending on the cuisine type, and cooking methods. • Charcoal warms the house during the cold months and according to local residents prevents children from suffering from *Pneumonia,* colds and flu. • Kerosene was considered generally easy to purchase and convenient because of its availability in small quantities. • There were numerous kerosene and charcoal kiosks within approximately 20 meters of each house. • Despite negative health impacts of charcoal and kerosene fuels, families continue to use these fuels because they are considered cheap.
	6. What factors are responsible for the observed trends and patterns in available bioethanol fuel technologies?	• Semi-structured household surveys. • Experts and key informant interviews. • FGDs. • Ethnography.	• 59% of the sampled population is have heard of bioethanol fuels. • 21% of bioethanol fuel users evaluated cost to be the biggest hindrance to make a complete switch to bioethanol fuels.	• Bioethanol fuel and stoves are sold at strategic locations such as biocentres and suburb supermarkets that are too far for residents. • Bioethanol fuel cooks food approximately as fast as

			• 14% of bioethanol users evaluated cooking time to be the second most important factor when combining fuels.	kerosene and the flame is comparable to LPG. • Bioethanol fuels are priced at USD 1 per litre compared to kerosene priced at 0.65 – 0.85 USD per litre. • Bioethanol fuels take longer to prepare a meal compared to kerosene and because of that, participants recommended the price to be much lower than of kerosene.
To propose policy measures and technological options based on empirical evidence that could facilitate adoption and sustained use of bioethanol fuel in Kibera.	7. What policy and technological options can accelerate the adoption rate and sustained use of this technology in Kibera?	• Desktop studies. • Experts and key informant interviews.		• Need for tax reforms targeting domestically used bioethanol as a cooking fuel. • Strengthening the bioethanol programs by issuing incentives, subsidies and tax holidays. • Regularization of the biomass sector. • Certification of quality bioethanol fuels and stoves. • Women to be at the forefront of championing bioethanol fuels and should be involved the bioethanol value chain. • Campaign strategies to raise awareness levels of bioethanol fuels. • Impose tariffs on fossil fuel imports.
	8. What are the roles of the public and private sectors in advancing	• Desktop studies.		• Setting of standards for quality bioethanol fuel and stoves.

	the use of bioethanol fuels in Kibera?	• Experts and key informant interviews.		• Strengthening the bioethanol distribution networks to ensure accessibility is a non-issue. • Setting up the much-needed infrastructure such as micro distilleries to ensure sustainability in supply. • Use of micro-finance channels such as *chamas* to reduce cost burden on users.

5.1. Bioethanol Cooking Technologies and the Multiple Fuel Use Model

Using bioethanol fuels as an alternative cooking fuel fits perfectly into the fuel combination practices of low-income households. As revealed by the study, a majority of families in Kibera use two or more stove types which they use interchangeably. The current findings add to a growing body of literature on the 'Multiple Fuel Use Strategies' model, which states that inter-fuel substitution within households is attributable to a number of different factors, but mainly based on the household's perceptions of cost, efficiency and convenience (Van Der Kroon, Brouwer, & Van Beukering, 2013; Aya Yonemitsu et al., 2014). As such, bioethanol fuels stand a great chance of uptake in the market once users can evaluate them as more efficient, affordable and convenient to use in comparison to kerosene fuels.

