Doctoral Thesis

博士論文

Adoption and impacts of clean bioenergy cooking technologies in rural Kenya: A transect approach in Muranga and Kiambu counties

（ケニアの農村地域におけるクリーンバイオエネルギー調理技術の採用と影響：ムランガとキアンブの各郡における横断的アプローチ）

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ABSTRACT

Access to modern and sustainable cooking energy has moved at the forefront of the international policy discourse and has been enshrined in a dedicated Sustainable Development Goal (SDG7) on energy. Apart from being a key element of SDG7, access to safe and sustainable cooking energy is also central to achieving other SDGs pertaining to poverty alleviation (SDG1), good health (SDG3), gender equality (SDG5), ecosystem conservation (SDG15) and climate action (SDG13), among others.

Like other parts of sub-Saharan Africa, Kenya has been striving to modernize its household energy system. The adoption progress has been notably slow, with only 14% of Kenyans currently having access to clean cooking options such as biogas, liquefied petroleum gas (LPG), solar or ethanol stoves and 26% using improved biomass stoves. This situation seems a bit paradoxical considering that Kenya has a long-established clean cookstove sector compared to other SSA countries. Several researchers have *"requested"* for more nuanced local-specific policies and holistic scientific assessments to fully understand the sustainability challenges of traditional bioenergy cookstoves.

In order to address the inherent knowledge gaps, this research assesses the factors of adoption and the impacts of clean bioenergy cooking interventions in Kenya and propose policies that could enable scaling up their adoption. The specific focus is on the dynamics between traditional and modern (i.e. biogas, improved biomass stoves) cooking options in rural settings of the Murang'a and Kiambu counties. The specific objectives include to: (a) identify the drivers, challenges and perceived impacts of clean cooking interventions in Kenya through expert interviews; (b) elicit user preferences and trade-offs inherent to stove choice behavior using household surveys and choice experiments; (c) identify and asses the impacts of cooking energy technologies through a mixed-method approach; (d) suggest policy and practice options to influence sustainable transition pathways for achieving universal access to clean cooking in Kenya.

Household surveys were collected along two biomass transects in the two study districts. In particular, both transects sought to reflect increasing fuelwood scarcity, and traversed from the state forest towards the urban center (Kiambu) and the semi-arid interior (Muranga). Approximately 200 households were selected randomly in each study transect, with a further 100 biogas users purposively selected in the Kiambu transect.

First, an extensive literature review was conducted to synthesize the current knowledge about historical development of cooking technologies, policies, stakeholders, impacts and factors of adoption of clean bioenergy cooking interventions in Kenya. For objective (a) 28 semi-structured key expert interviews sought to elicit the perspectives and insights of the main stakeholders involved in the Kenyan stove sector about adoption (drivers and barriers), perceived impacts and requisite approaches to enable scaling up access to clean cooking in Kenya.

For the first part of objective (b), it was hypothesized that stove adoption is predicated on a linear combination of demographic, socioeconomic, institutional and ecological factors. A probit regression model was used to estimate the probability of the hypothesized variables on adoption of biogas and improved biomass stoves. A path analysis was further carried out to determine the direct, indirect and total effects of productive resources on stove adoption. In addition, a qualitative mapping of 23 participatory ethnographic surveys was carried out to identify contextual factors affecting stove acquisition and sustained use.

For the second part of objective (b), a stated preference survey and discrete choice experiment was designed for two main alternatives, namely LPG and charcoal stoves. A combination of conditional logit and mixed logit models were conducted to understand trade-offs inherent to household stove choice behavior and preference.

For objective (c), a sustainability assessment framework was developed to assess the social, economic and environmental impacts of stove adoption. Mixed method approaches are used to establish patterns, both between stoves and across the enumeration transect zones.

For objective (a): Due to the radically different roles of the interviewed stakeholders and unique interest in the clean cooking value chain, there is a broad variation in their perspectives about specific drivers and barriers of stove adoption. Despite this variation, there is a good level of consensus about the main barriers and impacts of clean cooking options in Kenya. Some of the identified and interconnected factors that affect stove adoption include stove affordability, awareness, behavioral change, reliable supply/distribution networks, business financing mechanisms, stove design and performance, community involvement, and quality assurance. The study identifies that such points of convergence can be mobilized to coordinate efforts in the otherwise fragmented institutional landscape.

For the first part of objective (b): the estimated factors with the highest total effects on adoption of biogas stoves include: income, number of livestock, farm size, credit access, education and gender of the household head. For improved biomass stoves, agroforestry practices, gender, income, credit access, education level and participation in social groups had the highest total effects on adoption. The results further indicate that adoption of improved biomass stoves significantly increase by 4.2% $(p<0.05)$ with each additional kilometer walked from the homesteads to the most frequent fuelwood collection woodland. From a gendered perspective, the results suggest that, despite the fact that women bear disproportionately the burden of fuelwood procurement and cooking tasks, they were found to have limited access to productive resources and less income as compared to males. Nonetheless, the results suggest that women have better opportunities for adoption in terms of access to credit services and participation in social groups.

For the second part of objective (b): the discrete choice analysis results signify respondents' preference for the modern, LPG stove as compared to charcoal stove alternative. However, the estimation results further suggest that a given increase in stove price, monthly fuel usage cost and indoor pollution reduces respondents' probability for LPG preference. Based on the relative magnitude of the coefficients, fuel usage cost was found to affect decision making 3 times more than the stove price. The magnitude of this utility is not universal for all but varies by geographical location and intra-household factors.

For objective (c): Adoption of improved biomass stoves was found to reduce the average daily per capita fuelwood consumption by about 40%. The population strata located at close proximity to the forest had a higher per capita consumption than those farther away. In terms of GHG emissions, improved biomass stove and biogas stoves had an emission reduction potential of 1.97 and 5.03 tCO_2e/household/year, respectively. When it comes to economic impacts, improved biomass stoves and biogas stoves were found to reduce the opportunity cost of unpaid time investment by about 26% and 48%, respectively. From an economic feasibility perspective, the analysis suggests that households relying on commercial fuelwood can save an estimated average of USD 54.68/year in Muranga and USD 64.21 in Kiambu and enjoy a discounted payback period of about 8 months for a USD 15 stove investment. Biogas adoption was found to provide an average annual saving of about USD 164.20 at a discounted payback period of 8.23 years for a USD 1000 stove investment. For social impacts, probit regression models were conducted to estimate the probability of prevalence of self-reported respiratory health symptoms. The results suggest a significant protective effect on prevalence of respiratory symptoms by cooking outdoors and in kitchens installed with appropriate ventilation structures.

From a policy perspective, this study suggests that, effective transition towards universal clean cooking can be achieved in Kenya by fostering measures to: (a) enhance multi-stakeholder and cross-sectoral collaboration; (b) implement appropriate financing mechanisms and economic incentives; (c) adopt local-specific policy approaches and stove dissemination activities; (d) facilitate awareness and behavioral change among stove users; and (e) strategize clean cooking technologies as cost-effective catalysts to deliver impact and interlinkages across multiple SDGs.

(1255 words)

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DEDICATION

I dedicate this PhD thesis to my parents Mr. Jessee Karanja and Mrs. Mary Njeri Karanja

"Thank you so much for believing in me, praying for me and supporting me!

You have truly given me the world!

I thank you so much for all the love and sacrifices you have made for me."

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ABBREVIATIONS

AMS	Approved Methodology Small-scale
ASC	Alternative Specific Constant
CCA	Clean Cooking Alliance (also Global Alliance of Clean Cookstoves)
CCAK	Clean Cooking Alliance of Kenya
CDM	Clean Development Mechanism
CO	Carbon monoxide
DCA	Discrete Choice Analysis
DEB	Dendro-energy Biomass (woody aboveground biomass less stump and twigs)
ER	Emission Reduction
f-NRB	Fraction of Non-Renewable Biomass
GACC	Global Alliance of Clean Cookstoves (also Clean Cooking Alliance)
GDP	Liquefied Petroleum Gas Megajoule
GHG	Greenhouse gas emissions
GoK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
KCAP	Kenya Country Action Plan
LPG	Liquefied Petroleum Gas
MAI	Mean Annual Increment (MAI)
MEPI	Multi-dimensional Energy Poverty Index
MPI	Multi-dimensional Poverty Index
Mt	Million tons
MWTP	Marginal Willingness to Pay
NGO	Non-government Organization
$PM_{2.5}$	Particulate matter (2.5)
SDGs	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
SP	Stated preference
SSA	Sub-Saharan Africa
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

LIST OF UNITS OF MEASUREMENT

KES	Kenya shillings
US$	United States dollars
USD	United States dollars
kg	kilogram
km	kilometers
m	meters
t	metric ton
Mt	Million tons
kt	kilo tons ('000 metric tons)
od	oven dry
kt od	Thousand metric tons of oven dry matter
t/CO_2 e	metric tons of carbon dioxide equivalents

CHAPTER 1

BACKGROUND

1.1 Introduction

Energy security, and particularly access to modern energy, remains a major sustainability challenge in Sub-Saharan Africa (SSA), as it affects nearly every aspect of economic development and human wellbeing (IEA et al., 2018, 2019). Approximately 780 million people (out of a population of 915 million) are reportedly using traditional biomass such as firewood, charcoal and animal dung in open fires and inefficient stoves in poorly ventilated areas for daily cooking and heating (IEA et al., 2018; World Bank, 2017). Such cooking practices have been linked to poverty, environmental degradation, gender inequality, and generally poor and unhealthy living conditions (Sovacool, 2012; Dutta, 2005; Person et al., 2012; WHO, 2016; Bailis et al., 2015).

Several studies have reported the dangers of traditional inefficient stoves (Person et al., 2012; Puzzolo et al., 2016; Ruiz-Mercado et al., 2011; World Bank, 2006), particularly the health complications due to exposure to indoor air pollution from solid fuels (WHO, 2016). These emissions have been estimated to cause over 600,000 premature deaths annually in SSA (WHO, 2014). The potential environmental impacts of current cooking practices on ecosystem degradation and greenhouse gas emissions are also substantial (Owen et al., 2013). Thus, energy demand and use has steadily become one of the major sustainability challenges in Africa, which is highly interlinked with other major environmental and socioeconomic issues (Janssen and Rutz, 2012; Brew-Hammond and Kemausuor, 2009).

Following the launch of the Global Alliance of Clean Cookstoves (GACC) in 2010, clean cooking has gained tremendous recognition into international policy and practice. GACC has been at the forefront of strengthening supply, enhancing demand and creating a thriving market to catalyse the adoption of clean and efficient cookstoves and fuels by 100 million households by 2020 (GACC, 2016; Venkata et al., 2015). Similarly, the Sustainable Energy for All (SE4All) global platform that aims to facilitate access to modern energy for all by 2030, acknowledges clean cooking as one of its high impact opportunities (ESMAP, 2012). The World Bank launched in 2010 the Biomass Energy Initiative for Africa (BEIA) to modernize the biomass energy sector and incorporated it into the Bank's lending portfolios. The World Bank also launched in 2012 the Africa Clean Cooking Energy Solutions (ACCES) to develop a market-transformation program to demonstrate enterprise-driven approach to disseminating clean cookstoves, as an effective mechanism to enable scaling up adoption in the SSA (World Bank, 2015; IEA et al.,2015). Among others, these strategic partnerships and initiatives are good indicators of how modern energy is perceived as a bridge to other development priorities such as health, gender equality, equitable economic development, climate change mitigation and environmental protection.

However, despite all these efforts, the adoption of clean cooking options has remained notably slow throughout the continent (Winrock International, 2014.). Kenya is a good example of this situation. While it is among the pioneers of clean cookstove development, marketing and distribution in Africa (World Bank, 2017), only 14% of the Kenyan population has access to clean cooking fuels and technologies (IEA et al., 2019; Wiesmann et a., 2014). Over 85% of its population (7.2 million households) still depend on traditional woody biomass for their energy needs (GoK, 2013; Githiomi and Oduor, 2012; Githiomi et al., 2012.). The majority of these households come from rural and resource-poor settings, and thus face disproportionately problems associated with the use of traditional biomass fuels and inefficient stoves (GACC, 2013).

Considering the above, the main aim of this chapter is to synthesize the current knowledge about the policies, technologies, stakeholders, impacts and factors of adoption of clean cooking interventions in Kenya. The focus is on clean bioenergy cooking options including improved biomass stoves and biogas stoves, as they have attracted extensive attention and they form important part of clean cooking energy provision in Kenya. To the extent possible, for the review of the impacts and the factors of adoption, the focus is on information from peer-reviewed literature specific to Kenya. Where needed this evidence is supplemented with grey literature and/or evidence from other parts of Africa.

Section 1.2 explores the current state of the biomass energy sector for cooking in Kenya, including an overview of the main national energy policies, regulatory frameworks and major government players related to clean bioenergy stoves. Section 1.3 discusses the history and commercialization of clean bioenergy stoves in Kenya, as well as the main stakeholders across the value chain. Section 1.4 summarizes the main impacts of clean bioenergy cookstoves and Section 1.5 outlines the potential factors that drive or impede stove adoption, maintenance and future replacement. Section 1.6 synthesizes the existing knowledge and provides some highlights for policy implications.

1.2 The biomass energy sector in Kenya

1.2.1 Overview of the sector

Biomass constitutes 68% of the final energy use in Kenya (Mugo and Gathui, 2010), and about 98% of energy use in the rural domestic sector (Liyama et al., 2014). About 70% of this biomass energy is derived from wood, mainly in the form of firewood and charcoal for cooking and heating (Karekezi et al., 2004). Biomass energy use in Kenya depends on various socioeconomic and environmental factors, such as income distribution patterns, geographical location, land use and cultural values, norms and practices (Karekezi et al., 2012; Githiomi et al., 2012).

As of 2010, more than 82% of Kenyan households (7.2 million households) were reported to rely on biomass as the main fuel for cooking, with firewood contributing to 68.7% and charcoal to 13.3% of households respectively (Wiesmann et al., 2014; GoK 2015b). Only 1.6 million households use predominately other cooking fuels such as paraffin (11.5%), liquefied petroleum gas (LPG) (5%), and electricity (1%) (Wiesmann et al., 2014; KNBS, 2017). About 87% of total firewood consumption occurs in rural settings and 37% charcoal in the urban settings (Drigo et al., 2015).

Forests, which cover about 7% of the national land area, cater for about 45% of the biomass energy resources (Mahiri and Howorth, 2001; GoK, 2013a), providing for a large fraction of the domestic firewood and charcoal demand. The remainder is derived from farmlands as woody biomass, as well as agricultural residue and animal dung (KEFRI/UNDP, 2016). However, the conventional methods of charcoal production rely on inefficient earth kilns and are a major contributor to deforestation, land degradation, biodiversity loss, and atmospheric emissions (Liyama et al., 2014). Overall, the charcoal industry in Kenya contributes substantially to national economic activity at approximately KES 32 billion (US$ 450million) annually (GoK, 2015b). Charcoal production and trade has been legalized, with regulation and permits handled by the Kenya Forest Service (KFS). However, the management and regulation of the woodfuel industry in Kenya still remains a major challenge due to overlap of mandates among the ministries in the charcoal value chain (Njenga et al., 2018; Johnson et al., 2016).

Due to large discrepancies in supply and demand, Kenya has a large annual wood supply deficit, in the order of 10.3 million m^3 of wood in 2010 (Iiyama et al., 2014). Biomass energy forecasts indicate a 20.0% increase in supply and 21.6% increase in demand by the year 2032, which imply a gradually increasing firewood and charcoal deficit, at 18.3% and 19.1% respectively (Githiomi and Oduor, 2012). The low supply levels have been linked to inadequate management practices, lack of alternative fuels, loss of forest areas to agriculture and human settlements, while the high demand has been linked to a growing population, high dependence on wood, and inefficient processing and utilization technologies (Drigo et al., 2015; GoK, 2015b; Jeffery et al., 2015). The combination of the above have contributed to the degradation of fuelwood stocks and have exerted pressure to agrarian communities, forcing households to utilize animal dung and crop residues for cooking rather than as fertilizers (Mugo, 2014; Johnson et al., 2014; Liyama, et al., 2014). The combination of these effects has further increased the loss of forest and illegal charcoal production (Kituyi et al., 2004; Githiomi and oduor, 2012; I. Mahiri and Howorth, 2001).

It is in this context of increasing biomass fuel demand and decreasing supply that efficient energy cooking options are championed as a means of addressing the deficit of woodfuel supply and demand in Kenya, and its associated negative environmental and socioeconomic impacts (Gok, 2013a; 2015; Birundu, et al., 2017)

1.2.2 Biomass energy policies and main stakeholders

Kenya has a long history of energy planning and programme interventions related to biomass production and use (Owen, et al., 2013; GoK, 2004; UNDP, 2017). Table 1-1 outlines the main recent policies and strategies in energy sector, and their link (or lack of) for promoting clean bioenergy cooking options in the country.

One of the most important recent policies has been the Sessional Paper No 4 of 2004, which articulates the energy policy frameworks to realize economic growth strategies. A key element has been the promotion of cost-effective, affordable and adequate quality energy services, which need to be made available nationally in the period 2004-2023. This policy laid a very solid foundation for household cooking energy, establishing a target to increase the rate of adoption of efficient charcoal stoves to 80% by 2010 and to 100% by 2020 in urban areas (and to 40% by 2010 and 60% by 2020 in rural areas). At the same time, the policy aimed to increase the rate of adoption of efficient firewood stoves to 30% by 2020. Furthermore, there are prescription to (a) offer training opportunities for *Jua Kali* artisans at the village level for the manufacture, installation and maintenance of renewable energy technologies (including efficient cook stoves) and, (b) promote public health education on the appropriate use of biomass fuels (Kituyi et al., 2001)

The Energy Act No 12 of 2006 did not include any provision for the promotion of clean bioenergy cookstoves. However, in 2013, a miscellaneous provision related to Improved Biomass Cookstoves was added into the act through the intervention of the Clean Cookstoves Association of Kenya (CCAK) and for the development of the Sustainable Energy for All Action Agenda (GoK, 2016a). These regulations apply to (a) licensing of manufacturers, importers, distributors, technicians, and contractors of Improved Biomass Cookstoves and institutions using biomass fuels for cooking and heating; (b) providing a warranty to customers, and (c) disposing of stoves following other national environmental laws. The provision has categorically defined improved biomass cookstoves as those that comply with the Kenya Standard KS 1814-1:2005 (GoK, 2013b)

The 2013 National Climate Change Action Plan (NCCAP) estimates that up to 5.6 million tCO_2e (ton CO_2 equivalent) can be saved annually by 2030 through the introduction of improved cookstoves and alternative cooking fuels (GoK, 2017a). The NCCAP formulated the Nationally Appropriate Mitigation Actions (NAMAs), which identify clean cooking as one of its Low Emission Development Strategies (Adkins et al., 2010). In regard to clean bioenergy cookstoves, this NAMA expect that improvements in trade promotion, licensing, poverty reduction and capacity building will be achieved through the implementation of clean cooking manufacturing and distribution centers in the country.

Finally, the Energy Bill, 2015, consolidates a series of laws relating to energy. It aligns the powers and functions of the national and devolved structure of the government for establishing regulatory framework in the energy sector (see Table 1-2 for the main relevant government entities and their stipulated responsibilities). Unlike its predecessors, the Energy Bill of 2015 does not include any provisions to promote clean bioenergy stoves, an element that could strengthen the promotion of clean cooking at local level.

An overarching vision of several of these policies has been to modernize the production, processing, distribution and consumption of energy, and especially biomass energy (Owen et al., 2013; Clough, 2012). This entails various interventions and measures are necessary to facilitate energy transitions, promote enabling conditions, expand sustainable biomass supplies, and capitalize on recent technological advances (O'Keefe and Raskin, 1985; Kituyi, 2004). Perhaps the main driver of promoting the policy aspects related to cooking have been linked to urbanization, which has increased the demand for charcoal in Kenya, and raised concerns over resource degradation and energy insecurity (Ndegwa et al., 2016; Kiplagat et al., 2011; Daley, 2013; GoK, 2013a; 2015b). Other drivers include the accelerated economic growth, income equality and poverty alleviation (Nguu et al., 2011; Githiomi and Oduor, 2012; Owen et al., 2013; UNDP, 2005).

However, the demand-supply imbalance and deficit of biomass energy (see Section 2.1) has greatly hindered the effective implementation of the existing energy policies and legal framework in Kenya (GIZ, 2007). Furthermore, insufficient investment in the biomass energy sector has also been a major constraint due to branding biomass energy as inferior to other energy options such as electricity, which is still unavailable or unaffordable for the majority of Kenyan households (UNEP, 2006).

It is worth mentioning that policy formulation and implementation has, until recently, been solely a responsibility of the government. Key stakeholders in the bioenergy and stove value chains (see also Section 3.3) have had limited participation in creating a conducive policy environment to promote clean bioenergy cooking options (Mugo and Gathui, 2010; Mugo and Ong, 2006; Owen et al., 2013; UNEP, 2006; Karekezi et al., 2004; Kees and Feldmann, 2011; World Bank, 2006). However, the recent Kenyan experience with developing biomass energy strategies indicate that policymakers are either unaware or ignorant about the importance/relevance of traditional biomass use (and possible solutions) besides electricity and fossil fuels (Kappen et al., 2014; Karekezi, 2002). Apart from the role that cooking energy can play for poverty alleviation, it has remained a neglected topic in development interventions and in the formulation of alternative energy policies in Kenya (GoK; 2004), compared to other social challenges such sanitation, malaria and HIV/AIDS. It has been suggested that the adoption of an integrated set of measures that can formalize, and modernize the biomass energy sector, and capitalize on technological innovations could improve the successful of implementation of current energy policies (Van der Kroon et al., 2014; Johnson et al., 2017; Lambe and Senyagwa, 2013).

Table 1-1: Key energy policies in Kenya and their relation to clean cookstoves

Policy/Legislation	Overall aim	Biomass energy	Cookstove intervention	Elements related to cookstove promotion agenda
Sessional Paper No. 4 of 2004 on Energy (GoK, 2004)	Lays the policy framework for cost-effective, affordable and adequate quality energy services on a sustainable basis.	✓	✓	- Mainstream gender issues in energy planning - Initiate programmes aimed at improved stove promotion and education - Increase the efficiency and rate of adoption of charcoal and firewood stoves - Train local stove artisans
Energy Act No. 12 of 2006 (GoK, 2006)	Amends and consolidates the law relating to energy. Provides for the establishment, powers and functions of the regulatory authority.	✓	X	- Promote renewable energy technologies (including biomass) - No mention of energy efficient cookstoves per se
The Kenya Vision 2030 (GoK, 2007)	Outlines the national long-term development blueprint for Kenya.	✓	X	- Planting of at least seven billion trees to enhance food, water and energy security, and restore 10% forest cover
Kenya National Climate Change Response Strategy (2010) (GoK, 2010)	Puts in place measures required to address challenges posed by climate variability and change.	✓	✓	- Catalyse lifestyle and livelihoods interventions, by promoting energy efficient cookstoves - Provide subsidies and tax waivers for poor households to acquire energy efficient stoves
The National Climate Change Action Plan, (NCCAP) 2013-2017 (GoK, 2017a)	Identifies the key priorities for Kenya to successfully achieve a low-carbon, and climate-resilient growth to realize the ambitions of Vision 2030.	✓	✓	- Undertake a programme to support the use of improved biomass cookstoves and LPG cookstoves - Increase awareness of improved cooking practices and stove quality - Undertake pilot initiatives to promote the use of LPG fuel and stoves - Increase access to soft loans, build capacity of stove producers, and improve access to testing facilities.
The Energy (Improved Biomass Cookstoves) Regulations, 2013 *(Miscellaneous provision to Energy Act No. 12 of 2006)* (GoK, 2014b)	Provides regulations for manufacturers, importers, distributors, technicians and contractors of improved biomass cookstoves.	✓	✓	- Establish requirements for improved biomass stove entities in the value chain in terms of licensing, standards, warranty and disposal
National Energy and Petroleum Policy, 2015 (GoK, 2015d)	Ensures affordable, competitive, sustainable and reliable supply of energy to meet the national and county development needs, while protecting the environment.	✓	✓	- Acknowledges that kerosene stoves cause indoor air pollution - Incentivize consumers to switch to clean household energy options
The Energy Bill of 2015 (GoK 2015a)	Consolidates laws relating to energy, to provide for National and County Government functions in relation to energy. Provides for the establishment, powers and functions of the major energy sector entities.	✓	X	- - N/A

Table 1-2: Main government actors in the energy sector and their functions under Energy Bill of 2015

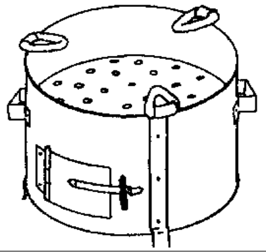
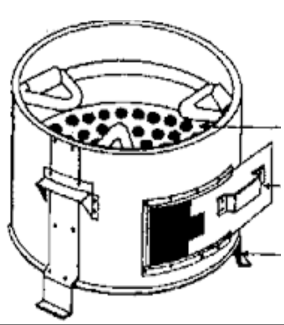
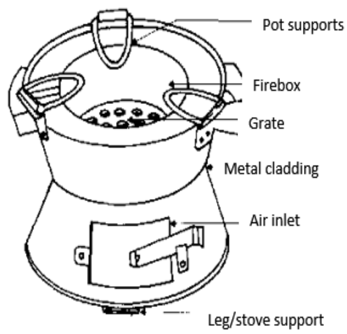
Entity	Key responsibilities
Ministry of Energy	– Develop an enabling environment for investors and protect consumers – Enforce regulations and standards – Create awareness for the efficient use of energy, and energy conservation
County Government Ministries of Energy	– Develop energy plans and policies to meet national energy needs – Regulate and license renewable energy systems, and charcoal production and distribution – Establish energy centers for the promotion of renewable energy technologies
Energy Regulatory Commission (ERC)	– Regulate the production, conversion, distribution, marketing and use of renewable energy – Ensure the import of efficient and cost-effective energy appliances and equipment – Formulate, enforce and review environmental, health, safety and quality standards
Energy Tribunal	– Quasi-judicial body in the energy sector
Rural Electrification and Renewable Energy Corporation	– Develop, disseminate and promote renewable energy and technologies – Build local capacity for the manufacture, installation, maintenance and operation of renewable energy technologies
Energy and Petroleum Institute	– Undertake research, development and dissemination activities in the energy sector – Promote local production of renewable energy technologies – Create awareness and disseminate information on the conservation and efficient use of energy
Centre for Energy Efficiency and Conservation (CEEC)	– Implement energy efficiency and conservation programmes nationally
Kenya Climate Innovation Centre (KCIC)	– Provide support to climate technology innovators through business incubation, seed financing, specialized policy interventions, network linkages and business training

1.2.3 Commercialization of clean bioenergy cooking technologies in Kenya

1.2.3.1 Improved and energy-efficient biomass stoves

Improved and energy-efficient stoves are designed to increase fuel efficiency by 25-60% and reduce indoor air pollution to achieve health benefits relative to the traditional three-stone fire (Hyman, 1987; Kinyanjui and Childers, 1983; Westhoff, 1995). The first improved cookstoves appeared in Kenya in the 1900s and since then, multiple other designs have been promoted making Kenya a pioneer in establishing energy-efficient biomass cookstoves as summarized in Tables 1-3 and 1-4 (see Appendix 4 for stove images' copyright permissions)

Table 1-3: Evolution of improved biomass stoves

Year of Inception	**Stove name**	**Technological description** (Cr: Hyman, 1985, 1987; Karekezi, 1995)	**Stove images** (credit: Weshoff, 1995)
1900s	Traditional *jiko* design	– Introduced by Indian railroad laborers – A charcoal stove made of scrap metal and assembled by local tinsmiths on a cottage industry scale. – Uninsulated hence radiating heat radially and to the pot. – Retailed at KES. 35-45 – At full use, a traditional jiko lasts about a year, but its metal grate needed replacement after three months at a cost of KES. 10.	
1981	*Umeme* (power) Stove	– Promoted by UNICEF – An all-metal, double-walled, charcoal stove with an insulating layer between the two walls – Weighs about 6.5 kg. Has a high fuel efficiency due to the enclosed combustion chamber, good convective transfer of heat to the inserted pot, insulated chamber walls and regulated airflow. – Remains hot for a long time, cooks fast, and is durable, while the large firebox diameter provides stability. – Retailed at KES. 97-125 at a production cost of KES. 60 per unit	
1982	Kenya Ceramic *Jiko* (KCJ)	– Funded by USAID and implemented by the Ministry of Energy – Portable and designed to cook one pot at a time. – The ceramic lining reduces heat loss from lateral radiation and increase stove durability – Has a door for draught control and perforated grate for ash collection beneath, three hinged triangular-shaped flaps to hold one cooking pot, stove legs for support and a handle. – Retailed at KES. 125- 250 at a production cost of KES. 100 per unit	

In the early 1980s, there were accelerated efforts to promote efficient cooking devices due to the expected changes in population, household size, urbanization, incomes and predicted increases in charcoal consumptions (Hyman, 1987; Karekezi, 1995). By then, the sustainability challenge of charcoal stoves was a result of charcoal scarcity in the rainy season that interfered with charcoal production in outdoor earth pits or kilns, while at the same time the agricultural labour requirements are at their peak (Hyman, 1987; Namuye 1989; Opole, 1988)

In the late 1900s, the Kenyan Ceramic *Jiko* (KCJ) was designed through a collaboration between donors, local ceramists and metal working artisans (Karekezi and Kithyoma, 2002). The efforts to promote this stove type were driven largely by GIZ in partnership with the Ministry of Agriculture, Practical Action and the Ministry of Energy. Inspired by the Thai bucket stove, the KCJ is among the most successfully commercialized improved stoves through the efforts of various public and private sector (Hyman, 1986; Barnes et al.,1994).

In 1985, about 125,000 KCJ stoves were disseminated in Nairobi and other urban areas (Barnes et al., 1994; Hyman, 1985; Kinyanjui and Childers, 1983; Hyman, 1987; Namuye,1989). The success of the implementing the program was as a result of training of local artisans, provision of working capital assistance, demonstrations and marketing to raise awareness (UNDP, 2009). The KCJ stove was reportedly successful because it incorporated the design and features of the traditional stove and it allowed the evolution of the stove through extensive field-tests and continuous design modification.

Today, the KCJ stove is very popular in Kenya where it is used in over 50% of urban and 16% of rural households and has spread to neighbouring African countries such as Uganda, Rwanda, Ethiopia, Malawi, Niger, Senegal, and Sudan (GIZ, 2007). However, due to its mass production in the informal sector, there have been challenges in enforcing manufacturing standards to ensure efficiency since the local artisans tend to change the design and use inferior stove liners (Karekezi and Turyareeba, 1995; Kammen, 1994; Karekezi et al., 2012; Urmee and Gyamfi, 2014)

In the late 1990s to early 2000s, efforts to promote improved biomass stoves accelerated. The common goal was to enhance commercialization through programmatic support for the sustained production and dissemination of stoves (Winrock International, 2014). This was accomplished through the provision of incentives for the production of stoves for groups and local artisans using locally available materials and, focus on women empowerment and creation of local employment (UNFCCC, 2017)

From the late 2000s upto the present, carbon finance and private investments have become prominent in the Kenyan stove sector for both firewood and charcoal stoves. This has been accompanied with the massive manufacturing and importation of stoves. The ability to earn revenues through the carbon markets also attracted a number of large international actors, increasing the financial capacity of the sector (UNDP, 2017). Driven by climate change mitigation and adaptation efforts, the Clean Development Mechanism (CDM) and the Gold Standard carbon market programs have massively influenced the adoption of clean cooking in Kenya by reducing the cost of high-quality stoves in Kenya. As of 2017, carbon finance is relatively advanced in Kenya with eight (8) cookstove Programmes of Activities (PoA) already registered under several carbon project developers active in the market (GoK, 2016). The stove projects claim emission reductions between 2.4 to 3.0 tCO_2/y per stove (Silk et al., 2012). Despite the uncertainties in the carbon market, this trend is likely to increase by developing innovative financing mechanism, capacity building and scaling up carbon finance opportunities e.g. the Green Climate Fund to support adaptation and mitigation actions within the country (GIZ, 2017).

Within the current market regime, there has been significant technological improvements in the design and operational characteristics of cooking stoves. Most of these new designs have been tested in laboratories for thermal efficiency and reportedly consume less fuelwood, emit less smoke and soot, and are safer and more convenient to use (GACC, 2014). In 2006, GIZ launched the Energizing Development programme to increase access to modern energy for households, social institutions and small and medium-sized enterprises. By mid-2016, approximately 5 million people had been commercially served with modern cooking energy with an aim to reach 6.2 million people by mid-2018 (GACC, 2014). Other imported stoves like Envirofit models and Jiko Poa have been introduced into the market with high uptake especially in the urban and peri-urban areas. Table 1-4 summarizes some of the most popular improved cookstove options currently available in Kenya.

Table 1-4: Common designs for Improved Biomass Stoves in Kenya

Stove name	Implementing entity	Technology description	Stove image
Jiko Kisasa	GIZ (EnDev-Kenya)	- Fixed stove with a combustion liner made from clay. - Designed to work with firewood, crop waste and other biomass materials can be used. - Fuel is fed through a single opening at the front of the stove. - The stove does not have a chimney, can reportedly produce less smoke than an open fire - Can reportedly use 40% less firewood compared to the traditional three-stone stove	
Jikokoa	Burn Manufacturing Ltd	- Mobile stove designed in the USA and manufactured in Kenya. - Has a fuel efficiency of 48% and can reportedly achieve60% smoke reduction - Its design incorporates a high-efficiency combustion chamber, light-weight ceramic insulation and insulated handles and has an ashtray designed to collect ashes and for draught control	
Envirofit Rocket wood stove	Envirofit International Ltd	- A highly engineered wood stove and manufactured in China. - The dimensions of the stove's internal combustion chamber encourage the mixing of gases and flames above the fuel, which results to cleaner and more complete burn. - It is composed of an outer iron steel part, and an inside ceramic liner made of high-quality clay material. - Results of performance tests of the stove reportedly show a thermal efficiency of 24.3%.	

Fixed Brick Rocket Stove	GIZ (EnDev-Kenya)	- The wood stove made entirely from ceramics based on the rocket stove principle (burning small pieces of wood in a high temperature combustion chamber) - The design of the pot rest allows allow the generated heat to reach the cooking pot. - It reportedly has a thermal efficiency of 24-32% and can achieve 30% smoke reduction compared to the three-stone stove	

Note: Photo credits to the respective stove implementing entities (see Appendix 4 for copyright permissions)

1.2.3.2 Biogas stoves

Biogas is produced through the anaerobic fermentation of biomass, animal slurries and other organic waste (Mengistu et al., 2015). It contains 50-70% methane, 30-50% carbon dioxide (depending on the substrate input) (Nzila et al., 2012). Biogas is increasingly becoming popular in Kenya for empowerment of small-scale dairy farmers in the rural communities to produce clean fuel and enriched organic fertilizer from the bio-slurry (Laichena, 1989; Ngigi, 2009). The Kenya Standard (2520:2013) was developed to establish parameters to ensure that biogas stoves and digesters installed in Kenya are efficient, safe and durable (GoK, 2013b)

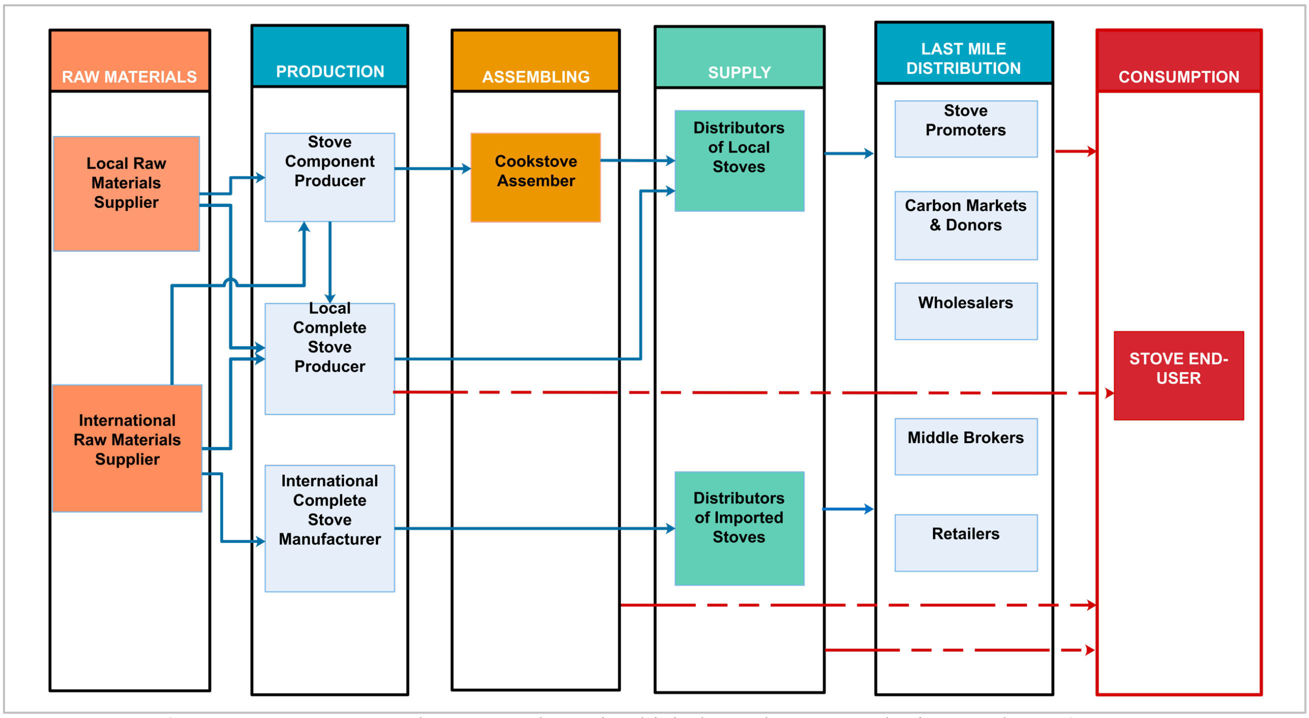
Historically, Kenya was among the first countries in Africa to adopt biogas technology in the early 1950's, and by 1986 there were about 200 installed biogas plants with less than 25% of these were operational (Ghimire, 2009). Over the years, the uptake remained low until the Kenya National Domestic Biogas Programme (KENDBIP) was rolled out in 2009 under the framework of Africa Biogas Partnership Programme (ABPP) (Ngigi, 2009). Within the first phase (2009-2013), the programme constructed 11,529 bio-digesters and programme provided an investment subsidy to reduce upfront cos, with each biogas plant allocated a subsidy at a flat rate of KES 25,000. During Phase 1 (2009- 2013) 11,529 plants were constructed. Phase 2 (2014–2017) aims to install 27,500 digesters, without household subsidies (UNFCCC, 2012).

In parallel to the KENDIP programme, there are private, and carbon financed investments in the biogas sector promoting different designs such as the floating dome digester, fixed dome type, tubular/balloon type etc. (Mwirigi et al., 2014; Nzila et al., 2012; Sovacool et al., 2015). Among the most successful CDM projects in Kenya is the Nairobi River Basin Biogas Project, which aims to construct by 2020, about 10,000 domestic biogas digesters (of 2-3m³ capacity) for rural households, with a minimum of two zero grazing cows, in Kiambu county (KNBS, 2017). Reportedly, about 30% of units of the installed biogas systems may not be operational due to poor design and construction, low end-user awareness on system management and poor water supply (Kangmin, 2006).

1.3 Clean bioenergy cookstove value chain and related stakeholders in Kenya

The clean bioenergy cookstove value chain in Kenya entails different stages, namely raw material extraction, production and assembly of stoves, distribution and retail of stoves, and final consumption (GVEP, 2012). Due to the various technological options (see Section 1.2.3), various stakeholders are relevant to clean bioenergy cookstoves in Kenya (Table 1-5).

These include a series of stakeholders directly involved with the development and delivery of cookstoves to final consumers (Figure 1-1) from them, there is a plethora of other stakeholders with vested interest in clean bioenergy cookstoves (Table 1-5) that are not directly integrated in the cookstove value chain. These include stakeholders such a government institution, NGOs, research organization, donors and international organizations. While these organizations are rarely involved in the actual delivery of cookstoves, they are very important for the overall successful integration of clean bioenergy cookstoves. Table 1-5 includes an overview of the activities and direct roles in the clean bioenergy cookstoves value chain.