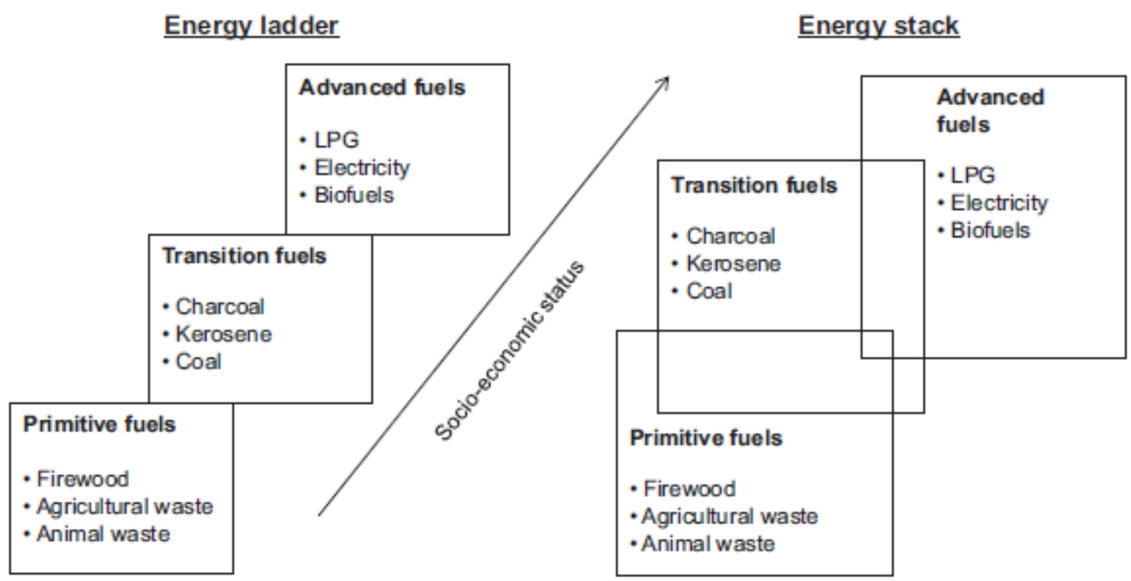

Figure 5.1. Energy ladder model of energy transition.

5.2. Bioethanol Fuel and Cookstove in Kibera – Evaluating Applicability

In an ideal scenario, bioethanol fuels are a viable substitute to kerosene fuels, and they can be used to completely phase out polluting kerosene fuels in Kibera. According to the study results, 81.71 % of households use kerosene fuels in combination with charcoal among other cooking fuels. As mentioned in the literature review, kerosene and charcoal fuels have a rich history of use in informal urban settlements (Karekezi et al., 2008; Yonezumi, 2015). During the surveys, most participants expressed a preference for using liquid fuels because they could be sold in quantities as little as 20 ml, trading at approximately USD 0.20. Unfortunately, this was not the case with bioethanol fuels. Bioethanol fuels were sold in the manufacturer's bottle packages of a minimum of 300 ml, trading at approximately USD 0.40. If the packaging of bioethanol was readjusted to imitate that of kerosene fuels, and the price adjusted accordingly by retailers, more Kibera residents would consider purchasing bioethanol fuels, as indicated by the fact that 70% of the survey participants evaluated both charcoal and kerosene as having negative impacts on health.

Figure 5.2. The difference in packaging of bioethanol fuel in comparison to kerosene fuels.

Clearly, in order to be competitive in local markets the price of bioethanol must be comparable to the prices of charcoal and kerosene. This is not currently the case in Kibera, where the price of the bioethanol cookstoves was high in comparison to the available alternatives. Results from the surveys indicated that a single burner bioethanol cookstove traded at USD 25, and a double burner at USD 40, while a comparable kerosene stoves traded at USD 6 charcoal stoves at USD 3. According to the energy ladder theory, consumers will prefer to spend minimally on a cooking stove, even if the cooking fuels that they are presently using have known negative health impacts. It is therefore necessary that bioethanol cookstove prices are adjusted downwards if Kibera residents are to step away from using charcoal and kerosene fuels.

Figure 5.3. A single and double burner bioethanol cookstoves in comparison with the Kenya Ceramic Jiko (KCJ) and the Kerosene stove.

Despite the high cost of the bioethanol cookstove, it was evaluated favourably by users on the basis of various other factors when compared to the KCJ (i.e. charcoal) and kerosene cookstoves. Numerous women placed aesthetic value on the bioethanol cookstove and expressed how they enjoyed keeping it within their living spaces. These findings match those observed in earlier studies (Atanassov, 2010; Jürisoo & Lambe, 2016). Other women expressed how the cookstove was comparable to LPG in terms of how easy it was to control the flame. As space is usually at a premium in informal settlements, where the living spaces by day also serve as sleeping spaces by night, the compact design of the bioethanol cookstove made it easy to create space as it could easily be pushed under a table, or under a bed. The fact that it could be used indoors with minimal smoke emissions, and the fact that it left cooking utensils clean and the wall drapers clean was indeed very desirable to all users, especially women.

Literature often points to socio-cultural factors among the key determinants of fuel choice within a specific community (Atanassov, 2010; Omar, 2012). Indeed, cultural barriers were apparent when some women commented that they would not switch to cooking with bioethanol fuels no matter what. Most of these comments lacked valid reasons and were not backed by any empirical evidence or first-hand experience. The study therefore concludes that if the government (Ministry of Energy and Petroleum) and its partners implemented more targeted efforts to raise the profile of bioethanol fuels, most households in informal settlements would consider switching to bioethanol for domestic cooking. Since several women interviewed considered the bioethanol flame to be weaker than a typical kerosene flame, the study concludes that the government must ensure that the domestic bioethanol fuel market is tightly regulated and monitored to ensure fuel purity and quality standards are established and complied with, in order to reduce cases of adulterated fuels by scrupulous businessmen.

5.3. Emission Reduction Potentials of Bioethanol Fuels

The evidence from this study suggests that bioethanol fuels have the potential to avert approximately 98% of GHG emissions generated from both charcoal and kerosene fuels. These results are consistent with those of other studies and suggest that bioethanol fuels the climate impact associated with black and organic carbon by 91% (Lefebvre, 2016). Currently the Kenyan Government is running a program targeted at completely phasing out kerosene fuels in low-income households by promoting LPG (Mburu, 2018). In theory, this would be a great energy transition initiative. However, results from this study further reveal that a majority of residents prefer using liquid fuels for various reasons. Government-led programs would be more successful if greater consideration were given to energy transition models and then decision-making was adjusted accordingly. Instead of focussing only on one method to solve the energy challenges related to domestic cooking, bioethanol technologies should be promoted in parallel as an additional suitable alternative to current polluting cooking fuels.

5.4. Policy Assessment on Bioethanol Fuels

With the right policy instruments, bioethanol fuels can become mainstream just like kerosene fuels already are. Results from this study illuminate various areas where policies in favour of championing bioethanol fuels are lacking. For example, fuels such as LPG, charcoal and kerosene do not attract any VAT (value added tax), while bioethanol attracts a whopping 16% tax rate, which is typically passed on to customers. In addition, feedstock agriculture aimed at producing bioethanol fuels is currently marred with problems such as competition with staple food crops. Farmers therefore have preferred to invest in food agriculture at the expense of bioethanol feedstock, hampering the continuity of bioethanol supply in local markets. Little has been done by the government to encourage the private sector to invest in the bioethanol fuels value chain. Furthermore, since the failure of the ethanol fuel blending program that occurred in the 1970s, government ministries have not invested sufficient effort into trying to fully understand bioethanol fuels (Landfried et al., 2015). There has been insufficient cross-fertilization of knowledge between ministries regarding progress in relevant research. It is therefore necessary to establish a strong policy framework on bioethanol fuels as a first step to encouraging the private sector as well as consumers to embrace the product.

5.5. Theoretical Contributions and Applicability

A key theoretical contribution of this study to literature lies in estimating the total GHG emissions generated from cooking fuels under business-as-usual scenarios within Kibera and comparing those emission scenarios with alternative scenarios in which bioethanol uptake significantly increases. The study successfully estimated that $3764.39\ \mathrm{t\,CO_2e}$ is generated annually from domestic fuel combustion under the business-as-usual scenario. This is equivalent to cutting down approximately $3{,}765$ trees given that one mature sycamore tree (*Acer pseudoplatanus*) will store approximately $1\ ton$ of $\mathrm{CO_2}$ (Ecometrica, 2011; Jandl, 2007). This result is significant in that the Analysis of Input Fuel (AIF) model can be replicated and applied to calculate the total GHG emissions generated in Kenya's other informal settlements. It is imperative that theoretical models incorporate empirical evidence to support energy policy frameworks that guide programs into long-term sustainability.

The study further provided deeper insight on the cooking fuel technologies that are currently available in Kibera, and a deeper understanding of domestic energy consumption dynamics in urban informal settlements. The last comprehensive domestic energy survey was conducted by the government during the last national census in 2009, which is almost a decade ago, yet domestic energy planning requires quality and up-to-date data to be effective. A clear understanding of current household energy dynamics is essential to advance policies in the energy, environment and health sectors.

5.6. Mainstreaming Bioethanol Fuels – a Holistic Process

While steps have been taken to ensure that bioethanol fuels are currently available to low-income households, results from the study clearly reveal that adoption levels are still very low (only approximately 10% of surveyed households use it). Some of the surveyed families also indicated that they had once used bioethanol fuels before reverting to their previous cooking methods due to price considerations as well as issues of availability and habit.