(Key: — · · — · ▶ Other routes through which the end user can obtain a cookstove)

Figure 1-1: Simplified value chain of clean bioenergy cookstoves (adapted from (UNDP, 2012)

Table 1-5: Important stakeholders in the clean bioenergy cookstove value chain in Kenya

Stakeholder groups	Individual stakeholders	Role in the clean cookstove value chain
Private Sector	Cookstove manufacturers such as Burn Manufacturing Ltd, Afrisol Ltd, Sustainable Energy Strategies Ltd., Flexi biogas, Envirofit, Cookswell Jikos, Moto Poa Ltd.	– Design, manufacture and distribute of clean and efficient cookstoves including improved biomass stoves, biogas, ethanol, and biomass gasifiers, among others
	PayGo Energy Ltd	– Improve product-market fit by selling LPG in small quantities through a product service platform that uses smart metering and a pay-as-you-go approach
	Equity Bank Ltd	– Provide financing towards the acquisition of clean cookstoves for their customers – Offers the *Ecomoto* loan, an initiative that employs flexible processing and repayment modalities
	Local Artisans (individuals and groups)	– This diverse stakeholder group includes clusters of informal metalworking artisans that are active near marketplaces and either sell directly to end-users or work with last-mile distributors.
	Women Producer Groups	– This diverse stakeholder group includes various women groups that develop networks to assist the production, sales and promotion of stoves as local ceramicists, marketers and installers. – Groups such as the Keyo Pottery Women's Group in Western Kenya have built and sold stoves since the 1980s.
Carbon Market Developers	Various ventures such as Impact Carbon, My Climate, Carbon Africa Limited, Climate Care	– Generate a market for carbon offsets through the dissemination of clean cooking technologies – Register projects in the UNFCCC Clean Development Mechanisms, Gold Standard and other voluntary markets
Government	Ministry of Energy	– Formulate energy policy and regulate the energy sector – Provide technology adoption incentives, e.g. through the KENDBIP Biogas program
	Kenya Bureau of Standards	– Design and maintain the stove standards for locally manufactured and imported stove products – Develop test methods and protocols for biomass and biogas cookstoves
Non-Governmental Organizations	The Clean Cookstove Association in Kenya (CCAK)	– Facilitate business capacity development and advocacy for clean cooking policy formulation, public awareness and behaviour change
	Global Alliance of Clean Cookstoves (regional secretariat is based in Nairobi, Kenya)	– Accelerate the production, deployment, and use of clean and efficient cookstoves and fuels – Offers funding, research, social and logistical support, and economic feasibility assessments
	W-Power programme	– Formulate a cohesive and targeted advocacy agenda to strengthen women involvement in clean energy access and entrepreneurship
	Various NGOs such as Energy 4 Impact; Kenya Climate Innovation Center, Practical Action, Winrock International	– Support a range of innovative projects, initiatives and business models – Provide financial/technical assistance, resources and facilities to innovators to realise their ideas, develop management and business skills, and grow their businesses
	The University of Nairobi	– Provide market intelligence and test the efficacy of the stoves being introduced in the market

Academia and Research institutes	African Centre for Technology Studies	
	Kenya Industrial Research and Development Institute (KIRDI) Stove Testing Center	– Research, design and develop energy efficient technologies – Champion the growth of biofuels and other renewable energies pathways
	Kenya Forest Research Institute	– Carry out research on woodfuel characterization (charcoal and firewood) and biomass gasification – Influence policies on forest resource management
	Stockholm Environment Institute (SEI) World Agroforestry Center (ICRAF)	– Conduct research and implement projects related environmental and development challenges, including energy access and sustainable biomass production
Donors and International Development Organizations	GIZ-EnDev Programme	– Develop energy markets to foster the diffusion of renewable energies and technologies to households, social institutions and businesses.
	SNV Netherlands Development Organization	– Collaborate with local partners to facilitate market creation and development of clean cooking technologies and fuels.
	Hivos International	– Partner with government, local organizations and entrepreneurs to promote market-based clean cookstoves and domestic biogas – Employ carbon finance to support this incentive, and offer a guarantee system to protect end-users against faulty construction
	The International Fund for Agricultural Development (IFAD)	– Support labor-saving technologies and innovations that reduce rural women's workload, including improved biomass stoves and biogas technologies
	The United States Agency for International Development (USAID)	– Develop the clean cookstove sector through projects that strengthen the business operations of cookstove enterprises and encourage private sector participation; – Work with financial institutions to increase private-sector finance available to consumers that seek to purchase cookstoves and enterprises involved in the cookstove supply chain
	United Nations Development Programmme (UNDP)	– Supports business incubators to promote entrepreneurship in renewable energy technologies – In 2012, partnered with Project Gaia and Practical Action in piloting bioethanol in Nyanza province of Kenya to test its viability and stimulate demand for it in households in rural areas and humanitarian settings (Mugo, F. and Gathui, 2010)
Stove users	Various individual stove users (e.g. households, restaurants, food vendors) and institutional users (e.g. schools, hospitals)	– They are end user of various stove technologies – Different factors can affect decisions over stove adoption and sustained use (see Section 5)

1.4 Impacts of clean bioenergy cookstoves

1.4.1 Enhance household energy security and reduce energy poverty[1]

In the year 2000, fuelwood supplied 89% of Kenya's rural energy demand (annual per capita consumption of 741 kg) and 7% of urban household energy demand (annual per capita annual consumption of 691 kg) (Mugo, 2016). However, biomass stocks in Kenya are declining (Section 1.2.1). Hence there are substantial concerns about the ramifications of increasing fuelwood scarcity on the (primarily poor) households that over rely on fuelwood and charcoal for cooking (Egeru et al., 2014; Scheid, 2018; Gutta, 2014)

At the same time clean biomass stoves tend to be more efficient, requiring less fuel to achieve the same cooking outcomes compared to traditional biomass stoves. In fact, improving the thermal energy efficiency of cookstoves has been advocated as a means of reducing excessive fuelwood use through the delivery of improved energy services that that have high energy savings (Bailis et al., 2007; Bailis and Edwards, 2007; GoK, 2013a; Smith et al., 2015). Various lab-based water-boiling tests and field-based kitchen performance tests have determined stove efficiency and fuel savings from improved biomass stoves in Kenya, reporting, fuelwood consumption savings of between 25-60% (depending on stove characteristics) compared to traditional three-stone stoves (Agea and Okia, 2010; Anenberg et al., 2013; Egeru et al., 2014). In addition, similar studies have determined that access to cleaner cooking options can have substantial time savings from time-consuming activities such as fuelwood collection and cooking with inefficient stoves (on average 4-6 hours a day for a family) (Beltramo, et al., 2015; Abadi et al., 2017).

Thus, the adoption of clean cooking stoves has been advocated as a means of improving the energy security of the (predominately poor) households that depend on traditional biomass stoves (Adeoti et al., 2001; Sikei et al., 2009). Depending on the technology, the adoption of clean biomass stoves can reduce (e.g. improved biomass stoves) or eliminate totally (e.g. biogas stoves) fuelwood use (Table -6). This can reduce household vulnerability to fuel scarcity that can manifest for example through escalating fuel prices (Daurella and Foster, 2009) or increased time needed to harvest fuelwood (e.g. travelling longer distances) (Egeru et al., 2014; Mahiri, 2003; Sikei et al., 2009).

When it comes to monetary costs, the savings from procuring fuel (Adeoti et al.,2014; Kammen and Kirubi, 2008; Katrak, 2009) can be diverted to meet other basic household needs, which can be especially beneficial for low-income households that reportedly spend about 15% of their income on fuel (Hammond and Kemausuor, 2009). However, the cost of procuring and maintaining the stove needs to be considered, as it might be a very

[1] The term 'energy poverty' encapsulates the multiple problems that arise from the inadequate access to energy source. This entails a variety of economic, social equity, education, health concerns and other sustainability aspects as will be discussed in the following sections below.

large upfront cost for poor households to assume (Rhodes et al., 2014; Surendra et al., 2014). The save time can be invested to pursue other livelihood and educational activities (Section 1.4.4-1.4.5), especially for women and girls (Section 1.4.7).

1.4.2 Reduce environmental impacts

By reducing the amount of charcoal/fuelwood use or switching to a totally different fuel (Section 1.4.1), clean bioenergy cooking options can reduce impact on the environment (Table 1-6). For example, inefficient biomass stoves require the extensive use of firewood and charcoal sourced or produced from different ecosystem types such as forests and woodlands. The unsustainable harvesting of fuelwood (for direct use, or charcoal production) often degrades such ecosystems, having adverse environmental impacts (Bailis et al., 2015). For example, fuelwood extraction and charcoal production are major drivers of deforestation and land degradation in Africa (Fontodji et al., 2011; Naughton et al., 2007) and Kenya in particular (Kiruki et al., 2017; Ruuska, 2013). Land use and cover change due to fuelwood harvesting and charcoal production can reduce species habitat contributing to biodiversity loss (Lattimore et al., 2009) At the same time, it can affect multiple other ecosystem processes and services such as watershed functions, carbon storage (Anenberg et al., 2013a; Kiplagat et al., 2011; Kiruki, et al., 2017; Ministry of Environment, 2013; Tinsae Bahru, 2012; Zschauer, 2012) and soil fertility/health (Robert Bailis et al., 2015a), among several others. Several studies have pointed to the benefits that a switch to cleaner bioenergy cooking alternatives can have on ecosystems, and their multiple functions and services (Gerst et al., 2015; Jeuland and Pattanayak, 2012; UNEP, 2017; WLPG and UNDP, 2003).

The combustion of conventional biomass in inefficient stoves can also emit large amounts of greenhouse gases (GHG) that affect the global climate estimated at 1.0-1.2 Gt CO_2e yr-1 (or 1.9-2.3% of global emissions) (Drigo et al., 2015). On the contrary clean cooking options have generally lower GHG emissions due to the different fuel or higher efficiency (Dresen et al., 2014; Masera et al., 2010; Lee et al., 2013; Smith et al., 2000). Studies have found that switches to biomass-efficient cooking options can have substantial GHG emission savings in the order of 1-3 tCO_2eyr^{-1} per stove Some clean bioenergy cooking options, such as biogas, can capture and use methane (CH_4), a potent GHG, and substitute chemical fertilizers, reducing thus direct and indirect GHG emissions (Ezzati et al., 2000; Foote et al., 2013a; Ochieng et al., 2013).

1.4.3 Reduce risks to health and safety

The inefficient combustion of biomass in traditional biomass stoves can emit large amounts of indoor air pollutants such as fine particulate matter (e.g. $PM_{2.5}$), carbon monoxide (CO) and nitrogen oxides (NO_x) (Kumari et al., 2016; Person et al., 2012). The exposure to such indoor air pollutants is particularly high among women, girls and young children, who spend the most time in the (often poorly ventilated) kitchen (WHO, 2014; Dohoo et al., 2013; Ezzati and Kammen, 2002a; Njenga et al., 2016). In 2012, it was estimated that about 4.3 million premature deaths (600,000 in Africa, 14,300 in Kenya) occur each year due to indoor air pollution, largely from cooking with traditional biomass fuels (Olopade et al., 2017; Pope et al., 2010). Some of the reported health complications of cooking with solid biomass fuels and inefficient stoves include respiratory diseases, chronic obstructive pulmonary disease, eye irritation, cataract formation, headaches and burns (Dherani et al., 2008; Foote et al., 2013). Additionally, indoor air pollution from cooking with solid fuels has been linked to adverse pregnancy outcomes such as stillbirth, child survival, low birth weight (Dohoo et al., 2013), as well as pneumonia risks in children under the age of five years (Anenberg et al., 2013b; Ezzati and Kammen, 2002; Foote, et al., 2013; Rosenthal et al., 2017; WHO et al., 2016).

The promotion and sustained use of clean bioenergy cookstoves has been proposed as an option to reduce indoor air pollution, and its associated respiratory infections (Balakrishnan et al., 2014). For example, improved stoves can reduce the emission of CO and PM2.5 (Dohoo et al., 2013; Foote et al., 2013). For example, a typical $PM_{2.5}$ exposure of 300 μg/m^3 is assumed for traditional stoves and 70 μg/m^3 for clean stoves, based on the wide range of observed concentrations (Chafe et al., 2015; Pilishvili et al., 2016; Pope et al., 2017). Studies have found that a switch from conventional cooking options to clean cooking options can have substantial health benefits. (Abadi et al., 2017; Dohoo et al., 2013; Njenga et al.,2000). To achieve maximum benefits, it has been recommended to prioritize community-wide use of clean fuels to achieve WHO's air quality guidelines limits for carbon monoxide and PM2.5 emissions (Edwards et al., 2014; Pope et al., 2017)

It should be noted that fuelwood collection often entails walking long distances and carrying heavy loads on the back or head, which enhance the possibility of injuries and other adverse health effects (Dohoo et al., 2013; Lambe et al., 2015; Njenga et al. 2013). Especially for women and young girls, venturing long distances to collect fuelwood increases their vulnerability to harassment, safety risks and other forms of violence (AFDB, 2016). Clean bioenergy stoves that have lower fuel requirement reduce to a large extent the frequency and the time spent for fuelwood collection, hence reducing drudgery and associated health effects such as back pains (Kammen and Kirubi, 2008).

1.4.4 Improve livelihoods

Local employment and income opportunities can be generated along the clean bioenergy stove value chain (Section 1.3.3), related to stove design, manufacturing, marketing, distribution and sales (GIZ, 2017; Ghimire et al., 2009; Mengistu et al., 2015; Nzila et al., 2012). Some of these jobs are high-skilled and can provide sufficient income to ensure a decent livelihood (Abadi et al., 2017). For example, in 2016, GIZ reported to have created about 1000 jobs in different private enterprises in Kenya, related to stove production (Karekezi et al., 2012; Owen et al., 2013). Other clean bioenergy cooking options such as biogas can generate employment and income opportunities outside the stove value chain (see Section 1.3.3), for example for masons, plumbers, and civil engineers that build the biogas infrastructure (FAO, 2017; Smith et al., 2017).

However, it should be mentioned that the fuelwood and charcoal sector is a major source of livelihoods for rural communities in Africa (GoK, 2015b; GIZ,2014), and Kenya in particular. Approximately 200-350 jobs are generated across the charcoal value chain per TJ of energy consumed (Openshaw, 2010), while commercial biomass energy employ about 13 million people in Sub-Saharan Africa (Wagura and Nyangena, 2011.). Fuelwood and charcoal production accounts for a large proportion of the informal economy in Kenya, with about 635,000 people involved (GoK, 2015b), adding an estimated US$1.6 billion per year in the national economy (Anderson, 2015; Ghimire et al., 2009; GIZ, 2017). However, the reliance on imported stoves can curb the reported business creation and employment generation potential (marketers, stove installers and local producers) in African countries (Stephen Karekezi et al., 2012; Openshaw, 2010; Owen et al., 2013; Simon et al., Laurent, 2014; WHO et al., 2016) and job/income opportunities in the fuelwood and charcoal value chains. It is highly possible that important livelihood trade-offs might occur when promoting clean and improved cooking options that need to be considered in such promotion efforts.

1.4.5 Enhance educational opportunities

As discussed above, traditional biomass and energy inefficient stoves require more time for fuel collection and cooking. These tasks are often bore by young children, especially girls, whose time could have otherwise been spent attending school or doing homework (Kituyi et al., 2011). Similarly, overburdened parents often keep children from going to school in order to assist with fuelwood collection and cooking (Ndiritu and Nyangena, 2011). Clean bioenergy cookstoves can reduce the time needed for such activities, thus offering a real opportunity to enhance educational outcomes, especially in rural contexts (Musungu et al., 2014). Furthermore, clean bioenergy cooking options can free parents time for household care work such as for example preparing breakfast for their children attending school (Bizzarri et al., 2010; Musungu et al., 2014).

Furthermore, clean and improved cooking options can offer several advantages for educational institutions. In Kenya, schools reportedly spend about USD 128-148 per month on firewood to cook school meals (depending on number of children and location of the school) (Kappen et al., 2014). The availability of clean and energy-efficient cookstoves in schools can help children receive properly cooked meals on time (Kituyi and Kirubi, 2003; Moronge and Maina, 2015), while relieving financial pressure on school budget. This can have multiple benefits both for school attendance (e.g. school meals can incentivize poor families to send children at school) (Kafayat and Abraham, 2014), as well as possibly improve educational services by relieving school budget constraints (Giovenuti et al., 2016; Person et al., 2012; Sola et al., 2016.

1.4.6 Enhance food security

The unsustainable collection of wood for fuel and charcoal production can contribute to loss of watershed functions, land degradation and desertification (Thorlakson and Neufeldt, 2012) (see also Section 1.4.2), which place further pressures on agricultural systems in Africa. Loss of agroecological functions due to fuelwood extraction and charcoal production can curb agricultural productivity in some African contexts (Kituyi and Kirubi, 2003), being a possibly important driver of food insecurity in some contexts (Sola et al., 2016).

Furthermore, the overexploitation of forests and woodlands for fuelwood and charcoal can lead to fuelwood scarcity (Section 1.4.1). There are reported links between fuelwood scarcity and cooking habits, such as not boiling water enough, eating half-cooked food, and cook food items with low nutritional value that require less cooking time (Anderman et al., 2015). On the other hand, some studies have reported higher diet diversity and nutritional quality for households with clean bioenergy cookstoves (Dohoo et al., 2013; Orskov, 2014; UNHCR, 2017). This is because the cooking temperature can be easily regulated to cook meals that were previously avoided due to their time-consuming preparation, sensitivity to heat, or high risk of spoilage (Dohoo et al., 2013). Similarly, households can in theory invest the saved money and time from using a clean bioenergy stove (see Section 1.4.1) to improve their access to more nutritious food varieties and adopt better food preparation practices (Sola et al., 2016). However, there is no clear empirical evidence for the mechanisms and magnitude of such effects.

Finally, some clean bioenergy cooking options can have indirect positive effects to food production. For example, households with biogas systems can use the bio-slurry as an organic fertilizer to boost food productivity and crop diversity (Mbuthi et al., 2007). Furthermore, studies have found that households producing sugarcane for ethanol have better access to fertilizers due to their involvement in out-grower schemes, which has positive outcomes on food crop productivity and food security (Herrmann et al., 2018).

1.4.7 Empower women and promote gender equity

As outlined above, some of the negative health and educational outcomes of traditional cooking options are gender-differentiated, with females being disproportionately affected (Section 1.4.3 and 1.4.5). In particular women and girls often bear disproportionately, the tasks of gathering fuelwood and cooking. For example in Kenya, women reportedly spend at least 1 hour per day gathering fuelwood for cooking (Musungu et al., 2014), which reduces their available time to pursue other activities such as education or employment. Furthermore women and girls face disproportionately higher exposure to indoor air pollution due to cooking (Shankar and

Onyura, 2014), and face higher health/safety risks due to fuelwood collection (Miller and Mobarak, 2013). This high time investment in unpaid household work and exposure to indoor air pollution can have substantial negative health outcomes for females, and curb their education and/or economic opportunities (Assmann et al., 2006; Cecelski, 2000; Dutta, 2005; Miller and Mobarak, 2013; Shankar et al., 2015; UNDP, 2009)

Clean cookstoves value chains can also provide opportunities for women to engage in entrepreneurial activities related to stove design and distribution (Choumert et al., 2017; Shankar et al., 2015) (Section 1.3). Deeper engagement of females in such activities can not only promote gender empowerment (Gunning, 2014), but also enhance the adoption and effective and sustained use of the stoves considering that women are the main stove users (Lehne et al., 2016) (see Section 1.5).

1.4.8 Humanitarian impact

Globally, more than 65 million people had been displaced from their homes due to conflict, war and natural disasters according to 2016 statistics (Bellanca, 2014). Refugees are particularly vulnerable groups, living in very difficult conditions and often in conflict with surrounding communities. Most refugee camps have very limited access to reliable forms of energy, and almost all lack clean cookstoves and fuels (Giovenuti et al., 2016; Lehne et al., 2015). While the vast majority of food is distributed by humanitarian organizations, cooking fuel is rarely provided. This accentuates all the impacts described above.

The Moving Energy Initiative estimates that more than 26,000 ha of forest are lost each year to meet the energy needs of displaced families living in camps (Githiomi and Oduor, 2012; Nyambane, et al., 2014; Sikei et al., 2009). This further enhances the probability of conflict with the host communities due to competition over the often-limited local biomass resources (Gitau, 2011). There are also various reported fuel scarcity coping mechanisms employed in refugee settings including skipping or undercooking meals, food bartering and selling for cooking fuel (Giovenuti et al., 2016). Gender-differentiated effects are particularly prevalent in such humanitarian contexts as adult female and young girls, who are disproportionately tasked with cooking and fuelwood collection tasks, risk physical and sexual attack, dehydration, physical injuries and walking long distances to fetch for firewood to cook food (Anenberg et al., 2013; Barbieri et al., 2017; Kiplagat et al., 2011; Njuru, et al., 2017; Thulstrup and Henry, 2015)

Dissemination and sustained use of clean biomass cookstoves in humanitarian settings can serve as a powerful humanitarian and development mechanism (Bailis et al., 2003; Ezzati et al., 2000; Whitman et al., 2011). For Instance, the GIZ-EnDev programme spearheaded production and distribution of *mandeleo* fuelwood stoves in Dadaab refugee camp (Gitau, 2011)

Table 1-6: Impacts of clean bioenergy cooking options

Impact categories	Selected impact mechanisms	Kenya References	Other References
Energy Security	– Reduce household vulnerability to fuelwood scarcity by reducing or eliminating the need for fuelwood/charcoal – Provide economic savings from fuel procurement, which can be invested for other household needs	(Abadi et al., 2017; Bailis et al., 2007; Bailis and Edwards, 2007; Beltramo et al., 2015; Mahiri, 2003; GoK, 2013a; Kammen and Kirubi, 2008;)	(Adeoti et al., 2001; Agea et al., 2010; Anenberg et al., 2013a; Daurella AND Foster, 2009; Debbi et al., 2014; Egeru et al., 2014; Guta, 2014; Halff et al.,2014.; Katrak, 2009; Kumar et al., 2016; Rhodes et al., 2014; Waris and Antahal, 2014)
Environment	– Reduce deforestation and habitat loss (and the associated loss of biodiversity and the degradation of ecosystem services) by reducing demand for fuelwood and charcoal – Reduce carbon stock loss and greenhouse gas emissions by reducing demand for fuelwood and charcoal – Biogas system capture methane reducing GHG emissions – Bio-slurry from biogas systems reduces the demand of chemical fertilizers, indirectly reducing GHG emissions	(Anenberg et al., 2013a; Dohoo, Ezzati et al., 2000; Foote et al., 2013a; Mengistu et al., 2015; Nzila et al., 2012; Ochieng et al., 2013; Sovacool et al., 2015)	(Dohoo, VanLeeuwen, et al., 2013; Ezzati et al., 2000; Guernsey, et al., 2013)
Health and Safety	– Reduce negative health effects related to indoor air pollution (e.g. respiratory diseases, post-pregnancy complication, stillbirths, pneumonia risk) by reducing the emissions of indoor air pollutant through the more efficient combustion of biomass (in improved biomass stoves) or use of clean fuels (e.g. biogas, ethanol), – Reduce the risk of burns, scalds and safety risks associated with solid fuel combustion in open-fire traditional stoves – Improve kitchen hygiene and home ventilation due to lower smoke emissions	(Ezzati and Kammen, 2002a; Foote et al., 2013a; Njenga et al., 2016; Lambe et al., 2015)	(Dohoo et al., 2013; Olopade et al., 2017; Person et al., 2012; Pope et al., 2017; Pope et al., 2010; Puzzolo et al., 2014)
	– Reduce negative health effects (e.g. back pains, injuries) associated with fuelwood collection – Reduce vulnerability to safety risks (e.g. violence, rape) associated with fuelwood collection	(Dohoo et al., 2013; Karekezi et al., 2012b; Njenga et al., 2016;)	(GIZ, 2017; AFDB, 2016; World Bank, 2006)

Livelihoods	– Offer opportunities for income generating activities and local employment across the value chain – Cause employment loss in the charcoal and fuelwood sector	(Abadi et al., 2017; Kammen and Kirubi, 2008; Mengistu et al., 2015)	(Wagura and Nyangena 2011; WHO et al., 2016)
Education	– Enhance school attendance by reducing the workload placed on children (and especially girls) for fuelwood collection – Relieve budget pressure on schools, with the savings invested for improving educational services	(Dohoo et al., 2013; Kituyi and Kirubi, 2003)	(Person et al., 2012)
Food Security	– Prevent crop productivity decline due to the loss of ecosystem functions, by reducing pressure on ecosystems (see above) – Enhance crop productivity by using the bio-slurry generated from household biogas systems as an organic fertilizer – Promote diet transitions and improved food nutrition through improved cooking practices	(Porras et al., 2015; Sola et al., 2016; Mbuthi et al., 2007; Shankar and Onyura, 2015; Kituyi et al., 2011)	(World Bank, 2014; Anderman et al., 2015; Recha et al., 2016; Orskov et al.,2014; Giovenuti et al., 2016)
Women Empowerment	– Reduce burden on women and girls from fuel collection and exposure to indoor air pollution, to rest, pursue an education or engage in income-generating activities – Offer opportunities for women to engage in entrepreneurial activities and employment along the stove value chain	(Dohoo et al., 2013; Kappen et al., 2014; Miller and Mobarak, 2013; Shankar et al., 2015)	(Barbieri et al., 2017; Ghimire et al., 2009; Giovenuti et al., 2016; Gunning, 2014; Lehne et al., 2016; Miller and Mobarak, 2013; Owen et al., 2015; UNDP, 2009; UNHCR, 2017)
Humanitarian	– Reduce the multiple vulnerabilities that displaced communities experience – Prevent/reduce conflicts with local host communities over limited biomass resources	(Lehne et al., 2016; Musungu et al., 2014; Ndiritu and Nyangena, 2011;)	(Bellanca, 2014; Bizzarri et al., 2010; Nerini 2017; Giovenuti et al., 2016; Lahn et al., 2016. Puzzolo et al., 2014)

1.5 Factors influencing stove adoption in Kenya

1.5.1 Conceptual framework

Switching to clean and energy-efficient cooking interventions depends on a set of factors that collectively affect stove acceptance, initial uptake, sustained use, maintenance and future replacement. Previous systematic reviews have identified various relevant factors related to stove characteristics, household characteristics, and the policy environment, among several others (Debbi et al., 2014; Puzzolo et al., 2016; Rehfuess et al., 2014; Van der Kroon et al., 2014). The framework developed by Puzzollo et al., 2016 was populated using literature from Kenya across the following domains to be discussed in Section 1.5.2-1.5.7:

- Fuel and technology characteristics,
- Intra-household and household setting characteristics,
- Knowledge and perceptions,
- Financial and subsidy aspects,
- Market development,
- Regulation, legislation and standards,
- Programmatic and policy mechanisms.