In as much as there have been actions by the government and its partners to ensure that informal settlement households have clean cooking fuels, there are still additional avenues that can be considered for maximum sustainability. For example, instead of viewing women exclusively as the final users of the technology and developing products for them, women should be involved in the decision-making process right from the designing phase of bioethanol cookstoves (Lambe et al., 2015). They should be viewed as champions for bioethanol fuels, since they are the ones that are most often involved in the cooking process and know exactly what they need. Stove designers, on the other, hand should carefully assess the cultural values of target communities through a reflexive transdisciplinary lens, before developing products that may never take off.

Within the larger framework, the government can support awareness-creation campaigns to elevate the profile of bioethanol fuels as clean alternative cooking fuels. Using bioethanol fuels within low-income households will not only increase the living standards of families but will also go a long way in reducing Kenya’s GHG emissions footprint.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This study set out to determine the potential of bioethanol fuels to reduce GHG emissions generated from domestic fuel combustion in Kibera. While the study was based on a comparatively small sample of 400 households, the findings indicate that kerosene and charcoal were the most important cooking fuels and were typically used in combination with each other. These findings strongly support the multiple fuel use model for cooking fuels within low-income households. It can therefore be deduced that bioethanol fuels have a significant potential to find a market niche within the domestic energy sector if they are made affordable and accessible to the customer. The analysis further showed that approximately 10% of Kibera families are already cooking with bioethanol fuels. Taken together, these findings suggest that with more coordinated efforts by the relevant government agencies and their partners, including the review of current taxation policies which unfairly penalise bioethanol compared to other cooking fuels, and with additional, targeted awareness-raising campaigns aimed at elevating the profile of bioethanol fuels, there is a significant potential to substantially increase the number of Kibera families using bioethanol as a primary cooking fuel.

One of the most significant findings to emerge from this study was that approximately $3{,}764.39 \text{ t } CO_2e$ emissions will continue be generated annually from the Kibera urban informal settlement if charcoal and kerosene fuels will continue to be used under a business-as-usual scenario. It was further established that these emissions are equivalent to cutting down approximately $3{,}765$ mature trees per year, given that one mature sycamore tree (*Acer pseudoplatanus*) will store approximately $1\ ton\ of\ CO_2$ (Ecometrica, 2011; Jandl, 2007). The study results not only provide empirical evidence in terms of the total annual emissions generated by burning charcoal and kerosene fuels for cooking, but also calculated the total emission reduction potentials of bioethanol fuels.

In general terms, the Analysis of Input Fuel (AIF) model used in this study has the potential to be broadly replicated and applied to calculate the total GHG emissions generated from Kenya's other informal settlements. In this regard, it is imperative that theoretical models incorporate empirical evidence to support energy policy frameworks that guide programs into long term sustainability.

The study also provided a deeper understanding of context-specific factors that could facilitate adoption and sustained use of bioethanol fuels in Kibera. It was established that the current biofuels policy framework contains numerous weaknesses and loopholes that make the use of bioethanol fuel technologies on a large scale unfeasible under the present conditions. The study therefore concludes that the Kenyan Government and its institutional partners should play a central role in reshaping national policies aimed at supporting thee timely adoption of clean cooking fuels by economically-marginalised households. In this context, private sector stakeholders should be encouraged and supported in marketing both bioethanol fuels and stoves that are affordable in terms of price to the consumer.

This study also showed that cultural values were critical factors that affected cooking technology uptake. These findings support the idea that stove designers must assess and take into consideration the perceptions and aspirations of target communities in order to avoid developing technologies that may fail to take off due to socio-cultural barriers.

6.2. Recommendations

As described in the sections above, this study highlights some of the key challenges and complexities involved in promoting alternative cooking technologies within low-income communities in Nairobi, Kenya. In this regard, this section formulates a number of recommendations aimed at strengthening the work of Kenyan policy-makers, marketers and private sector stakeholders to ensure that bioethanol fuels and technologies are increasingly adopted as the primary household fuels within low-income communities.

To policy-makers:

1. More targeted actions by the government are needed to reduce costs along the bioethanol value chain. Such actions could involve the use of tax holidays, subsidies, incentives, microfinance programs and tariff plans to make the bioethanol stove and fuel price competitive alongside locally-available fuels such as charcoal, kerosene and firewood.
2. In implementing its Big 4 Universal Health Transformation Agenda, the national government should put in place policies to support the production and use of bioethanol as a domestic cooking fuel. This will in turn encourage the private sector to invest in bioethanol technologies.