1.5.2 Fuel and cookstove characteristics

As already discussed, clean bioenergy stoves tend to require lower amounts of fuelwood (or even nullify the need for fuelwood), offering substantial monetary and time saving (Section 1.4.1). Costs play an important role on the adoption and sustained use of stoves as several studies have shown in Africa (Nerini, 2017; GACC, 2014; Mwirigi et al., 2014; Ochieng et al., 2013) and Kenya in particular (Zschauer, 2012). Lower expected operational costs or monetary savings (actual or expected) often contribute substantially on decisions to uptake improved bioenergy stove, especially for households that mainly buy fuel from markets (Kammen et al., 2001; Malla et al., 2011; Ndegwa et al., 2011; Van der Kroon et al., 2014). On the other hand, fuel/cost savings are not regarded as an important factor of stove adoption for households that obtain their fuel largely for free or at low costs, due to, for example, their proximity to forests (Dohoo et al., 2013; Sesan, 2012; Van der Kroon et al., 2014). Additionally, for households that invest substantial time in the collection of fuelwood, the expected time savings can influence the adoption of stoves that consume less fuelwood and cook faster (Njenga et al., 2016). Reportedly, where fuelwood and labour are abundant, the opportunity costs of time spent on cooking or fuel collection may not be considered as important in decision making for stove adoption (Rhodes et al., 2014). However, the high capital cost of clean bioenergy stoves, such as biogas, and the need to maintain it can be substantial barriers for the adoption of stoves for poor households (Sovacool et al., 2015; Surendra et al., 2014).

Stove characteristics can also be an important factor affecting stove adoption. For example, when the material and design of a stove allows for the improved heat transfer, energy efficiency and simultaneous cooking of different dishes on multiple potholes, can result in substantial cooking time savings (Lambe and Senyagwa, 2013; Murphy, 2001). In addition, stove designs that meet user needs and allow the preparation of local dishes with traditional cooking utensils are often desirable (Nzila et al., 2012; Sovacool et al., 2015). However, stove designs that fail to accommodate specific cooking styles, types of fuel, and available resources for maintenance and renovation can prohibit stove adoption and sustained use (Wilson, 2007).

Biogas systems are a prime example of how these factors interact to influence stove adoption. On the one hand the technology offers a good return on investment as it can reportedly offer substantial monetary saving related to fuel purchase, about USD 0.40/m^3 biogas compared to fuelwood (Nzila et al., 2012). While the installation/capital costs are very high for poor households (Hamid and Blanchard, 2018; Sovacool et al., 2015; Wilson, 2007), the operating costs are often very minimal for household that have ready access to waste or animal dung for feedstock (e.g. livestock owners) (Henriques and Schnorr, 2010; Van der Kroon et al., 2014). Biogas systems are reportedly marred with technical and operational difficulties (Porras et al., 2015; Sesan, 2012). Proper user-training, reliable local support and post-acquisition support is essential to both highlight the technology as well as to ensure the sustained use (Malla et al., 2011; Van Der Kroon et al., 2011).

1.5.3 Household characteristics and setting

Household characteristics such as income, education, size and gender dynamics can influence substantially the decision to adopt clean bioenergy stoves. For example, household income can be a particularly important determinant of initial stove uptake (Henriques and Schnorr, 2010; Sovacool et al., 2015). This is especially crucial when moving up the energy ladder, whereby as the quality of stove increases the upfront cost increases. (Fraser et al., 2006; Mwirigi et al., 2014; Nguu et al., 2011; Nzila et al., 2012; Osiolo, 2017; Van der Kroon et al., 2014). Other household characteristics such as education level are often related to knowledge and awareness on the perceived benefits of clean cooking (Fraser et al., 2006; Ochieng et al., 2013; Osiolo, 2017; Porras et al., 2015).

Household size also affects stove adoption, as for example, large households where fuelwood collection and cooking tasks are shared among members can assign a lower value to the time and labor needs to perform these tasks, thus having a low incentive to adopt clean bioenergy stoves (Schlag and Zuzarte, 2008). Intra-household gender dynamics are also crucial for stove adoption in households where women cannot either make independent or consensual decisions on household budget allocation stove purchase might not be prioritized over other household needs (Mwirigi et al., 2014).

Other studies highlight that home ownership, especially of a permanent dwelling, may increase the willingness to invest in home improvements, including the acquisition of built-in stoves with chimneys (Nzila et al., 2012; Van der Kroon et al., 2014). For some technologies, such as biogas systems, there is the added need of a spacious compound, reliable land tenure, and ownership of at least 2-3 cows to provide a sustained source of fuel (Johnson et al., 2016; Lambe and Senyagwa, 2015; Loo et al., 2016; Rhodes et al., 2014).

1.5.4 Knowledge and perceptions

Several studies in Kenya have highlighted the lack of awareness on either the available cooking alternatives and stove options, or the consequences of cooking with traditional and inefficient stoves (Barnes et al., 2015; Beltramo et al., 2015; Johnson, Lambe, et al., 2016; Silk et al., 2012). Enhancing public awareness and sensitize the public about the benefits of clean cooking (including health, safety, hygiene and environmental benefits) is critical in spurring the widespread adoption of clean bioenergy cooking options (Karekezi et al., 2009; Mutua and Kimuyu, 2015).

Recent studies on consumer behaviour and stove choices indicate that strongly focusing on health and climate messages does not influence substantially the adoption if the stove cost is not affordable (Beltramo et al., 2015; Clough, 2012; Evans et al., 2017; Goodwin et al., 2015; Shankar et al., 2014). In such situations, it is recommended that messages that reflect time and money savings are more likely to boost the willingness to pay for clean bioenergy stoves options (Vulturius and Wanjiru, 2017).

Social relations combined with behaviour change techniques can influence the diffusion and adoption of clean cookstoves by creating a social multiplier effect amongst peers (Beltramo et al., 2015; Murphy, 2001; Rhodes et al., 2014; Sesan, 2014; Shankar et al., 2014; Treiber et al., 2015). However, social networks and peer influence can have either a positive or negative effect on stove adoption depending on the actual experience of the influencer (Rehfuess et al., 2014).

Traditional practices and beliefs can also enable (or act as a barrier to) stove adoption. For example, adopting a clean cookstove can be hindered in cultural contexts where stove users use smoke as an insect-repellent, black soot for medicinal purposes or generally like the smoky taste of food (Lambe et al., 2015; Rhodes et al., 2014).

1.5.5 Financial and Subsidy Aspects

Subsidies and cost/price incentives can highly influence the initial acquisition of clean bioenergy stoves, especially if stoves are expensive or the potential users experience liquidity constraints (Abadi et al., 2017; Bazilian et al., 2012; Sovacool et al., 2015). However, it has been suggested that large subsidies can have a negative effect on the perceived stove value, constant maintenance and future replacements (Nguu et al., 2011).

It is recommended to consider a targeted version of offering subsidies such as upstream in the value chain e.g. research, manufacturing and distribution except for the low-income users (Johnson et al., 2016; Lambe et al., 2015). In a similar fashion, the need for additional cost of stove installation and maintenance especially for stoves prone to breakdown and that require regular technical maintenance may impede uptake and/or sustained use (Silk et al., 2012). The availability of consumer finance through microcredit/loans interventions, instalment payments, price incentives and promotional offers is essential to address high upfront costs (GIZ, 2017). On the other hand, short payback periods and high interest rates for microcredits and loans are reported to be a significant barrier to uptake of the loan for a clean cookstove especially for resource poor households (Johnson et al., 2016; Mutua and Kimuyu, 2015; Treiber et al., 2015).

1.5.6 Market Development

Well-developed consumer market strategies and reliable supply chains can contribute positively to the adoption of clean stoves. This is because market development increases marketing efficiency, distribution and sustained adoption of clean cookstoves (Henry Rotich, 2016). For bulky stoves and those prone to break down, poor road infrastructure can have an impact on the distribution, accessibility, availability and pricing of stoves that are not locally produced (GoK, 2013a). To avoid such problems, GIZ-Kenya, for instance, has trained local stove dealers and artisans to improve the local accessibility, installation, maintenance and replacement of the clean biomass stoves. These dealers also play an important role in raising local awareness and consumer education (Nerini, 2017).

1.5.7 Programmatic and Policy Mechanisms

The clean cooking programs ought to align their goals with the broader energy policies in the country (see Section 1.2). Through such coordinated efforts clean cookstoves can be mainstreamed in existing and future policies, thus creating a conducive policy environment that can facilitate the widespread promotion and adoption of clean cookstoves (Mbuthi et al., 2007; UNEP, 2006). The Government of Kenya has made several efforts to integrate cookstoves in energy policies, but not always in a coordinated manner (Section 1.2.2). One of the more recent efforts include incentives to attract investments for scaling-up access to clean cooking, including the exemption of value added tax (VAT) on LPG in 2016. In addition, the Government announced a reduction of the import duty on efficient cookstoves from 25% to 10% (GoK, 2017). However, there are still significant steps that need to be taken to integrate more meaningfully cookstoves in current energy policies (Section 1.6). For example, there is a need to link cookstoves with broader rural development programs and policies, as well as promote efforts to foster community involvement, for example to reflect better the perceptions of users to identify suitable stove designs.

1.5.8 Regulation and Standardization

Given the very diverse designs of clean bioenergy stoves that are available in Kenya (Section 1.2.3), it is important to ensure the quality and the performance of the marketed and disseminated stoves. This is both to ensure the protection and trust of the customers (Lambe et al., 2015), and ensure that proper incentives and market access is given to stove manufacturers depending on stove performance (Atteridge and Weitz, 2017; Silk et al., 2012).

The Kenya Bureau of Standards (KEBS) developed household stove standards in 2005 to ensure the quality of stoves introduced in the market. However, these standards currently address thermal efficiency, durability and the testing approach, but not the emissions of indoor air pollutants (Mudombi et al., 2018). On the other hand, several stove-testing facilities exist at academic institutions such as the University of Nairobi and the stove testing center facility at the *Kenya Industrial Research and Development Institute* (KIRDI). However, many local stove producers have limited access to these facilities due to their high cost (Bailis et al., 2007). Currently, enforcement mechanisms or penalties for non-compliance with the existing stove standards are yet to be formulated.

Table 1-7: Domain and factors of adoption of clean bioenergy stoves in Kenya (domains adapted from Puzzollo et al., 2016).

Domain/factor of adoption	Cited references
1. Knowledge and perceptions	
Health impacts of indoor pollution	Mwirigi et al., 2014; Ochieng et al., 2013; Fraser et al., 2006; Lambe and Senyagwa,2015; Johnson et al., 2016; Beltramo et al., 2015; Loo et al., 2016; Yonemitsu et al., 2014
Consumer research on stove design	Mutua and Kimuyu, 2015;
Perceptions from previous projects/programmes	NA
Cost of fuel collection e.g. time/energy;	Mugo and Gathui, 2010; Mahiri, 2003; Person et al., 2012; Ndiritu and Nyangena, 2011
Perspectives of international donor organizations	Pachauri and Rao, 2013; Van der Kroon et al., 2014; Mwirigi et al., 2014; Ochieng et al., 2013; Fraser et al., 2006; Karekezi et al., 2008; Mutua and Kimuyu, 2015;
2. Fuel technology characteristics	
Choice of newer more efficient stoves	Sovacool et al., 2015;
Choice of wide range of technologies	
Pilot programmes to assess performance in practice	Foote et al., 2013b; Loo et al., 2016;Joubert and Begovic, 2012; Lambe et al., 2015;
Quality and safety standards	Wang and Corson, 2015;
3. Financial, tax and subsidy mechanisms	
New finances linked to climate change monies	Sammut et al., 2015; Harvey et al., 2014; Kees and Feldmann, 2011;
Lessons from finance models used in small scale energy projects	NA
Role of financial institutions in administering funds	Silk et al., 2012; Muok and Kingiri, 2015
Private sector involvement	Beltramo et al., 2015;Freeman and Zerriffi, 2015
Option of spreading cost of stoves over time.	Silk et al., 2012; GIZ, 2017; Johnson et al., 2016;
Impact of short-term financing	NA
Government grants	NA
Impact of financial model used	Foote et al., 2013; Opole, 1988;Abadi et al., 2017; Bazilian et al., 2012; Sovacool et al., 2015;
Technical assistance to support cookstove manufacturers	Porras et al., 2015
Indirect subsidies e.g. stove design/promotion, capacity development;	Simon et al., 2014; Nguu et al., 2011; Lambe, Jürisoo, Lee, et al., 2015;Mwirigi et al., 2014;

4. Regulation and legislation	
Cookstove standards	NA
Quality control	Rosenbaum et al., 2015; Takama et al., 2012; Yonemitsu et al., 2014;
Role of national institutions	Johnson et al., 2016
5. Market development	
Use of consumer research and feedback	Loo et al., 2016; Wang and Corson, 2015;
Addressing issues of perceived performance and availability	Shankar et al., 2015;Kees and Feldmann, 2011;
Views of women	Zschauer, 2012;
Role of private sector	Malla et al., 2011;
Impact of household characteristics;	Van Der Kroon et al., 2011 and 2014; Ndiritu and Nyangena, 2011;Pachauri and Rao, 2013; Mwirigi et al., 2014; Ochieng et al., 2013; Fraser et al., 2006; P. Sola et al., 2017;
Desirability, affordability, convenience	Johnson et al., 2016;
Tension of cost vs sophistication	
6. Programmatic and policy mechanisms	
Evidence of multi-sectoral approaches e.g., energy, gender, health, forestry, climate	Porras et al., 2015
User training	Johnson et al., 2016;Beltramo et al., 2015;
Use of specific systems	Foote et al., 2013; Shankar et al., 2015;
Use of local artisans vs. benefits of mass production	Atteridge and Weitz, 2017;
Capacity building	Ray et al., 2014; Schlag and Zuzarte, 2008;
Role of national coordinating agencies	NA

Note: NA denotes that the factors could not be identified from relevant literature from Kenya

1.6 Knowledge synthesis

Section 1.5 outlined the very diverse factors that influence the initial uptake and sustained use of clean bioenergy cookstoves in Kenya. Some factors play a more critical role to catalyze the initial household decision to uptake/adopt the stove, while other factors play a more important role in maintaining the stove condition, consistent use it and future replacement. These factors create a complex web of social, economic, cultural, technical, organizational and individual factors. Figure 1-2 illustrates the main linkages between these factors in the context of Kenya as they emanate from this literature review.

From the demand-side (i.e. user-side), the review indicates that besides the awareness and willingness to uptake a "better" cooking stove, affordability is a key determinant for the initial uptake. Affordability can be related to the socioeconomic status (i.e. purchasing power) of the household or the availability of subsidies and economic incentives. However, the factors that motivate stove purchase, may not necessarily motivate the ultimate adoption.

Sustained adoption can depend more critically on the stove technology characteristics and design, and as an extension on the benefits accruing from these. As already mentioned in Section 1.2.3, there are very different clean bioenergy stove designs in Kenya, which have different characteristics related to fuel, time and monetary investment, smoke emission and ability to meet various of cultural requirement related to food taste and ability to cook multiple meals (see Section 1.4.).

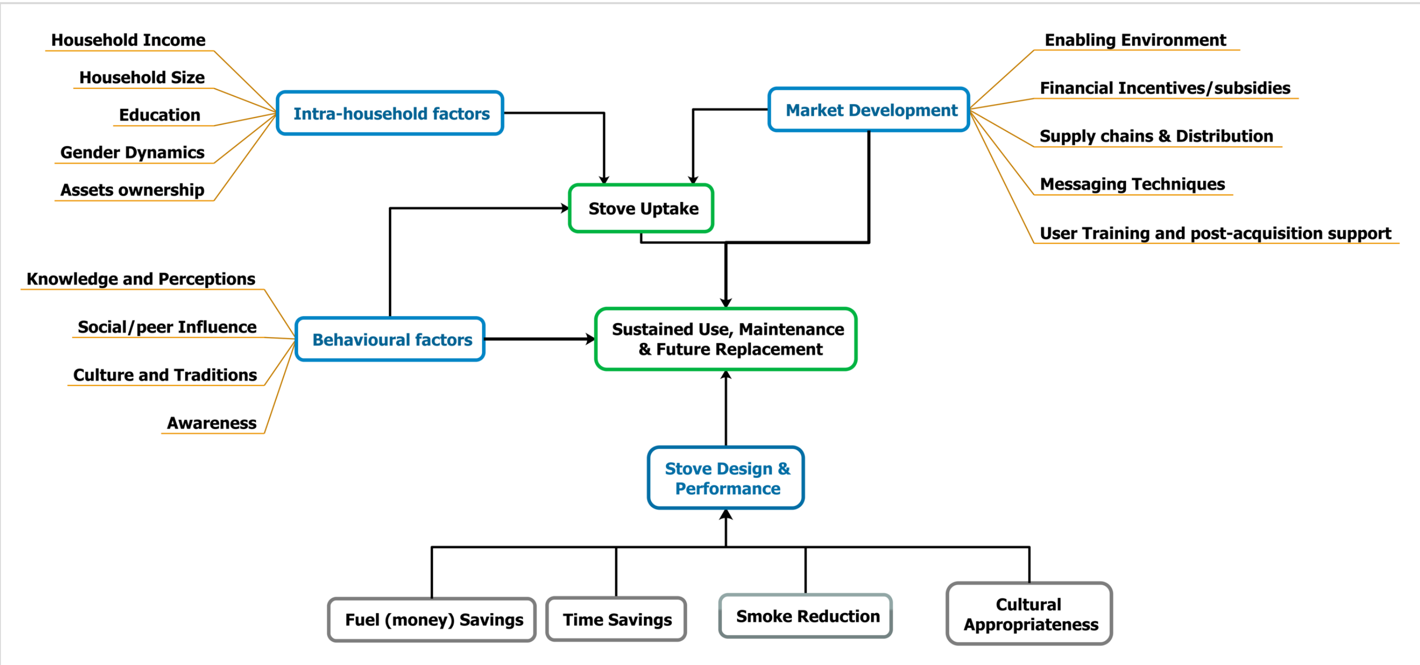


Figure 1-2: Linkages and interactions between the different factors of stove adoption in Kenya (source: Karanja and Gasparatos, 2019)

From the supply-side, the review illustrates that stakeholders involved in stove, promotion and dissemination can influence stove adoption by influencing the market in terms of accessibility, availability and affordability of stoves. This can be achieved through effective supply chain management, user engagement, demand creation and provision of appropriate financial incentives and subsidies. That said, stove dissemination programmes and sales campaigns ought to provide the right mechanisms to ensure readily available support for the maintenance and future replacement of stoves.

Economic incentives such as reduced taxes and import duties can create an enabling environment for investments in clean cooking interventions and facilitate the diffusion of clean cooking technologies at affordable prices (Section 1.5.5 and 1.5.8). It is important to keep in mind that the values held by stove programs and promoters (e.g. health improvement, climate change mitigation, ecosystem conservation) may resonate strongly with the factors that influence households to adopt the different stoves. Stove promotion programs must engage the targeted stove users and local communities, particularly women, in the design of stoves to ensure that the stove attributes and features resonate to their needs, expectations and values.

Similarly, stove adoption and sustained use can have a series of positive impacts related to household energy security (Section 1.4.1), ecosystem conservation (Section 1.4.2), human health (Section 1.4.3), livelihoods (Section 1.4.4), education (Section 1.4.5), and food security (Section 1.4.6). Some of these impacts are gender-differentiated so the adoption of clean bioenergy cookstoves can provide an important impetus to female empowerment and gender equality (Section 1.4.7). Furthermore, clean bioenergy cookstoves can have substantial benefits in humanitarian settings, reducing the multiple vulnerabilities that displaced groups face (Section 1.4.8). However, some negative effects might also manifest due to the loss of local livelihoods (Section 1.4.4). These trade-offs must be considered in stove dissemination strategies in order to minimize to the extent possible the negative trade-offs of clean bioenergy cookstove adoption.