3. County-level authorities can support bioethanol fuel initiatives by creating awareness on the available clean energies, their benefits and undertake measures that making them affordable and available to households. They could also allocate space for conducting clean energy demonstrations by marketers.
4. Greater involvement of government and NGOs in bioethanol fuel and stove activities is necessary in order to facilitate adoption and sustained use, for example, in the provision of funding to support bioethanol related projects.

To marketers:

1. Stove designers should use inclusive and participatory processes to involve potential bioethanol users in their design phase to reduces cases of maladaptive equipment.
2. Create awareness campaigns that are co-sponsored by the government and other key actors with the aim to increase bioethanol adoption, targeted at key Kibera villages such as Kisumu Ndogo that may be relatively economically marginalized compared to other villages. The focus should also be on improving residents' health by reducing indoor pollution associated with domestic cooking.

To the private sector:

1. Retailers of bioethanol fuels and stoves should take advantage of microfinance groups such as *chamas*, community groups, religious congregations etc., to enable users access credit for clean energy technologies.
2. The private sectors should undertake more action in promoting bioethanol fuels in villages such as Kisumu Ndogo and Soweto West where all the residents use kerosene as cooking fuel. Since bioethanol is also a liquid fuel, it can be targeted towards these communities.

6.3. Areas for Further Research

1. Further research to assess the impact of cultural factors in limiting the adoption of stove technologies in informal settlements should be conducted. "Poor people do not want to buy products advertised for poor people" – advised Vincent Okello during the expert interview segment of the study. Instead, aspirational products that reflect a modern lifestyle have significant appeal even among the urban poor. Research on how to develop marketing

strategies and awareness-raising initiatives that strike a chord with Kibera residents would significantly improve the potential for greater uptake of bioethanol as a cooking fuel in the future.

2. The full impact on water and land use as a result of cultivation of sweet sorghum as bioethanol feedstock should be holistically assessed. Information reviewed as part of this study indicated that a high-yielding variety of sweet sorghum was developed by the KSB and ICRISAT for the production of bioethanol fuels. However, the experimental sorghum variety was never given to farmers to grow.
3. There is a need to conduct long-term assessment studies focusing on the adoption of bioethanol fuels to investigate the levels of sustained long-term use of the technology. Specifically, the emphasis should be on trying to understand what ae the drivers that cause some community members to revert to old, polluting cooking technologies after having tested bioethanol for domestic cooking. To achieve significant environmental and energy independence benefits at the national level, it is vital to focus on ensuring that the adoption of bioethanol is sustainable and not simply a short-term experiment.

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APPENDIX I: EXPERT INTERVIEWS

Semi-Structured Key Informant and Expert Interviews Questionnaire

A: Initial questions

What is your role and organizational affiliation?

Which initiatives/research related to bioethanol for domestic cooking are you involved in?

B: Benefits of adopting bioethanol fuels

What is the potential of bioethanol fuel for domestic cooking in urban informal settlements?

Can you please briefly describe bioethanol fuel users? Have you conducted any impact assessment studies in the field?

C: Practicality and technological aspects

What can you tell me about the durability and maintenance of bioethanol cook stove and the bioethanol fuel? Refilling alcohol?

What can you tell me about the storage of bioethanol cook stoves and bioethanol fuels?

D: Financial aspects

Are you aware of any financial incentives that promote usage of bioethanol cook stoves and production of bioethanol fuel?

What do you suggest that can be done in relation to financing bioethanol fuel initiatives?

E: Prospects for development

What do you make of the future of bioethanol fuels and cook stove production in Kenya? Do you think bioethanol fuels should be promoted for scale?

Can you please describe how the current policy framework on bioethanol fuels look like?

F: Supply aspect

Can you please elaborate the current supply chain aspect of bioethanol fuels?

G: Certification and legislative issues

Can you please describe any measures put in place to certify quality and safety standards of bioethanol stoves and stoves?

What are some of the activities put in place that support user training on bioethanol stove and fuel use?

Please describe the role of the government in advancing the use of bioethanol fuels in low-income areas?

What is the role played by the private sector in advancing bioethanol fuels usage?

What research do you feel would be most useful given the current evidence base?

H: Social issues

What is the role of women in advancing the bioethanol cook stoves and fuels in low-income households?

I: Final questions

What do you feel needs to be put in place if bioethanol fuels are to be successfully scaled up?

Any final comments/opinion that you would like to add?

Are you aware of any other expert in this field who could be interested in participating in this research?