It is worth mentioning that the type, magnitude and mechanism of the impacts of clean bioenergy cookstoves can depend substantially on several factors such as the technology, use patterns, the socioeconomic, environmental and cultural context within which the stoves are promoted, and the institutions that govern stove/fuel development, dissemination and use. It is important to understand the effect of these factors to inform the development and implementation of clean bioenergy stove activities that aim to maximize the positive impacts of clean bioenergy stove adoption.

Overall the existing research on the impacts and adoption of clean bioenergy stove is highly fragmented. There is an urgent need to study issues of adoption and impacts in a more integrated manner. The main research deficit is anchored in the the lack of systematized quantitative empirical data on the real-life performance of the modern cooking solutions, and the lack conceptual frameworks at the interface between clean bioenergy cookstoves, health, livelihoods, gender, environment and consumer values and preferences.

1.7 Summary

This Chapter has provided a comprehensive outlook on the state of the clean cooking sector in Kenya, and especially of clean bioenergy stoves. It has established a case that clean bioenergy cookstoves can provide multiple solutions in the face of the rising demand-supply imbalance of biomass energy in the country. The Chapter has showcased that extending access to clean cooking is pivotal in unlocking progress and delivering impacts across multiple sustainability domains ranging from women empowerment, health saving lives, improving livelihoods, and protecting the environment.

The Chapter identifies that a wide range of factors affect the adoption and sustained use of clean bioenergy cooking options in Kenya, including market structure, consumer awareness, stove design/quality, and the socioeconomic status and cultural practices of stove users. Nonetheless, all these factors are interlinked and have varying degrees of importance depending on the context. However, the deeper understanding of the interaction between the factors that influence adoption and the impacts of stove adoption can provide a solid evidence basis for the development of policies and strategies to promote clean bioenergy cooking options in Kenya.

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CHAPTER 2

RESEARCH GAPS, AIMS AND STRUCTURE

2.1 Introduction

There has been a long discussion about how to transition to a modern and reliable energy system in Sub-Sahara Africa (SSA) (Jansen and Rutz, 2012; Simon et al., 2015). Often, national debates have focused on electrification, national grid development and the appropriate mix of fuels for power generation (Owen et al, 2013; UNEP, 2016). While progress in up-scaling adoption of clean cooking options has been painfully slow in SSA, evidence from a number of countries such as Senegal and Ghana suggest that accelerated change is possible (UNEP, 2003; Karimu 2015; GLPGP 2017).

Paradoxically, while Kenya is among the pioneers of clean cookstove development, marketing and distribution in Africa (World Bank, 2017), only 14% of the Kenyan population has access to clean cooking fuels and technologies (IEA et al., 2019). The majority of these households relying on traditional bioenergy come from rural and resource-poor settings, and thus face disproportionately problems associated with the use of traditional biomass fuels and inefficient stoves (GACC, 2013, KNBS, 2017). However, there is a broad consensus that replacing (or at least reducing the demand for) traditional biomass and increasing demand for clean and efficient cooking options could have multiple benefits (Section 1.4).

In this respect, the clean cooking sector is evolving rapidly in Kenya, with a myriad of technological options available to consumers (Section 1.2). The strong policy push to promote clean cooking is evident in the target of the Kenya Country Action Plan for 5 million households and institutions to adopt clean cooking practices by 2020 and universal access by 2030 (GoK, 2016a). However, despite this progress, the existing research about the impacts and adoption patterns of clean bioenergy stoves is limited and highly fragmented (Section 1.6; Karanja and Gasparatos, 2019).

2.2 Research gaps

To begin with, the major knowledge gaps in the existing literature revolve around lack of systematized quantitative data on the performance of new cooking solutions (IEA et al., 2019), and lack conceptual frameworks at the interface between clean bioenergy cookstoves, health, livelihoods, gender, environment and consumer values and preferences (section 1.4). Second, is the lack of market and consumer intelligence by international stove manufacturers and across the clean cookstove value chain, which is often highlighted as the biggest technical constraint in quest for development of socio-culturally appropriate stove prototypes (GACC, 2016; WHO, 2016, ESMAP, 2013). This is attributable to the limited evidence-based insights about local capabilities, consumer needs, values and stove preferences (Lambe et al, 2015; Rhodes et al., 2014; Simon et al., 2014; Yonemitsu et al., 2014)

Section 1.3 demonstrates that there exist many different stakeholders operating in Kenya's clean cooking sector, in what often appears to be a crammed space. Often, these stakeholders hold radically different perceptions about how to enhance promotion and adoption of clean cookstoves and improve the sustainability of the sector. This result in uncoordinated and fragmented actions, which curtail effective large-scale adoption of clean cooking options in the country (Karanja and Gasparatos 2019; Johnson et al., 2016). At least to the author's knowledge, there is no study that elicits the perspectives and insights from multiple stakeholders about stove promotion, adoption dynamics and requisite approaches to enable scaling up access to clean cooking in Kenya.

In order to promote policies and programs to enable scaling up stove adoption and long-term use, the inherent bottlenecks and enablers at the household level must be understood (IEA et al., 2019; IEA, 2016). Although some studies have attempted to assess the factors influencing adoption of clean cooking technologies (Tigabu 2017; Okuthe and Akotsi, 2010; Mwirigi et al., 2009), they remain highly fragmented and limited in terms of scope (see 1.5.3-1.5.4). In addition, several studies have asserted that women bear disproportionately, the burden pertinent to household cooking system (Karlsson, 2012; Blackden and Wodon, 2006; UNDP, 2017). However, there is a lack of in-depth studies to elicit and identify gendered constraints affecting stove adoption and sustained use.

In Section 1.2, the study has identified that there exists a myriad of highly engineered, efficient and aesthetically-pleasing clean cooking options (both domestic and imported). However, their large-scale uptake in Kenya has been slow and complex (IEA et al., 2018). When it comes to household stove choice behavior, the existing studies (albeit few) often focus on demographic and socioeconomic characteristics such as income, age, gender and education (Osiolo, 2009; van der Kroon et al., 2014; Yonemitsu et al., 2014) but the role of stove-specific features has received limited attention. The fundamental scholarship is that stove-specific attributes can be easily revamped within a relatively short time to develop an appropriate stove design that resonate to targeted user culture, needs and preferences (Takama et al., 2012; Tamire et al., 2018). In addition, whereas geographical variations have been cited as key determinants contributing to choices of cooking technologies (van der Kroon, 2014; Drigo et al., 2015), the nature and magnitude of its contribution remain obscure in the existing literature.

Finally, although availability of fuelwood is often perceived to be sufficient at global and national scales (Smeets et al., 2007; Openshaw, 2011), some previous studies report that unsustainable woodfuel harvesting causes pressures on a local scale (Drigo et al., 2015, Arnold et al., 2006). However, there are limited studies eliciting about the dynamics and ramifications of fuelwood scarcity pertinent to household procurement and consumption patterns. In addition, there exist an expectation that adoption of clean bioenergy cooking options can help address fuelwood supply deficit and the associated negative socio-economic and environmental impacts (GoK, 2013a; Birundu, 2017). Most of current studies focus on single (or a limited subset of) impacts of adoption, location and stove types. There is a call for more comprehensive quantitative studies to fully understand the sustainability challenges of traditional bioenergy (Drigo et al., 2015; Arnold et al., 2016; IEA et al., 2018).

2.3 Research aims and objectives

In order to address the inherent knowledge gaps identified in Section 2.2, this study assesses the factors of adoption and the impacts of clean bioenergy cooking interventions in Kenya and propose policies that could enable scaling up their adoption. The specific focus is on the dynamics between traditional and modern (i.e. biogas, improved biomass stoves) cooking options in rural settings of the Murang'a and Kiambu counties. The specific objectives include to:

a) identify the drivers, challenges and perceived impacts of clean cooking interventions in Kenya through expert interviews;
b) elicit user preferences and trade-offs inherent to stove choice behavior using household surveys and choice experiments;
c) identify and asses the impacts of cooking energy technologies through a mixed-method approach;
d) suggest policy and practice options to influence sustainable transition pathways for achieving universal access to clean cooking in Kenya.

2.4 Study significance

2.4.1 Academic significance

The originality of this study is entrenched in the use of a "biomass gradient" transect technique and a holistic multi-impact assessment approach (Chapter 6). The transect concept (see Section 3.2.2.2) was employed in order to establish a comparative outlook between different geographical locations by proximity to resources (i.e. distance from the state forest and urban center). In addition, the study utilizes multiple-methods and analytical techniques to holistically identify the inherent enablers and bottlenecks in household stove adoption, preferences and choice behavior patterns (Chapter 5). Through multiple stakeholder perception analysis approach (Chapter 4), this study is able to identify convergences and divergences of the highly fragmented stakeholders' perception in order to establish a consensus about key priority areas to target in stove promotion.

In quest to address most of the issues raised in the above paragraphs, the study involves more critically the voices of users and local communities. For example, participatory ethnographic research approaches to elicit some of the socio-cultural factors that might affect stove adoption and impacts. The use of such research-based evidence garnered from multiple approaches could enhance the relevance of empirical research to policymakers and the different stakeholders involved in clean stove value chains.

2.4.2 Policy and practice relevance

For Kenya, clean cooking is steadily gaining some traction in national policy and its key international commitments for climate change. The outcomes of this study could enrich current debates about how to facilitate the wide adoption of clean cooking options that are usually informed by rigorous, yet highly compartmentalized research. The study considers this information drawn from multiple methods crucial for both policy makers in the government and practitioners including stove producers, promoters and stove programme developers.

From a policy perspective, the study bridges the interface between clean cooking technologies and the wider sustainability transitions as it cuts across several SDGs. Section 1.4. makes a case that adoption and sustained use of clean cooking solutions is not only an energy security (SDG7) imperative but it is also central in catalyzing towards achieving other sustainable development goals pertaining to poverty alleviation (SDG1), health (SDG3), gender (SDG5), climate action (SDG13) and ecosystem conservation (SDG15), among others.

2.5 Dissertation structure

This dissertation covers four main aspects (see Figure 2-1): (a) how stoves are ***promoted*** (objective 1, Chapter 4) informed by a multi-stakeholder perception analysis; (b) how stoves are ***adopted*** by analyzing factors affecting adoption of clean bioenergy stove and trade-offs inherent to stove choice behaviors (objective 2, Chapter 5); (c) the socio-economic and environmental ***impacts*** adoption of improved biomass stoves and biogas (objective 3, Chapter 6); and (d) policy and practice-relevant ***implications*** informed by a comprehensive synthesis of main findings from objectives 1, 2 and 3 (Chapter 7).

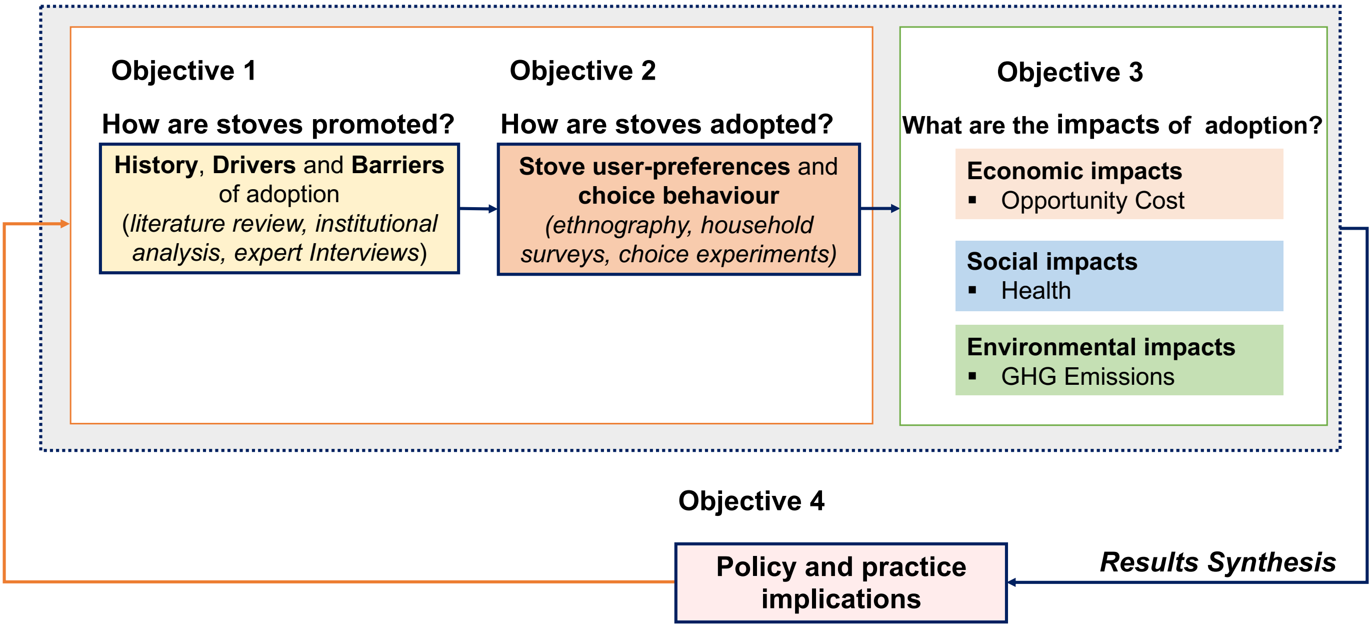


Figure 2-1: Research scope schematic diagram

Chapter 1 synthesizes the current knowledge about the policies, technologies, stakeholders, impacts and factors of adoption of clean cooking interventions in Kenya. The focus is on clean bioenergy cooking options including improved biomass stoves and biogas stoves, as they have attracted extensive attention and they form important part of clean cooking energy provision in Kenya.

Chapter 2 provides information about the key research gaps in existing literature. It then presents the aim of the study and specific objectives to fill the identified knowledge gaps. The academic significance and policy relevance of the study is discussed.

Chapter 3 provides detailed information about the methodological approaches used to address the objectives of this research as identified in Chapter 2. In particular, the research approach followed in the study is outlined including data collection methods, site selection, sampling techniques and data analysis are discussed in detail.

Chapter 4 elicits the perspectives and insights from the main stakeholders involved in the Kenyan stove sector about the adoption (drivers and barriers), perceived impacts and requisite approaches to enable scaling-up access to clean cooking in Kenya. The study outlines the convergences and divergences in perceptions established through semi-structured interviews with 28 stakeholders that play a major role in the clean cooking sector.

Chapter 5 is discussed in four main phases. In the first part, a probit regression of the hypothesized variables is conducted to identify their varying applicability, relative importance and significance levels. The second part presents results from path analysis aimed to establish the direct, indirect and total effects of productive resources on stove adoption. The third part provide results from choice experiment detailing how trade-offs are made in stove preferences based on stove-specific attributes. The fourth component involves mapping of ethnographic narratives about stove users' perception about enablers and barriers affecting stove acquisition and sustained use.

Chapter 6 present results from the sustainability impacts assessment. In particular, the chapter highlights the identified fuelwood sourcing patterns and the estimated quantities of household fuelwood consumption. From the multi-impact assessment, the discussed aspects include environmental impacts (GHG emissions), economic impacts (opportunity costs of unpaid time use and monetary expenditure) and social (health) impacts.

Chapter 7 presents a holistic synthesis of main findings derived from Chapter 1 – 6. The Chapter then provide policy/practice-relevant finding and implications to enable scaling-up adoption and promotion efforts of clean cookstoves in Kenya.

CHAPTER 3

METHODOLOGY

The aim of this Chapter is to provide detailed information about the methodological approaches used to address the objectives of this research (see Chapter 2). Section 3.1 describes the research approach for the study. Section 3.2 presents data collection methods, site selection and the sampling techniques. Section 3.3 outlines the data analysis approaches as used in this study.

3.1 Research approach

3.1.1 Sustainability science approach

In this study, the sustainability science methodological approach was adopted to allow for a comprehensive conceptualization of multi-stakeholder perceptions (how stoves are promoted, Chapter 4), stove choice behavior (how stoves are adopted, Chapter 5), and socio-economic-environmental impacts of stove adoption in rural Kenya (Chapter 6). The sustainability science approach is suggested as a useful tool for systematizing existing knowledge and frame empirical studies related to bioenergy (Gasparatos et al., 2013). This study thus applies the fundamental principles of sustainability science (Kates et al., 2001; Mielke et al., 2016) as: (a) a problem-focused approach; (b) an approach to conceptualize feedbacks between social-ecological systems; (c) an inter- and transdisciplinary focus; and (d) an open mindset to include knowledge gathered from different systems.

For (a), despite the fact that cooking energy dominates domestic energy demand in Kenya and most sub-Saharan African countries (Karanja and Gasparatos, 2019) there has been insufficient attention on how to enhance the sustainability of current cooking energy options. The study perceives adoption of clean bioenergy stoves (biogas and improved biomass stoves) as a pathway to formalize and modernize the biomass energy sector that could catalyze formulation of alternative energy policies in Kenya and other parts of SSA.

For (b) this study adopts a transect approach (see Section 3.2.2.2) reflective of fuelwood scarcity as experienced in most parts of rural Kenya (Arnold et al., 2003; Drigo et al., 2015). In particular, the study perceives fuelwood scarcity variations based on household's proximity to resources i.e. the forest and the urban center. The study then utilizes the transect concept to conduct a comprehensive empirical study about stove adoption dynamics, trade-offs inherent to stove choice behavior and impacts of clean bioenergy stoves (i.e. biogas and improved biomass stoves) in rural Kenya. In this sense, the study enjoins the social structures and ecological systems by identifying the mechanisms and impacts of stove use across the three key pillars of sustainability i.e. socioeconomic and environmental aspects (see Section 3.3.2.5).

For (c), this study acknowledges that in Kenya's cookstove sector, there exist many different stakeholders operating in what often appears to be a crammed space (see Section 1.3). Often, these stakeholders hold radically different perceptions about how to enhance promotion and adoption of clean cookstoves in Kenya. In this respect, the study adopts a solution-oriented perception analysis by integrating knowledge and opinions gathered from multiple stakeholders who often operate in different stages of the stove value chain. By utilizing such a transdisciplinary research approach and co-production of knowledge, the study is able to identify robust convergences and divergences of stakeholder perceptions to enhance the sustainability of Kenya's cookstove sector.

For (d), this study is informed by data collected using a combination of techniques including quantitative and qualitative data techniques. Apart from using extensive empirical analysis based on solid statistical tools, the study is designed in such a way to involve more critically the perceptions/needs of stakeholders and the voices of local communities. In this respect, household surveys and ethnographic research approaches coupled with multi-stakeholder interviews were used in order to enhance the relevance of empirical research to policy-makers and stakeholders involved in clean stove value chains.

3.1.2 Conceptualizing how clean cookstoves are promoted and adopted in Kenya (Chapter 4)

First, this study elicits on the perspectives and insights of the main stakeholders involved in the Kenyan stove sector about stove adoption (drivers and barriers) and requisite approaches to enable scaling up access to clean cooking in Kenya. The convergences and divergences in their perceptions help to identify their specific interest and roles in stove promotion efforts in Kenya.

Second, the study hypothesizes that the probability of stove adoption is predicated on a linear combination of demographic, socioeconomic, institutional and ecological factors. A probit regression of the hypothesized variables is conducted in order to identify their varying applicability, relative importance and significance levels of the identified variables. The conceptually logical and statistically significant productive resources (socio-economic and institutional factors) are selected to determine their direct, indirect and total effects on stove adoption using a path analysis approach.

When it comes to stove choice behavior, the role of stove-specific attributes and characteristics is investigated. A central scholarship of this study is that, within a relatively short period of time, stove-specific attributes can be easily revamped to an appropriate design and with features resonating with the needs, cooking culture and preferences of target market. The study considers this information as crucial for stove producers, promoters, stove programme developers and policy makers. This provides evaluative knowledge not only about the stove characteristics important to their target market segments, but also how much the users value and trade-off between the stove-specific attributes.