APPENDIX II: SURVEY QUESTIONNAIRE

Semi-Structured Questionnaire for the Household Surveys in Kibera

A: Identification of Respondent

Name of respondent: *Jina la Mhojiwa*:	Village: CODE003
Age:	Sex: Male ☐ Female ☐

B: Socio-Economic Status

Primary occupation: *Kazi ya Msingi*	Secondary sources of income: *Kazi ya sekondari ya mapato*
Number of people in household: *Idadi ya watu katika nyumbani*	Number of children under 5 years: *Idadi ya watoto chini ya miaka 5*
Education level: *Ngazi ya elimu*	Number of dependents: *Idadi ya wategemezi*

C: Questions on Domestic Cooking Fuel

1) What type of cooking fuel does your household use?
Ni aina gani ya technolojia ya upishi ambayo unatumia nyumbani?

Charcoal ☐ Kerosene☐ Firewood ☐ Gas ☐ Bioethanol ☐ Other ☐

If other, please elaborate:
Ikiwa ni vingine, tafadhali eleza?

2) What type of cooking stove does your household use?
Ni aina gani ya jiko la kupika ambalo nyumbani unatumia?

Jikos ☐	Biomass ☐	Kerosene Wick ☐	LPG ☐	Ethanol ☐	Other ☐
a) Type	Type	Type	Type	Type	

3) If other, please elaborate:
Ikiwa ni vingine, tafadhali eleza?

What are the main reasons for your choice of cooking fuel?
Ni sababu gani kuu kuufanya uchaguzi wako wa technologia unayopikia sasa?

4) How much quantity of cooking fuel do you use in a week/day/month?
Unatumia kiasi gani cha technolojia unayotumia kupikia kwa wiki/siku/mwezi?

5) How much does your household spend on cooking fuel in a day/week/month?
Je! Katika nyumba yako unaweza tumia pesa ngapi kubadilisha ama kuongezea teknolojia ya kupika kwa siku / wiki / mwezi?

6) If money were not an issue, which fuel would you use?
Ikiwa pesa haingekua suala, ni mafuta gani ungalifurahia/taka kutumia?

7) Have there been any changes in the cooking fuel(s) used in your household in the recent past? If yes,
Je, kuna mabadiliko yoyote katika technolojia ya upishi katika nyumba yako kwenye siku zilizopita? Kama ndio,

a) From what cooking fuel to which cooking fuel did you move from?
Uliondoka kutoka kwa technolojia ipi?

b) Why?
Mbona?

c) What have been the impacts of change to the new fuel?
Je, Kumekuwa na mabadiliko gani katika nyumba yako tangu ubadilishe teknolojia?

8) Have you heard of bioethanol or cooking with spirit fuel?
Je! Umesikia juu ya teknolojia ya kupika ya bioethanol ama spirit? Yes: ☐ No: ☐

a) If yes, why haven't you tested cooking with bioethanol fuel in your household?
Ikiwa ndio, kwa nini usijaribu kutumia teknolojia ya bioethanol katika nyumba yako?

D: Perception of bioethanol as a household cooking fuel

9) How does bioethanol fuel compare to the current cooking fuel(s) that you regularly use?
Unaweza linganisha aje teknolojia ya bioethanol spirit na technologia nyingine ambazo umetumia?

Income	☐	Religious Practices	☐
Taste Preferences	☐	Storage	☐
Culture	☐	Versatility e.g. smoking of food	☐
Ease to light fire	☐	Ease to extinguish fire	☐
Cooking time	☐	Cooking utensils used	☐

Household size	☐	Safety precautions	☐

E: Perception of respondent of health problems caused by cooking fuel

10) Does the cooking fuel you use have any health impacts?

Je, teknolojia unayotumia kwa sasa, kwa maoni yako, ina athari yoyote ya afya? Yes ☐ No ☐

If yes, please elaborate:
Ikiwa ndio, tafadhali fafanua

F: Perception of respondent of environmental problems caused by cooking fuel

11) Does the cooking fuel you use have any environmental impacts?

Je, teknolojia unayotumia kwa sasa, kwa maoni yako, ina athari yoyote kwa mazingira? Yes ☐ No ☐

a) If yes, please elaborate:
Ikiwa ndio, tafadhali fafanua

APPENDIX III: FGD SEGMENT QUESTIONS

Questions for a Focus Group on the Potential of Bioethanol fuel usage in Kibera

Objective: To identify key factors determining bioethanol fuel adoption in Kibera.