3.1.3 Conceptualizing impacts of stove adoption

The impacts mechanisms used to develop the sustainability assessment framework were identified through extensive literature review (see Section 1.4 and Figure 1-2). Based on the information synthesized in Table 1-6, the measurable benefits were identified, and a sustainability framework was developed pillared across social, environment and economic impacts of adoption of clean bioenergy stoves (see Figure 3-1and Table 3-1)

Table 3-1: Impact mechanisms of adoption of clean bioenergy cooking technologies

Impact	**Impact mechanisms**	**References**
Energy security	– Reduce household vulnerability to fuelwood scarcity through the reduction (e.g. improved biomass stoves) or elimination (e.g. biogas systems) of the need for fuelwood – Provide economic savings (time and money) from fuel procurement and cooking, which can be invested for other household needs	(Mahiri, 2003; Bailis and Edwards, 2007; Bailis *et al.*, 2007; MNRE, 2013; Beltramo *et al.*, 2015; Abadi *et al.*, 2017)
Environment	- Improved biomass stoves reduce deforestation and destruction local woodlands by reducing the demand for fuelwood - Improved biomass stoves reduce the loss of carbon stock and GHG emissions by reducing the demand for fuelwood - Biogas systems displace the consumption of fuelwood and the associated GHG emissions.	(Ezzati et al. 2000; Ochieng et al. 2013; Foote et al. 2013; Nzila et al. 2012; Mengistu et al. 2015; Sovacool et al., 2015; Anenberg et al. 2013; Dohoo et al. 2013
Health	- Reduce the negative health effects related of indoor air pollution (e.g. respiratory diseases, post-pregnancy complication, stillbirths, pneumonia risk) by reducing the emissions of indoor air pollutant through the more efficient combustion of biomass (in improved biomass stoves) or the direct use of clean fuels (e.g. biogas, LPG) - Reduce the risk of injuries (e.g. burns, scalds) associated with open-fire traditional stoves - Improve kitchen hygiene and home ventilation due to lower smoke emissions	Ezzati and Kammen 2002; Foote et al. 2013; Njenga et al. 2016; Person et al. 2012; Pope et al. 2017; Olopade et al. 2017; Puzzolo et al. 2014; Pope et al. 2010)

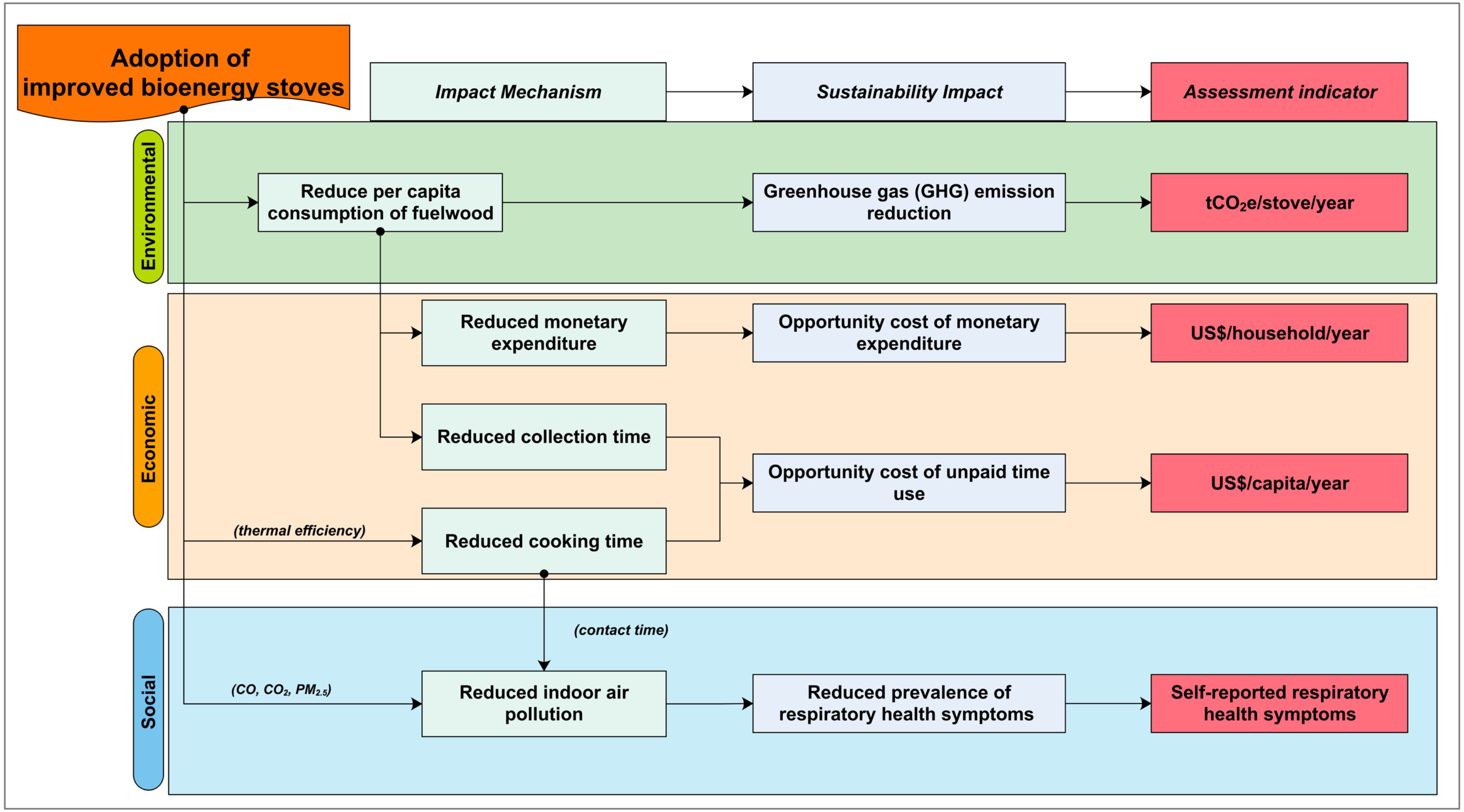


Figure 3-1: Conceptual framework for impacts assessment (source: thesis author)

3.1.4 Organization of study methodology

This study is structured in five (5) phases as summarized in Table 3-2, providing an overview about how stoves are promoted, how stoves are adopted and the associated sustainability impacts of adoption. The first phase is aimed to understand the institutional arrangement and players that have a bearing in the Kenya's clean cooking sector. This was done through extensive review of academic literature, policy documents and institutional reports (Section 1.3). From this output, key experts were identified and interviewed in order to identify convergences and divergence of their perception about drivers and barriers of stove adoption in Kenya (objective 1). The third phase of the study is drawn from household surveys where semi-structured questionnaires and a choice experiment were designed to identify factors affecting stove adoption and choice behavior (objective 2).

The fourth phase involved a quantitative assessment of socio-economic and environmental impacts of adoption of clean bioenergy stoves (Objective 3). In addition, participatory ethnographic surveys were conducted in order to put into perspective, the information collected from household surveys. The final stage synthesizes the main findings from the three objectives to draw conclusions and to suggest policy and practice implications to enhance stove promotion mechanisms and adoption in rural Kenya.

Table 3-2: Summary of study methodology

Approach	Objective	Issue	Data collection	Analysis	Output
Stoves promotion in Kenya (*Chapter 4*)	1	Institutional arrangement and actors	Institutional analysis	Content analysis	Identify key institutions and players in Kenya's stove sector
		Drivers, barriers and impacts of adoption	Literature review	Content analysis	Identify drivers, barriers and impacts of stove adoption in Kenya
		Drivers, barriers and way forward for stove adoption	Expert interviews	Coding and qualitative analysis	Multi-stakeholder divergences and convergences of perception
Stoves adoption in rural Kenya (*Chapter 5*)	2	Factors affecting adoption of clean bioenergy stoves	Household surveys	Probit regressions Path analysis	Identify the effects of demographic, socio-economic and institutional factors on stove adoption
		Trade-offs inherent to stove choice behaviour	Choice experiment	Discrete choice analysis	Identify the effects of product-specific attributes on stove choice behaviour
		Drivers and barriers of stove adoption and sustained use	Ethnographic surveys	Coding and qualitative analysis	Identify user-perception (users and quitters) about factors influencing adoption and sustained stove use.
Impacts of stove adoption (*Chapter* 6)	3	Environmental impacts	Household surveys	Quantitative analysis of per capita fuelwood consumption	GHG emission reduction potential (tCO_2e/stove/year)
		Economic impacts	Household surveys	Quantitative analysis of unpaid-time use and fuelwood monetary expenditure	Opportunity costs (US$/household/year)
		Social impacts	Household surveys	Probit regression	Self-reported prevalence of smoke-related health symptoms
Synthesis (*Chapter 7*)	4	Pathways towards universal access to clean cooking in Kenya	Findings synthesis (objectives 1,2,3)	Explanatory synthesis of findings	Practice and policy-relevant implications

3.2 Data collection

3.2.1 Expert interviews

To examine the drivers, challenges and impacts of modern cooking energy interventions in Kenya, primary data obtained through multiple stakeholder interviews was used. These interviews were conducted with the main stakeholders involved in the Kenyan clean cookstove sector as identified through an extensive institutional analysis (Karanja and Gasparatos, 2019).

Overall, interviews were performed with 28 stakeholders grouped into five main categories: (a) government agencies (n=6); (b) non-government organisations (NGOs) (n=6), (c) donors and international development organisations (n=4), (d) private sector (n=7), and (e) research organisations and academia (n=5). In each organisation the respondents that were highly involved in clean cookstove activities were identified, and in that sense could offer rich information on how their organisation views and approaches their involvement in the sector. Respondents were mostly senior within their respective organisations (Table 3-3).

The overall themes of the interviews revolved around the (a) drivers and barriers of clean cooking adoption; (b) impacts of adoption (both positive and negative); (c) national market trends, pitfalls and way forward towards universal access to clean cooking by 2030. Each respondent was required to reflect the position of their organization, rather than their personal opinion.

As the purpose of this survey was to capture the width of the perceptions of these stakeholders, the questions were semi-structured and open-ended. Thus, respondents were allowed to elaborate freely on their answers, and occasionally follow-up probes were used to elicit, systematically but flexibly, the stakeholders' opinions and experience. In particular through repeated questions, the stakeholders were asked to discuss all the different drivers/barriers and impacts of clean cooking adoption they are aware of, and subsequently to identify the most important. Most interviews were conducted in person (n=25) at the participant's venue of choice, but due to logistical issues some interviews were conducted through phone/Skype (n=3). Each interview lasted 30-45 minutes and was audio-recorded with the participant's consent. All interviews were conducted between July–December 2017.

Table 3-3: Description of interviewed stakeholders

Stakeholder category	Organisation	Department	Affiliation	Reference code
Academia and research	Kenya Forest Research Institute	Forest products development (bioenergy utilization)	Senior Researcher	KEFRI
	Stockholm Environment Institute	Household energy	Research Associate	SEI
	The University of Nairobi	Chemistry	Director/Professor	UoN
	Jaramogi Oginga Odinga University	Centre for research, innovation and technology	Director/Professor	CRIT
	Maasai Mara University	Forestry and wildlife	Professor	MMU
Government	Ministry of Energy	Renewable energy	Director	MoE
	Ministry of Public Service, Gender and Youth Affairs	Gender affairs	Gender Officer	MoGYA
	National Environment Management Authority	Environmental planning and research coordination	Climate Change Coordinator	NEMA
	Kenya Forest Service	Forest management and conservation	Ecosystem Conservator	KFS
	Ministry of Health	Public health	Deputy Director	MoH
	Ministry of Agriculture	Home economics unit	Head Officer	MoA
Private Sector	AFRISOL Ltd	Management	CEO	AFRISOL
	Sustainable Energy Strategies	Management	CEO	SES
	Burn Manufacturing Ltd	Management	Founder	BML
	Devaletech Ltd	Management	Founder	DVL
	MotoPoa Limited	Management	CEO	MPL
	ECO_2Librium	Stove for Life project	General Manager	ECO2
	Equity Bank	EcoMoto loan program	Financial Advisor	EB
Donors and international organisations	SNV Netherlands	Global energy sector	Sector Lead	SNV
	German Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)	Energy development programme (EnDev)	Programme Manager	GIZ-1
	German Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)	Energy development programme (EnDev)	Cluster Manager, Western Kenya	GIZ-2
	The International Fund for Agricultural Development	Mt. Kenya East Project	Desk Officer	IFAD
Non-governmental Organisations (NGOs)	Practical Action Consulting (East Africa)	Sustainable Energy Access	Project Manager	PAC
	Clean Cooking Alliance	East African region office	Regional Representative	GACC
	Kenya Climate Innovation Centre	Corporate services	CEO	KCIC
	Clean Cooking Association of Kenya	Management	CEO	CCAK
	Kenya National Biogas Development Program	Management	Programme Coordinator	KNBDP
	New Improved Stoves Association of Kenya	Management	Executive Secretary	ISAK

3.2.2 Household Surveys

3.2.2.1 Selection of study sites

As outlined in Section 2.3, the specific focus for this study is on the dynamics between traditional and modern (i.e. biogas, improved biomass stoves) cooking options in rural settings of Kenya. To capture the necessary variations and to allow for some level comparative outlook, two case study areas bordering Aberdare Forest Reserve (state forest), Kiambu (1.1462° S, 36.9665° E) and Muranga (0.7957° S, 37.1322° E) counties were selected (Figure 3-2).

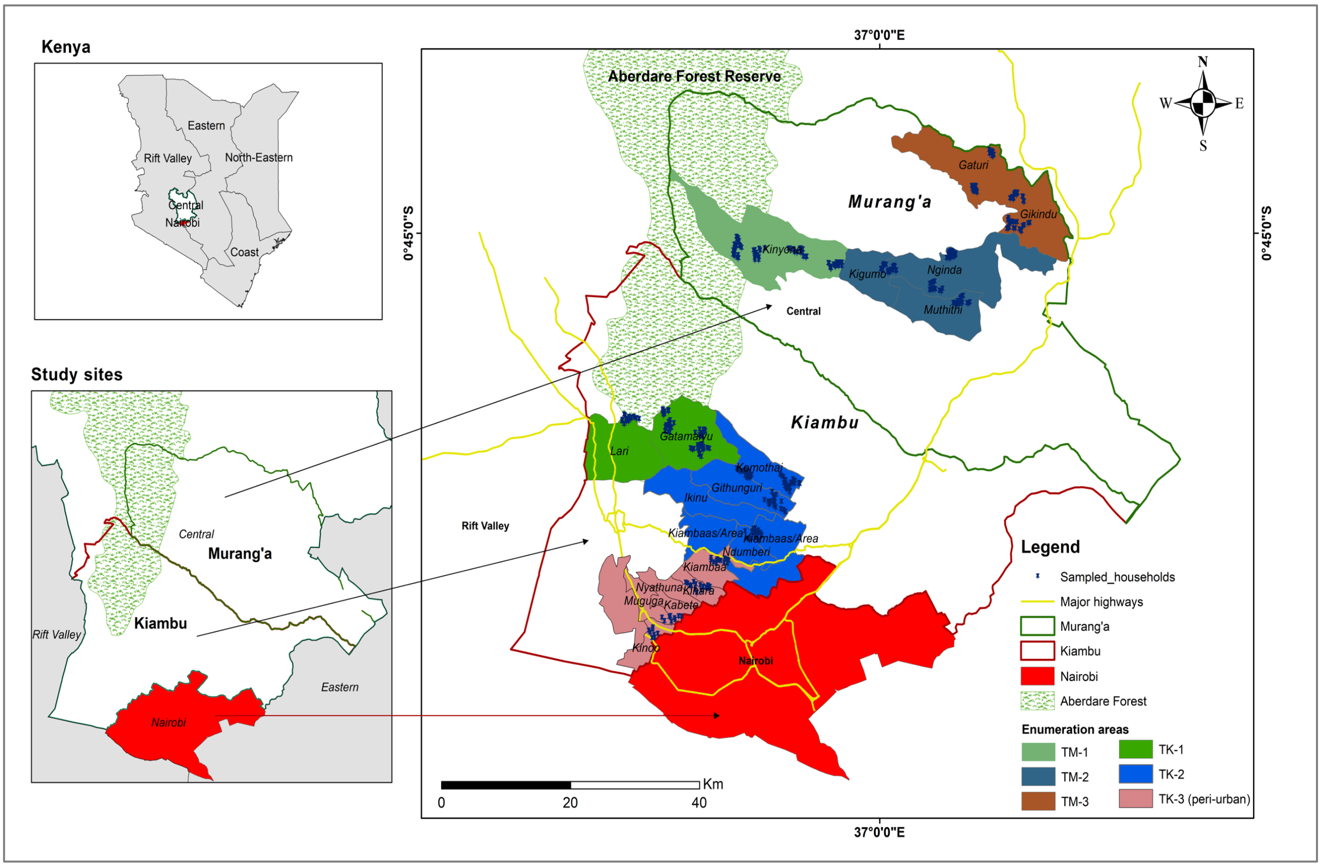


Figure 3-2: Map of Kiambu and Muranga counties

The selected study areas (Kiambu and Muranga counties) are ranked among the rural "hotspots" in Kenya that have experienced a drastic transition to fuelwood shortages with the threat of increasing future scarcities (Drigo et al., 2015). This selection criteria were reflective of fuelwood scarcity as experienced in most parts of rural Kenya which is often based on households' proximity to resources i.e. the forest and the urban center (Kituyi et al., 2001; Mahiri and Howorth, 2001; Arnold et al., 2006; Arnold. et al., 2015).

According to a Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) conducted in Kenya by Drigo et al (2015), there exists a large discrepancy in the local supply and demand, which cause large annual wood supply deficits (see Table 3-4, Figure 3-3). Reportedly, the total estimated mean annual increment (MAI) of dendro-energy biomass (i.e. woody fraction of the aboveground biomass suitable to be used as conventional fuelwood) is 0.435 Mt od/year in Kiambu and 0.247 Mt od/year in Muranga, which represent the average fuelwood supply potential. However, about 2% and 13% of these resources are considered non-accessible which is possibly attributable to build settlements and land privatization (see Table 3-4).

Table 3-4: Fuelwood supply-demand balances in Kiambu and Murang'a

		Murang'a	Kiambu	Kenya
Fuelwood Demand		631	1,704	27,380
Supply (kt od[2])	Total MAI	247	435	42,921
	Physically & legally accessible MAI	216	427	28,069
Balance (kt od)	Total MAI	-415	-1277	689
	Physically accessible	-31	-8	-14,852
	Local	-411	-1254	349
	Commercial	-414	-1255	-2193

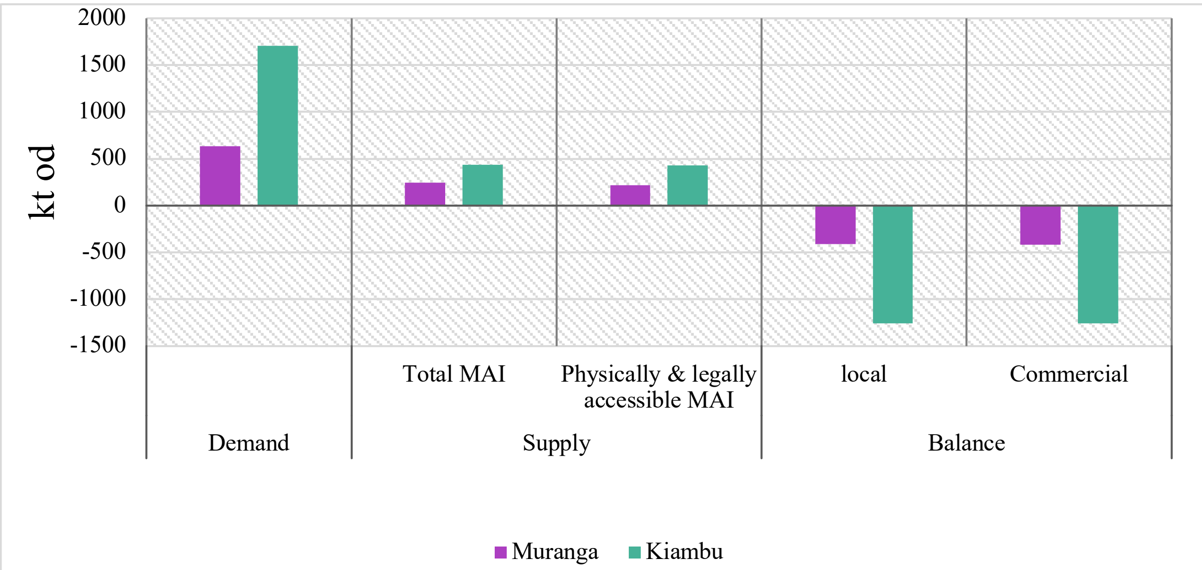


Figure 3-3: Fuelwood supply-demand imbalances in Kiambu and Murang'a counties, Kenya.

[2] (kilo tons of oven dry matter - kt od)

According to KNBS (2018), households in the selected study areas have varying cooking fuel patterns and distribution (Table 3-5). In addition, the regions exhibit distinct socio-economic and geographical characteristics (Table 3-6)

Overall, firewood is the main cooking fuel as used by 80.6% and 35.5% of households in Muranga and Kiambu, respectively. However, the diversity of cooking fuels is more pronounced in Kiambu that in Muranga. Economically, the GDP per capita in Kiambu is about US$.700 higher as compared that of Muranga.

Table 3-5: Percentage distribution of households in Muranga and Kiambu by primary cooking fuels

	Muranga	**Kiambu**	**Rural Kenya**
Firewood	80.6	35.6	84.3
Charcoal	2.4	15.1	8.9
LP gas	5.7	23.5	2.5
Biogas	0.3	0.5	0.2
Kerosene	8.1	21.7	2.3
Electricity	0.0	1.9	0.3
other	2.7	1.8	2.5

Source: Kenya National Bureau of Statistics (2018) for 2015/2016 Kenya household budget survey

Table 3-6: Key features and characteristics of the study areas

Feature	**Muranga**	**Kiambu**
GPS coordinates	0.7957° S, 37.1322° E	1.1462° S, 36.9665° E
Annual rainfall (mm)	1590	962
Forested area	10%	16.5%
Land area (km^2)	2559	2543
Population	942,581	1,623,282
Number of households	323,000	600,000
Density (people per km^2)	368	638
Incidence of poverty (2016)	30.7%	23.5%
GDP per capita (US$)	1090	1785
Number of poor individuals	311,699	386,258
Key livelihood activities	Subsistence farming, tea and coffee farming	Dairy farming, horticulture, tea and coffee farming

Compiled from KNBS (2018); and Socio-Economic Atlas of Kenya (2016)

3.2.2.2 Transect sampling approach

When it comes to issues related to sustainability of fuelwood, several studies have advocated for the use of local-specific studies reflective of the spatial differences in order to identify the specific areas where problems are arising or are expected to occur (Drigo et al., 2015; Arnold et al., 2003; Githiomi and Oduor 2012). In this respect, this study visualizes proximity to resources i.e. urban center and state forest as important criterion to unravel the complex household fuel switching behavior and stove adoption patterns.

In order to capture the fundamental variations, enumeration transects were identified in each of the study areas (see Section 3.2.2.3, Figure 3-2). The selection criteria were: (a) dynamics of biomass resource (abundance vis-à-vis scarcity) visualized by increasing distance from the state forest traversing towards a semi-arid interior in Muranga; and (b) market access and infrastructural development (proximity to the urban center) envisaged by distance from the state forest towards a peri-urban zone bordering Nairobi city.

The identified transect zones were identified to have varying and distinct characteristics in terms of agroecological zones and key livelihood activities (see Table 3-7). By matching datasets from the transect zones the study is able to partition and compare the inherent findings by household's geographical location and proximity to resources.