Engagement questions:

1. What cooking fuel forms are mainly used by Kibera residents?
2. How has been your experience with using a bioethanol cooking stove to prepare food?

Exploration Questions:

3. What are some of the factors influencing decisions on household stove and fuel-type?
4. What are some of the barriers that hinder the use of bioethanol fuel adoption within Kibera?
5. What are some of the facilitators that enable adoption of bioethanol fuels in Kibera?
6. Which fuel types do you think are dangerous?
7. Do you think the use of wood fuel and kerosene impacts on the environment?

Exit question:

8. Is there anything else we should discuss about the potential of the use of bioethanol fuels for cooking in Kibera?

APPENDIX IV: FGD PARTICIPANTS

	NAME	TELEPHONE NO.
GROUP A (Olympic Meeting)		
Kianda	Dorothy Adongo	0728 977 960
	David Odipo	0711 341 278
Olympic	Consolata Aoko	0726 439 500
	Kelvin Bai	0735 032 269
Raila	Mornica Anyango	0737 840 754
	Ken Gaya	0725 351 901
Soweto West	Gladys Akinyi	0706 325 120
	John Mutange	0712 222 170
Gatwekera	Okuro Charles	0720 247 979
	Doreen Liyala	0706 692 057

GROUP B (Makina Meeting)		
Makina	Nelson Auki	0725 207 709
	Lilian Ushamba	0716 394 797
Karanja	Christine Wairimu	0700 059 013
	Joseph Otieno	0723 256 710
Mashimoni	George Omondi	0725 879 193
	Susan Awour	0725 290 386
Kisumu Ndogo	Annette Okumu	0725 382 010
	Ombega Peter	0728 269 676
Kambi Muru	Winnie Abuto	0725 032 308
	Peter Bramstone	0715 552 764

GROUP C (Laini Saba Meeting)		
Laini Saba	Chrisphine Okoth	0718 225 059
	Sylvesta Otema	0726 911 510
Soweto East	Lilian Ushamba	0716 394 797
	Gabriel Mokora	0725 257 916
Silanga	Julius Ouna	0724 567 789
	Kelvin Mayabi	0790 461 889
Lindi	Joyce Onditi	0721 980 773
	Gabriel Wamukota	0727 566 354

APPENDIX V: LETTER TO EXPERTS

Sharon Barasa
P. O. Box 44294-00100
Nairobi, Kenya
sharonsambu@gmail.com

August 14, 2017

Dear Fenwicks Musonye,

My name is Sharon Barasa, a postgraduate student pursuing an MSc. Climate Change Adaptation at the University of Nairobi.

I am writing to request for an interview for a research study entitled "The potential of bioethanol fuel for domestic cooking to mitigate against black carbon emissions in urban informal settlements; case study, Kibera". The aim of the research is to map the progress of bioethanol fuels in informal settlements and to explore some of the barriers/facilitators to adoption of these fuels within these communities. The data will be used to write a Masters of Climate Change Adaptation thesis and, at a later stage, for a peer-reviewed publication.

Since you are a person who had research interests in bioethanol production, has formulated policy frameworks and set quality standards for bioenergy products, you are in an ideal position to give valuable first-hand information from your own perspective. As such, I duly welcome you to share your invaluable contributions to this study. Should you choose to participate, you will take part in an interview session (face-to-face or via telephone/skype), where you will be asked to give your opinion and share your knowledge on the research topic.

The interview takes approximately 20 – 30 minutes. The discussion will be recorded with an audio recorder. There will be no requirement for you to share any views and opinions that you do not wish to discuss, and the interview can be stopped at any time if you do not want to continue. Unfortunately, no reimbursement for your participation will be available, but I hope you will appreciate the important contribution your input will make to this research area.

If you wish to take part in the study, please respond to this email to schedule an interview at your convenience. If you require any further information on the study, please feel free to contact me at any stage.