Table 3-7: key description characteristics of selected enumeration transect zones

Study area	Transect zone	Agroecological zone	Key livelihood activities	Sampled households
Muranga	Close-forest	Forest zone (humid)	Tea and dairy farming	70
	Mid-transect	Semi-humid	Coffee (rain-fed)	65
	Semi-arid	Semi-arid	Coffee (irrigated)	65
Kiambu	Close-forest	Forest zone (humid)	Tea and dairy farming	70
	Mid-transect	Semi-humid	Coffee and dairy farming	65
	Peri-urban	Peri-urban	Subsistence farming, non-farm employment	65

3.2.2.3 Sampling strategy and sample selection

A novel sampling strategy was designed to generate a sample representative of the populations in the study areas and to meet the criteria for transect approach outlined in Section 3.2.2.2 (i.e. distance from the state forest and proximity to the urban center). In this respect, the sample was selected in four stages:

a) In Muranga, a main road was identified traversing from the state forest towards a semi-arid interior. In Kiambu the identified main road run from the state forest towards Nairobi (capital city of Kenya). Along these lines, sampling clusters (transect zones) were drawn following a stratified random sample of enumeration areas (EAs) from a master sample frame of 2009 Kenya Population and Housing Census (KNBS)
b) For the two study areas, the sub-county/ward maps were obtained in order to identify EAs boundaries (primary sampling units) within the sampling clusters (transect zones). In each cluster, a complete randomization was carried out to avoid selection bias. Random numbers were generated in MS. Excel against the EAs and the top five (5) enumeration areas were selected to represent the villages of that particular zone. Administratively, each enumeration village carries about 150 households.
c) The selected EAs were cross-referenced to a geographical information system (GIS) map of the study area. In order to ensure a reliable and unbiased identification of responding households, a grid-point was identified on the map at a road intersection of each enumeration area.
d) The tablet global positioning system (GPS) was used to locate the sampling reference point in each EA. A minimum of 15 households were randomly selected from each village. The sampled households were regularly spaced at every 5th household interval. In total, about 200 households were randomly selected in each transect (see Table 3-7).

3.2.2.4 Reducing non-sampling errors

In order to reduce non-sampling errors, a comprehensive protocol was developed for the design and implementation of the household surveys. The study followed quality assurance criteria of Gasparatos et al., 2018 for impact assessment studies in sub-Saharan Africa. These included dedicated steps for the:

a) household survey and design;
b) Questionnaire piloting;
c) Identification and training of data collectors;
d) Sampling techniques and household identification;
e) Data collection methods and triangulation.

For (a) and (b), a pilot survey was administered in August 2016 prior to survey development aimed to understand the site characteristics and efficacy for a full-scale survey. During these visits, key-informant interviews and in-situ observation were carried out. Pilot household visits were conducted as well to understand site-specific dynamics, stove use patterns, fuelwood procurement and consumption dynamics in the study areas. A draft questionnaire was designed, and a second pilot survey was conducted in Feb-March 2017. The aim was to test the survey instruments in order to appreciate the length/timing of the questionnaires, quality of obtained responses and identify local terminology under real conditions. Approximately 10-15 household surveys were pre-tested in each study site. Based on this pre-testing, some questions and translations changed slightly when developing the full-scale questionnaire in such a way to reflect the unique characteristics of study sites.

For (c), the full-scale survey was carried out between August 10 – September 20, 2017. The survey period was preceded by two days training period of 5 enumerators sourced from local universities who are well conversant with the study areas. Although the questionnaire was designed in English, the enumerators were trained in both *Swahili* and *Kikuyu* dialects (local languages). The overall aim, components and design of the household survey was clearly explained to the enumerators. In order to ascertain the intended procedures and data collection protocol was followed precisely, the thesis author was present during the training and fieldwork activities. This quality control included checking each submitted questionnaire on the Open Data Kit (ODK) online interface and re-instructing enumerators if data inconsistencies and mistakes were identified.

For (d), this study used the existing definition of a household to refer: "*a person or group of persons, related or unrelated, who usually live together, who acknowledge one adult member as the head of the household, and who have common cooking arrangements*" (KDHS, 2014). The questionnaire interviews were conducted in person and at the respondents' houses in order to allow the interview to take place in familiar and comfortable settings, as some questions could be perceived as sensitive (e.g. household assets, livelihood sources, income, etc.). It also allowed the enumerators to visually confirm the primary stove technology used by the household, and kitchen ventilation features (e.g. chimney, smoke hood, eave spaces etc.). The target respondent was the woman of the household or the next household member who was well conversant with fuel procurement and stove use patterns (whoever was available at the moment of the visit). The interviews were conducted with one person in each household to avoid interfering with the answers.

For (e), in order to triangulate the obtained data, 23 ethnographic surveys were conducted in each study site that aimed to elicit community perceptions about some of the studied themes/impacts (see Section 3.2.1.2). To further elicit the dynamics of adoption and impacts of clean bioenergy stoves, local key informant interviews were conducted.

3.2.2.5 Household survey format

The household surveys were carried out to assess the drivers, stove choice behaviors and impacts of adoption of clean bioenergy stoves using semi-structured tablet-based questionnaire. The Open Data Kit (ODK), a free and open-source suite of tools, was used for programming the questionnaire and for data collection (ODK collect). Apart from the questions and the answer options, ODK tools provided for quality control measures such as use of skip logic algorithms, validation constraints, clear instructions on how to capture and probe for answers. It also had built-in questions that could be used to check the internal consistency of the received answers. For navigation purposes, the geographical positioning systems (GPS) coordinates were captured and later converted into a geographic database (KML file), allowing to plot the sampled households on Google Earth in order to track sampling progress.

The questionnaire included both close-ended and open-ended questions employing fixed ranges that were coded appropriately (see Appendix 3). It consisted of seven (7) sections namely:

A: Intra-household demographic characteristics and socioeconomic profiles (all respondents)

B: Income, assets and livelihood sources (all respondents)

C: Household energy and stove use patterns (all respondent groups)

D: Choice experiment (non-modern stove users)

E: Fuelwood sourcing and consumption dynamics (fuelwood users)

F: Self-reported health symptoms and kitchen characteristics (fuelwood users).

G: General comments (all respondents)

The fuelwood sourcing (E) section dealt with questions about fuelwood procurement (both collected and purchased) and consumption patterns. The extent of fuelwood scarcity was judged by information gathered regarding: (a) the most frequent source of fuelwood collection; (b) perceived degree of fuelwood scarcity and difficulty experienced by the households; (c) walking distance (kilometer) from the homestead to the most frequent fuelwood collection woodland, (d) frequency of collection trips; (e) time consumed for actual fuelwood collection and walking (hours); (f) household members responsible for collection tasks (by gender and age); (g) fuelwood scarcity coping strategies. To further understand the severity and risks associated with fuelwood collection, information was collected regarding safety risks as experienced by the respondents.

In order to determine the amount of fuelwood consumed (kilogram), the main cook was asked to show the fuelwood equivalent to the quantity used to cook a complete meal *ugali (*a local cuisine consumed most frequently in the study areas). The enumerators weighed the fuelwood bundles using a weighing balance. The air-dry weight of the bundle use for a complete meal was recorded. Other questions probed about fuelwood consumption included information about number of bundles consumed in a day or week, the average number of meals cooked each day and average cooking time per meal.

In order to understand the health effects of stove use and fuel use (F), a list of prevalence of health symptoms associated with solid fuel use as described by the World health Organization (WHO, 2014) was probed. These questions were asked as experienced by the main cook in the past 30 days prior to the date of survey in relation to stove use. They include: (a) smoke-related respiratory health symptoms (nose/throat irritations, coughing, breathing difficulties); (b) eye irritations); and (c) kitchen safety-related injuries (i.e. burns/scalds). Further data was collected about a range of variables that are believed to affect the degree of exposure including: (a) cooking location (indoors or outdoors); (b) amount of time (hours) spent in the cooking area, (c) housing characteristics (separate kitchen room and ventilation structures patterns).

3.2.2.6 Choice experiment design and implementation

A stated preference survey was designed to elicit household decision-making, trade-offs and stove choice behavior in rural Kenya. In order to construct the survey instrument for the choice experiment, the relevant attributes, attribute levels and choice sets were identified and refined through feedback loops. (see Figure 3-4) (Hensher, et al., 2005).

The choice experiment was designed for two main alternatives (LPG and charcoal) which are the considered as the most immediate fuel switching alternatives for clean cooking in rural Kenya (GoK, 2016a). The survey was carried out across the randomly selected sample of 360 households in Muranga and Kiambu enumeration transects that use fuelwood as the main cooking fuel (see Section 3.2.2.2).

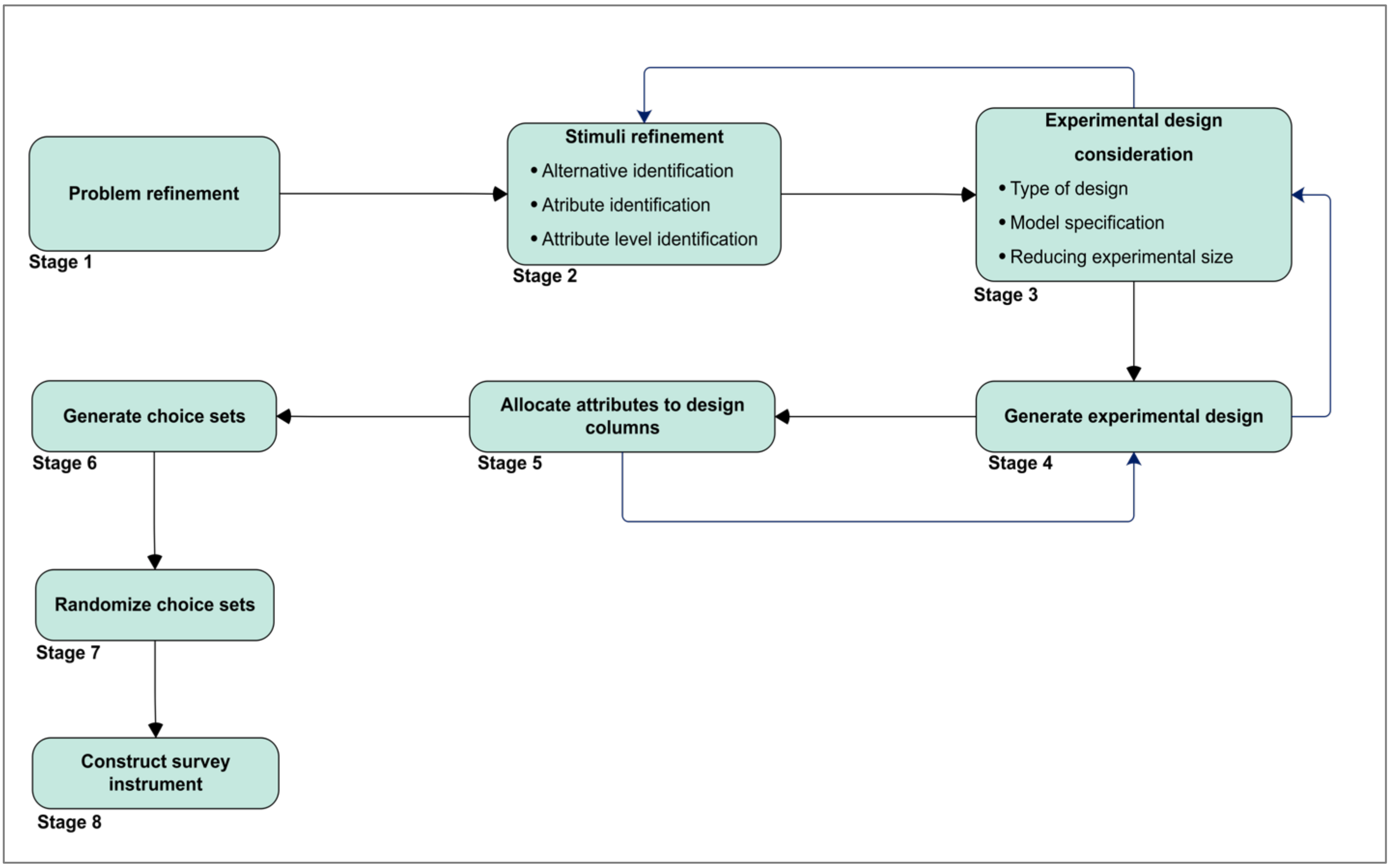


Figure 3-4: Design process of a choice experiment (adapted from Aizaki et al., 2014; Hensher, et al., 2005)

3.2.2.6.1 Identification of stove-specific attributes and attribute levels

As outlined in Section 2.2, it was identified that in a short-term, stove-specific features can be customized to design features that resonate with the target user preferences and needs (Takama et al., 2012). Based on extensive literature review (Section 1.6) and expert consultations, four stove-specific attributes were identified including: (a) stove price; (b) fuel usage cost, and (c) indoor pollution; and (d) environmental impact, expressed quantitatively for varying levels.

Previous studies suggest that including more than four attributes in a choice set may affect the quality of the data collected due to task complexity and psychological fatigue from the respondents (Aizaki et al., 2012; Alpizar et al., 2001). The assigned levels for stove price and monthly fuel usage costs were estimated based on market information gathered during a pilot survey conducted in February 2017, expert interviews and internet market research (see Table 3-8). The assigned levels for environmental impact was based on knowledge from literature review, site observation and in consultation with key experts in the Kenya's stove sector.

Table 3-8: Allocation of levels and labels for the four attributes

Stove attribute	**Charcoal stove**	**LPG stove**
Stove price (KES)	{3000, 3500, 4000, 4500}	{6000, 6500, 7000, 7500}
Usage cost (KES)	{450, 500, 550, 600}	{1000, 1100, 1200, 1300}
Indoor air pollution	1=Very Little Smoke; 2=Moderately Smoky	0=No Smoke; 1=Very Little Smoke
Environmental impact	{5, 10, 15} Trees	{15, 20, 25} Trees

According to a national survey (Mugo et al., 2013), an average rural household of four household members using a conventional charcoal stove consumes 50 kg of charcoal per month. Assuming laboratory test results of 40% thermal efficiency for a modern charcoal stove, the same household would consume 30 kg charcoal per month. In the study areas, at the time of this survey, a 50kg bag was being sold at the local market or from charcoal dealers at an average price of between KES. 750 – 1000 (US$7.50-10) depending on location.

The fuel usage cost levels ranged between a minimum of KES. 450 and maximum of KES. 600 (US$ 4.50 – 6.00) while the price of an advanced-modern charcoal stove costs between KES. 3000 – 4500 (US$30-45). When it comes to LPG, the market price for a stove set comprising of a burner, grill and gas ranged between KES. 6000 – 7500 (US$60-75). A single monthly refilling of a 6 kg gas cylinder was assumed for an average household, which cost between KES. 1000 -1300 (US$10.00-13.00) at the time of this survey.

3.2.2.6.2 Generation of choice sets

The choices presented to the respondents included two labelled alternatives (i.e. LPG and charcoal stove). Hensher et al., 2005 recommends that, *"if the objective of the choice experiment is to study the impact of the relationships different attribute levels have upon choice, then non-choice alternative is likely to be a hindrance to the analyst."* In other studies, it is also suggested that including such constraints appreciates behavioral realism, plausibility and logical consistency for the experiment to yield unbiased attribute trade-offs (Collins et al., 2014; Boxall et al., 1996; Louviere et al., 2000).

A personal communication with Dr. Takama Takeshi (author Takama et al., 2012) emphasized that inclusion of the dominant stove alternative (i.e. fuelwood stoves) from this choice experiment would introduce a selection bias since, "*respondents would choose it anyway.*" Dr. Takama emphasized that, regardless of the level of attributes, some respondents would stick with the dominant alternative that they are most conversant with (Personal communication, Takeshi Takama, July 2017).

In this respect, the respondents were not given opportunity for *"none of these"* or status quo option in this study. By "compelling" decision makers to make a choice, the study obliged respondents to trade-off and evaluate the attribute levels of the stove alternatives i.e. LPG and charcoal (see also Johnson et al, 2013; Alfnes and Stein, 2005). Figure 3-5 shows an example of a survey choice set used in the exercise.

In order to generate the choice sets, the orthogonal main effects design was used for its effectiveness in isolating the effects of individual attributes on a choice (Aizaki et al., 2014; Hensher et al., 2005). The generated final design consisted of 16 choice sets. A Pearson's correlation coefficient test was employed to ensure zero correlation (i.e. perfect orthogonality). However, the generated 16 choice sets were too large for one respondent to answer. To offset task complexity and respondents' fatigue, the choice sets were blocked into two subsets. Each respondent had to select a preferred option from the two possible alternatives in the eight choice sets. Pictograms were used in this choice experiment to ease the cognitive strain for the respondents (Davies et al., 2002).

Question:

"Imagine you are at a shop and you want to buy a new cookstove for your household and there are only two types in the shop. Each stove has 4 attributes about them listed on a card including ***stove price, fuel usage cost, indoor air pollution and environmental impact.*** *I will show you 8 cards, one at a time with each card showing different attributes for you to choose which one could be the best stove for your household. Do not consider what you had selected in your previous choice."*

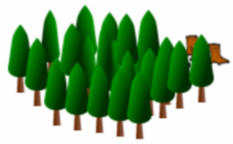
	Improved Charcoal Stove	LP Gas
		
Stove Price (KES)	3000	7500
Fuel Usage Cost/month (KES)	400	900
Indoor pollution	 moderate Pollution	 No Pollution
Environmental Impact		
Which option would you choose?	☐	☐

Figure 3-5: Sample of a choice card used in the survey

3.2.2.7 *Ethnographic surveys*

In order to complement and put the survey data within a broader social, behavioral and cultural context, participatory ethnographic surveys were conducted within the enumeration transects where the questionnaire surveys were carried out. To gain access to the target homesteads, the author carried a letter from University of Tokyo indicative of the strict academic intent of the study. Furthermore, in order to ease entry and trust into the target homesteads, the author was guided by identified contacts, local survey enumerators and local community leaders.

Upon getting well acquainted and establishing rapport within the local communities, the author gained access to the homesteads of users and quitters (i.e. dis-adopters) of improved stoves and biogas (see Table 3-9). With the consent and permission from the identified participant, the author spent 6-10 hours in the homesteads and actively participated in the activities of fuelwood collection, cooking, and biogas digester operation.

In order to probe the inherent issues in line with study objectives and interests, gentle in-depth interviews were conducted with the participant. In some cases where the participant was not able to give verbal information, non-participant/direct observation techniques were applied to identify habits and behaviors for different activities. The observed information was recorded in the field notebook.

For stove users, the information explored included: (a) reasons for initial stove uptake decision-making; (b) reasons for the sustained and consistent stove use; and (c) reasons for multiple fuel use (stove/fuel stacking). For stove quitters (dis-adopters) who had purchased a clean cookstove and switched to their former cooking methods, the ethnographic surveys sought to understand about reasons for switching back to traditional cooking methods. In addition, ethnographic surveys were conducted with exclusive traditional stove users to understand reasons deterring them from adoption of efficient/clean cooking methods and to continue relying entirely on traditional methods.

In addition, through the participatory ethnography, the author aimed to verify quantitative findings derived through household questionnaires including fuelwood consumption estimates, walking distance from homesteads to the collection woodland, time investment in fuelwood procurement activities and cooking tasks. Further narratives were compiled about characteristics of preferred fuelwood species and about local knowledge applied by households to strategize fuelwood shortage and save cooking time. The study also focused to identify cultural, beliefs and attitudes pertinent to cooking. Other issues that participants would otherwise find difficult or sensitive talking about in interviews were also identified.

The information gathered was detailed in field notes in form of quotes, comments, opinions, perceptions, sketch diagrams, anecdote and examples contained in the responses. Where applicable, some parts of the conversations were recorded with the consent of the respondent.

Table 3-9: Sampled households for ethnographic surveys within the enumeration transects

	Kiambu transect		Muranga transect	
Stove user group	Adopters	Dis-adopters	Adopters	Dis-adopters
a) Biogas stoves	3	3	N/A	N/A
b) Improved biomass stoves	4	3	3	2
c) Traditional stoves	3	N/A	2	N/A

3.3 Data Analysis

3.3.1 Qualitative data analysis

3.3.1.1 Multi-stakeholder perception analysis

Each stakeholder interview was transcribed verbatim for further analysis through NVivo, a computer assisted qualitative data analysis software. Responses were classified, coded and code categories were generated as appropriate. An inductive content analysis approach was used to identify the main themes.

These themes were informed through an extensive literature review on the state, adoption, impacts and policy instruments in the clean cooking sector in Kenya (Karanja and Gasparatos, 2019) and were complemented from other similar reviews and meta-analyses (e.g. Puzzolo et al., 2016; Debbi et al., 2014). The main emerging themes were outlines (see Chapter 4), highlighting where needed quotations and responses to emphasize the different views and opinions among stakeholders. To appreciate better the differences in stakeholder perception, the themes which were brought up by the different stakeholders were identified using the abbreviations outlined in (Table 3-3)

3.3.1.2 Ethnographic content analysis

The ethnographic narratives detailed in fieldwork notes and recorded conversations was transcribed verbatim for analysis.

The information was then sorted, coded and a deductive content analysis was conducted using NVivo software to map the convergences and divergences of perception between the adopters and dis-adopters (quitters) and traditional stove users (see Table 3-9).

3.3.2 *Quantitative data analysis*

3.3.2.1 *Descriptive statistics*

Depending on the data types, two-sample independent t-test or one-way analysis of variance (ANOVA) were used to compare means and test the statistical significance associated with the user groups using SPSS 23 and STATA 15.

3.3.2.2 *Empirical estimation of factors affecting adoption of improved biomass and biogas stoves*

The empirical specification of the adoption model of clean cooking technologies (improved cookstove vs. traditional, 3-stone stove) is hypothesized to be influenced by demographic, economic, ecological (for the case of improved biomass stoves) and institutional factors (see Figure 3-6). These factors were identified through extensive literature review (see Section 1.5; Figure 1-2; Karanja and Gasparatos 2019), expert interviews and site visits.