With many thanks for your time and input,

Best Wishes,
Sharon Barasa

APPENDIX VI: EXCERPT FILE OF 2009 KIBERA CENSUS DATA

Table 2: Population Distribution by Sex, Number of Households, Area , Density and Administrative Units						
	Male	**Female**	**Total**	**Households**	**Area in Sq. Km.**	**Density**
KENYA	**19,192,458**	**19,417,639**	**38,610,097**	**8,767,954**	**581,313.2**	**66**
NAIROBI	**1,605,230**	**1,533,139**	**3,138,369**	**985,016**	**695.1**	**4,515**
NAIROBI WEST	**352,227**	**332,538**	**684,765**	**212,295**	**261.8**	**2,616**
DAGORETTI	166,391	163,186	329,577	103,818	38.6	8,534
KAWANGWARE	59,430	53,856	113,286	38,249	3.9	29,092
GATINA	24,747	21,125	45,872	15,987	1.5	30,411
KAWANGWARE	34,683	32,731	67,414	22,262	2.4	28,258
KENYATTA /GOLF	16,710	18,645	35,355	9,401	9.5	3,714
KENYATTA /GOLF	10,876	11,940	22,816	5,987	5.1	4,475
WOODLEY	5,834	6,705	12,539	3,414	4.4	2,837
MUTUINI	9,015	8,958	17,973	5,454	5.0	3,583
KIRIGU	6,097	6,111	12,208	3,694	1.7	7,027
MUTUINI	2,918	2,847	5,765	1,760	3.3	1,758
RIRUTA	49,985	49,349	99,334	31,407	7.3	13,574
NGANDO	17,615	16,399	34,014	11,162	3.2	10,757
RIRUTA	32,370	32,950	65,320	20,245	4.2	15,717
UTHIRU-RUTHIMITU	15,928	16,647	32,575	9,868	7.9	4,124
RUTHIMITU	7,493	7,776	15,269	4,434	4.8	3,156
UTHIRU	8,435	8,871	17,306	5,434	3.1	5,656
WAITHAKA	15,323	15,731	31,054	9,439	5.0	6,242
KABIRIA	4,859	4,254	9,113	2,948	2.7	3,386
WAITHAKA	10,464	11,477	21,941	6,491	2.3	9,610
KIBERA	185,836	169,352	355,188	108,477	223.2	1,592
KAREN	7,450	6,338	13,788	4,223	39.6	348
KAREN	4,768	4,028	8,796	2,861	23.0	382
LENANA	2,682	2,310	4,992	1,362	16.6	301
KIBERA	48,001	39,548	87,549	28,878	1.6	56,483
KIBERA	5,293	4,493	9,786	3,237	0.2	65,197
LINDI	19,545	15,613	35,158	11,551	0.5	70,302
MAKINA	12,965	12,277	25,242	7,926	0.7	38,508
SIRANGA	10,198	7,165	17,363	6,164	0.2	71,072
LAINI SABA	28,547	23,826	52,373	18,341	0.8	68,785
LAINI SABA	15,688	12,494	28,182	9,927	0.4	75,942
NYAYO HIGHRISE	12,859	11,332	24,191	8,414	0.4	61,981
LANGATA	10,867	8,648	19,515	5,434	31.8	614
HARDY	4,848	4,266	9,114	2,568	14.3	638
LANGATA	6,019	4,382	10,401	2,866	17.5	595
MUGUMO-INI	22,322	24,715	47,037	13,079	126.4	372
BOMAS	7,912	8,734	16,646	4,601	123.4	135
MUGUMO-INI	14,410	15,981	30,391	8,478	3.0	10,186
NAIROBI WEST	39,840	40,739	80,579	22,925	22.0	3,662
NAIROBI WEST	15,812	17,565	33,377	9,166	6.9	4,833
SOUTH C	24,028	23,174	47,202	13,759	15.1	3,126
SERANGOMBE	28,809	25,538	54,347	15,597	1.0	52,433
GATWIKIRA	13,580	11,411	24,991	7,270	0.3	85,323
OLYMPIC/KYANDA	15,229	14,127	29,356	8,327	0.7	39,478

APPENDIX VII: LIST OF STAKEHOLDERS

Name	Stakeholder Tier	Profession
Anne Nyambane	Research, Promotion & International Institutions	Research Associate - Stockholm Environment Institute
Vincent Okello	Implementation of bioethanol projects	Consultant - Partnership for Clean Indoor Air (PCIA)
James Muyula	Implementation of bioethanol projects	Consultant - Integral Advisory Limited
Edwin Natimenya	Research, Promotion & International Institutions	Consultant – United Nations Development Programme/ MoEP GoK
Mohammed Uhuru kadhi	Implementation of bioethanol projects	Strategy & Business Development, Investor in Biofuels
Felix Okoth	Implementation of bioethanol projects	Bioethanol fuels packager and Stove seller
Fenwicks Musonye	Promotion and implementation of bioethanol projects/initiatives	Policy formulation and standard setting on biofuels/MoEP