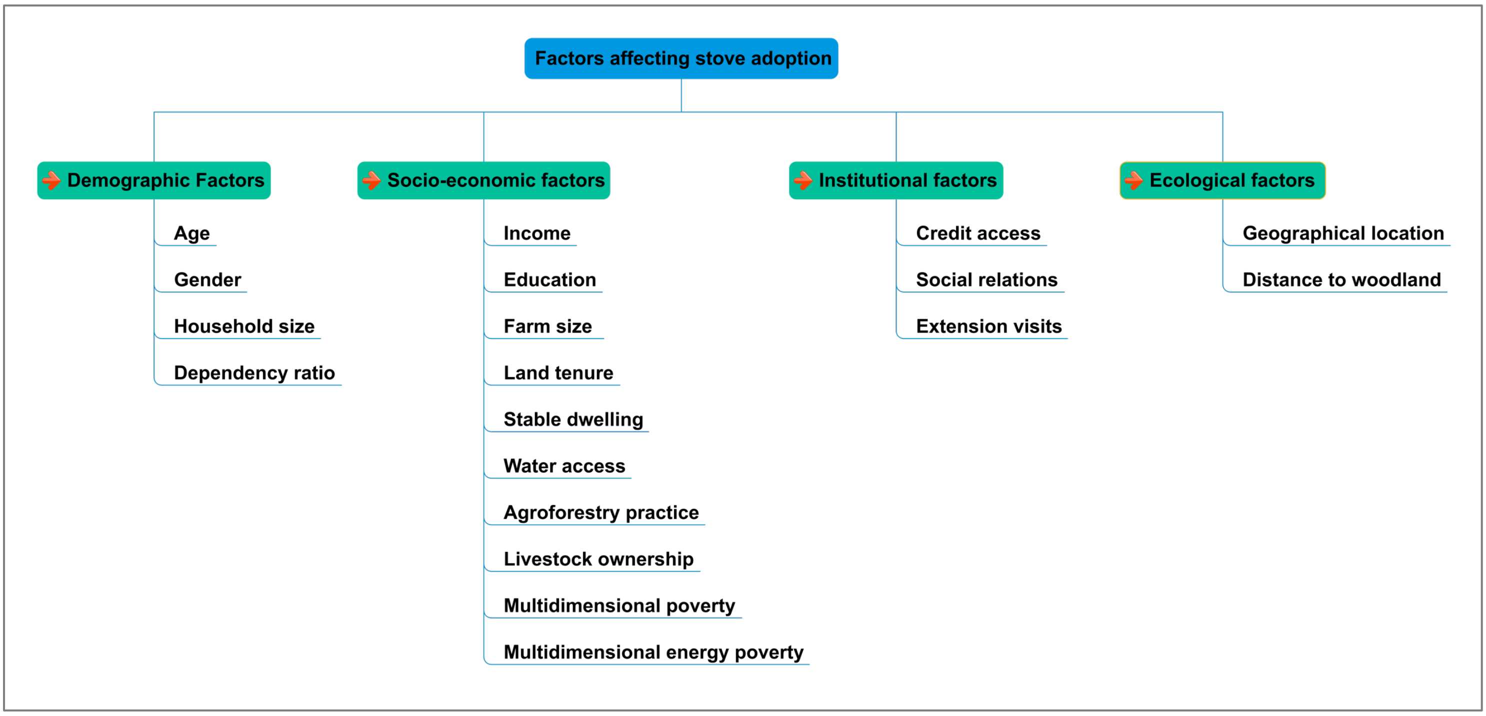


Figure 3-6: A conceptual framework: Factors affecting stove adoption

The models included illustrative variables representing the categories that are hypothesized to affect the stove adoption in the study area (see below, Tables 3-10 and 3-11)

As illustrated in Figure 3-6, these factors are categorized into: (a) demographic (gender, age and education level of the household head; household size; dependency ratio); (b) socio-economic factors (income; farm size; land tenure; agroforestry practice; water access; livestock (TLU), multidimensional poverty and energy poverty);

(c) institutional factors (credit access; social relations; extension visits); and (d) ecological factors (geographical location; and distance to main fuelwood collection woodland).

3.3.2.2.1 Empirical specification of binary probit regression models

The empirical model was estimated based on the conceptual framework in Figure 3-6 using the hypothesized factors influencing adoption of improved biomass stoves and biogas stoves.

The empirical model is specified in the following estimation formula:

$$Y_n = \beta_0 + \beta_1 x_{1n} + \ldots \beta_k x_{kn} + \varepsilon$$

Where: Y_n is a dummy coded 1 for adopters of improved biomass stoves or biogas users; and 0 for traditional stove users. This latent variable was assumed in this study to be a linear combination of household demographic, socioeconomic and ecological characteristics and institutional factors (x_{kn}) as well as the unobserved characteristics that are captured by the stochastic error term ε. Average marginal effects were also estimated depicting the change in probability of stove adoption when a predictor changes by one unit. The model was estimated using STATA 15.

3.3.2.2.2 Path analysis

We use path analysis to establish the direct, indirect and total effects of factors affecting household income (i.e. socioeconomic and institutional factors), which is seen as a major pathway to the adoption of clean bioenergy stoves (see below). The selection of the income factors is based on their statistical significance as identified through the Probit analysis (Section 3.3.2.2) based on their relative importance and statistical significance. The path coefficients are estimated by standard regression coefficients in a system of linear equation.

$$Y_n = \beta_0 + \beta_n x_1 + \ldots\ldots \beta_n x_k + \varepsilon$$

Where:

- Y_n endogenous variables (adoption and household income level)
- β_0 Constant term
- β_n A standardized regression coefficient, for the direct effect of an independent variable on *Yn*
- x_k the selected exogeneous variables explaining stove adoption
- ε disturbance/error terms reflecting the unexplained variance

The path analysis was conducted using SPSS-Amos software. A recursive path diagram that visually represents these hypothetical causal relationships was constructed. When the path of an independent (exogeneous) variable has an arrow directed towards the dependent variable, then it is said to be the direct effect. When an exogenous variable has an effect on the dependent variable, through another exogenous or mediating variable (i.e.

income), then it is said to be an indirect effect. The total effect of the exogenous variable is calculated as the sum of the direct and indirect effect and to establish the gender correlation effects with the productive resources. The indirect effects were further decomposed as described by (Duane and Hauser, 1975) in order to better understand the mediating/intervening power of income on adoption. The followed method entailed exploring the underlying assumptions that:

a) household income is affected by a combination of socio-economic, and institutional factors, which have important ramifications on the adoption of improved biomass stoves;
b) although women disproportionately bear the drudgery and burden when of fuelwood procurement and cooking, they have limited income resources, which curtail their purchasing power for clean cooking options.

Table 3-10: Description of hypothesized determinants of stove adoption

Domain	Variable	Theoretical expectation
Demographic factors	gender	– Gender of the household head affect stove adoption since the head of the household is often the sole/main decision maker in terms of budgetary allocations (Rhodes et al., 2014; Surendra et al., 2014). – Often, socio-cultural values and norms limit women's access rights and ownership of productive resources. (Assmann et al., 2006; Cecelski, 2000; Dutta, 2005; Miller and Mobarak, 2013; Shankar et al., 2015) – It is expected that women-headed households would embrace clean cookstoves to reduce the associated fuelwood procurement drudgery, compared to male headed households
	age	– Older heads are assumed to have accumulated knowledge over time to evaluate technological information than younger heads – older people can view modern stoves as non-traditional and therefore, oppose it – younger heads can have a relatively lower risk aversion and depict willingness to appraise new technologies
	family size	– Larger household have the capacity to reduce financial constraints for upfront costs (Schlag and Zuzarte, 2008). – Also, large household size is a measure of degree of labor availability and pressure to spend on other basic household needs such as food which can negatively affect adoption (Beltramo, et al., 2015; Abadi et al., 2017).
	dependency ratio	– Calculated as the ratio of non-income earning members of the household to income earning members of the household – Dependency ratio is a measure of active labour available in the household for economic activities, fuelwood procurement
	education	– higher education can influence respondents' attitudes and ability to analyze the benefits of the new cooking technology (Fraser et al., 2006; Ochieng et al., 2013; Osiolo, 2017; Porras et al., 2015).
Socio-economic factors	income	– Households with higher income are expected to have higher chances for adoption of clean cooking options (Mwirigi et al., 2014; Nguu et al., 2011; Nzila et al., 2012; Osiolo, 2017; Van der Kroon et al., 2014).
	Multidimensional poverty Index (MPI) Multidimensional energy poverty index (MEPI)	– MEPI (Nussbaumer et al., 2013) and MPI (Alkire et al., 2015) are often used as measures energy poverty and non-monetary poverty, respectively. Their estimation captures both the incidence and intensity of poverty *(see supplementary material for the estimation procedures)* – To determine the level of MPI and MEPI a poverty cut-off of 33.33% was used, implying that a household is poor if it scores above this threshold (Alkire et al., 2015) – MPI and MEPI are non-income indicators of poverty and can be possible deterrents of household ability to acquire a clean cookstove.
	dwelling	– biogas adoption requires an investment in long-term infrastructure since once constructed, biogas plants are structured permanently – modern housing could be positively affect adoption of biogas system since the installation demands a stable housing structure (Henriques and Schnorr, 2010; Nzila et al., 2012; Van der Kroon et al., 2014).

		– stable houses may also serve as a proxy indicator for wealth and more asset-rich for a given level of expenditures
	TLU (total)	– The number of livestock owned by the households converted into tropical livestock units [TLU] by species where the cattle are weighed with 0.7, pig at 0.2 and sheep/goat and chicken at 0.1 and 0.01 respectively. In this study, the species were selected on the basis of their applicability as biogas feedstock – Livestock is important component for sustained functionality of the biogas system and cooking gas production (Johnson et al., 2016; Lambe and Senyagwa, 2015; Loo et al., 2016; Rhodes et al., 2014).
	farm size	– Installation of biogas digester and management of the bio-slurry require a spacious and permanent land size
	land tenure	– A proxy of family wealth status and a prerequisite for installation of biogas system – Secure land rights facilitate planting of trees for fuelwood production and harvesting;
Institutional factors	extension visits	– Extension visits improve adequacy of information about farm and home improvement technologies
	credit access	– Access to credit from informal (e.g. table banking) or financial institutions (e.g. bank) – access to credit promote the adoption of risky technologies through reduction of cash liquidity constraint households (Johnson et al., 2016; Mutua and Kimuyu, 2015; Treiber et al., 2015).
	social group	– Partcipation of household members in social groups and organizations enhance social exchange of information about new and modern cooking technologies and change of perceptions (Beltramo et al., 2015; Murphy, 2001; Rhodes et al., 2014; Sesan, 2014; Shankar et al., 2014; Treiber et al., 2015)
Ecological factors	geographical location	– Locations determines supply, marketing and distribution infrastructural differences (Kituyi et al., 2001; Mahiri and Howorth, 2001; Arnold et al., 2006). – Urbanization is an indicator both of greater accessibility to modern fuels (improved market infrastructure) and of higher household income levels.
	agroforestry	– Integrating and planting trees on farm facilitate reliable access and sustainable supply of fuelwood Liyama et al., 2014).
	distance to woodland	– Long distance to the woodland is an indicator of fuelwood scarcity; and thus, can increase adoption likelihood to save fuelwood consumption and procurement drudgery (Scheid et al., 2019; Liyama et al., 2014; Drigo et al., 2013)

Table 3-11: Description of hypothesized variables used in the estimation models

Category	Explanatory Variables	Description	Type of measure
Demographic factors	Gender	Gender of the household head	1 if male; 0 if female
	Age	Age of the household head in years	Number of years
	Household size	The number of household members	Total number
	Dependency ratio	Ratio of non-income earning members of the household to income earning members	household dependency ratio
	Education	Categorized level of education level of the household head.	See table 5-3
Socio-economic factors	Income	Categorized household income level	See table 5-3
	MPI	A metric measure of multidimensional poverty	1 if household is poor; 0 if otherwise
	MEPI	A metric measure of multidimensional energy poverty	1 if household is poor; 0 if otherwise
	Farm size (acres)	Size of the farm land owned	Acres
	Land tenure	Right of land access.	I if land is purchased/inherited; 0 if rented/leased
	Livestock ownership	Number of livestock owned	Total livestock units (TLU).
	Water access (km)	Total distance to the household's main source of water from home	Kilometres
	Dwelling	Stable dwelling if floor is cemented	1 if stable; 0 if otherwise
Ecological factors	Distance to woodland	Total distance to the most common fuelwood collection woodland	Kilometres
	Geographic location	3 dummy variables for transect zones:	1 if peri-urban; if close-forest and 1 if semi-arid; 0 if otherwise.
	Agroforestry	Planted trees on farm	1 if planted; 0 if not planted
Institutional factors	Extension visits	Access to farm and/or home management extension services offered by government agencies	1 if households were visited by extension agents and 0 otherwise.
	Credit access	Access to credit from informal (e.g. table banking) or financial institutions (e.g. bank)	1 if have credit access; 0 if otherwise
	Social group membership	Household members' participation in community-based organizations and groups	1 if participating in social groups; 0 if otherwise

3.3.2.3 Discrete choice analysis

The choice experiment was designed and implemented following the Lancaster theory of value. The study hypothesize that the utility (U) that a respondent gets from a cookstove is based on the sum of product-specific attributes i.e. stove price ($price$), fuel usage cost ($cost$), indoor air pollution ($pollution$), and the environmental impact ($environment$) (*main effects*)

Under random utility theory, consumers choose their preferences, subject to constraints such as intrahousehold demographic factors, socio-economic characteristics and geographical location (*interaction effects*). Such variations in choices can be explained by proposing a random element as a component of the consumer's utility function. That is, $U_i = V_i + \varepsilon_i$. Where U_i is the unobservable true utility offered; V_i is the systematic (i.e. known component of utility; and ε_i is the random component representing errors in observation (Tait, et. al., 2009).

However, the presence of random component permits the analyst to only describing the probability of choosing alternative i over alternative j as;

$$prob(i\ chosen) = prob(V_i + \varepsilon_i > V_j + \varepsilon_j)$$

Therefore, in this study, a consumer faced with alternatives $LP\ gas$ and $Charcoal$, will choose alternative $LP\ gas$ if $U_{LPG} > U_{charcoal}$. The logistic form of the fitted model (the probability) for choosing the LPG stove is:

$$P(LPG) = \frac{\exp(V_{ch}^{lpg})}{\exp(V_{ch}^{lpg}) + 1}$$

Conditional logit was conducted using R-software packages described by Aizaki et al (2015) which provide the basic functions for supporting an implementation and analysis of discrete choice experiments.

Main effects model	$\boldsymbol{V_{ch}^{lpg}} = \boldsymbol{\alpha^{lpg}} +$ ((ß ^{price}(*lpg_stove_price*) + ß ^{usage}(*lpg_fuel_usage_cost*) + ß ^{pollution} (*lpg_indoor_pollution*) + ß ^{environment} (*lpg_environmental_impact*)) + ε
Interaction effects model	$\boldsymbol{V_{ch}^{lpg}} = \alpha^{lpg}$ + (α^{lpg} (ß ^{price} (*lpg stove_price*) + ß ^{usage}(*lpg_fuel_usage_cost*) $^{+}$ ß ^{pollution} (*lpg_indoor_pollution*) + ß ^{environment} (*lpg_environmental_impact*)) + δ^{lpg} (Ω) + ε

Where:

V_{ch}^{lpg}	= observed utility for LPG over charcoal
ß	= weighting parameter of a relevant attribute
α^{lpg}	= partial utility associated with a type of a stove which is not captured by other ßs (i.e. Alternative specific constant, ASC).
δ^{lpg}	= dummy of the alternative (LPG)
Ω	= determinant characteristics (geographical location and intrahousehold factors)
ε	= errors in observation

Alternative specific constant (ASC) for charcoal stove alternative was normalized to zero. The ASC for LPG alternative was included as the average effects of unincluded factors on utility of LPG relative to charcoal.

A mixed logit model was also carried out using to account for analytical robustness and heterogeneity (Train, 2009; Hole, 2013). In the mixed logit model, the utility parameters for all stove-specific attributes were specified as random parameters assuming a normal distribution. In this case, the probability for choosing the LPG stove is:

$$P(choice_n = LPG) = \frac{exp^{v(\beta_n, x_{lpg})}}{\Sigma_j exp^{v(\beta_n, x_{ch})}}$$

Where $\beta_n = f(\beta, \sigma|\nu_n)$, and β, σ are parameters to be estimated on the basis of stove preference heterogeneity or variations across the surveyed population. ν_n represent the individual or household-specific heterogeneity in stove preferences. Assuming a normal distribution, β and σ represent the mean and standard deviation, respectively.

In order to better understand the trade-offs made between specific attributes, the marginal willingness to pay (MWTP) was estimated based on stove price coefficient. The MWTP for each attribute was calculated to establish the amount of money surveyed respondents are willing to pay to obtain an additional non-monetary attribute (Ryan et al., 2008) .

The simulation method proposed by Krinsky and Robb, 1987 was employed

$$MWTP_i = \frac{\beta_{nm}}{-\beta_m}$$

where, β_{nm} is the estimated coefficient of the non-monetary variables (i.e. monthly fuel usage, indoor pollution, environmental impact), and β_{m} is the estimated coefficient of the monetary variable (i.e. stove price).

Note: In the design of the choice experiment described in this study, the monetary attribute levels illustrated in Table 3-8 were presented to the respondents in Kenya shillings (KES). However, the discrete choice analysis and marginal willingness to pay was conducted in US Dollars (USD) (Section 5.5). (At the time of this survey, the currency exchange rate used was 100 KES per USD)

3.3.2.4 Analysis of Impact Categories

3.3.2.4.1 Environmental impacts category

The per capita fuelwood consumption was estimated on the basis of total fuelwood consumed by a family, divided by the sample population (Kituyi et al., 2006). Averages and distributions were calculated for per capita fuelwood consumption (both self-collected and purchased). The analysis then focused on a comparison by stove use and geographical locations as depicted across the enumeration transects. Depending on the data types, two-sample independent t-test or one-way analysis of variance (ANOVA) with post-hoc Bonferroni test were used to compare means and test the statistical significance associated with the different study groups using SPSS 23. Ordinary least square (OLS) regression models were conducted to estimate the effects of geographical location and intrahousehold factors on fuelwood consumption. The following expanded log-linear specification for fuelwood consumption was used:

$$CNS_{FC} = \beta_0 + \beta_1 x_1 + \ldots \beta_k x_k + \varepsilon \quad (1)$$

$$CNS_{FP} = \beta_0 + \beta_1 x_1 + \ldots \beta_k x_k + \varepsilon \quad (2)$$

whereby CNS_{FC} / CNS_{FP} stand for the natural logarithm of the per capita consumption of self-collected (FC) and purchased fuelwood (FP); β_0 is the constant term; β_k is the standardized regression coefficient for the selected x_k variables explaining fuelwood consumption and ε is the error term.

The quantity of fuelwood saved was estimated as the difference between the quantity of fuelwood consumed while using traditional biomass stoves and the quantity of fuelwood consumed with the improved biomass stoves according to the formula:

$$B_{y,savings} = B_{y,traditional\ stove} - B_{y,improved\ cookstove}$$

In order to estimate the total greenhouse gas emission reduction potential, the methodology applied was based on UNFCCC[3] – CDM – AMS – II G, ver.10, "Energy Efficiency Measures in Thermal Applications of Non-Renewable Biomass" (UNFCCC, 2015). The Intergovernmental Panel on Climate Change (IPCC) default net calorific values (Johnson et al., 2010; UNFCCC, 2017), emission factors and fraction of NRB were used according to the formula:

$$ER = B_y \times fNRB \times NCV \times EF$$

[3] UNFCCC- CDM-AMS: The United Nations Framework Convention on Climate Change – Clean Development Mechanism – Approved Methodologies for Small scale projects

Table 3-12: Description of parameters

	Parameters	Value	source
ER_y	Emission reductions per stove	tCO_2e	Computed
B_y	Quantity fuelwood saved (substituted/displaced) per stove	tonnes	Survey estimates
NCV	Net calorific value fuelwood	0.0156 TJ/t	IPCC default value
EF	Emission factor of fuelwood	112 tCO_2/TJ	IPCC default value
f-NRB	Fraction of non-renewable fuelwood in study sites	Murang'a - 46.6% Kiambu – 53.4%	Drigo et al., 2015

3.3.2.4.2 Economic impacts category

This analysis was conducted to compare economic costs for households' switching from traditional biomass stoves to improved biomass stoves and the modern biogas stoves. By definition, unpaid work is essentially that work which does not receive direct remuneration and is not accounted in gross domestic product (GDP) calculations (UNDP, 2016) Quantifying the value of unpaid household work is important for time poverty analysis, as it highlight the fact that non-marketed provision of household services is essential for family welfare (World Bank, 2006).

In this study, the total unpaid time-use was estimated based on the estimated fuelwood collection time and cooking time as reported by the respondents. The unpaid time use was converted into a monetary value by assigning an hourly wage to the time spent using the replacement cost generalist approach (World Bank, 2006). This valuation method consisted of applying market wage rates from similar paid work occupations (UNRISD, 2015). In this study, the value of unpaid work was computed by executing what it would cost someone to do it following local hourly wage rates for casual agricultural labour in the study areas as described in equation 1 below (World Bank, 2006). At the time of this survey, the currency exchange rate used was 100 Kenya shillings per USD.

$OC_{it} = k_i + M_i + FT_i w + CT_i w$ …………………………………………….…….. (1)

In these equations:

OC_{it} = opportunity cost of the unpaid time use, for stove i

k_i = annual capital cost for the stove

M_i = the annual stove maintenance cost

FT_i = the time spent on fuelwood collection per annum,

CT_i = amount of cooking time per annum

W = measure of opportunity cost of the unpaid time use

For the household reliant on fuelwood purchased from the commercial fuelwood markets, the opportunity cost on monetary expenditure was estimated. The costs assessed include the stove upfront cost, fuel costs and maintenance costs as provided in equation 2 below. In the calculations, the capital cost for traditional stove is taken as zero since the three-stones are often freely collected within the household's environment. Based on consultations with local stove producers and marketers, the annual cost of stove maintenance and repair was assumed to be 5% of the stove cost.

$OC_{im} = k_i + M_i + FP_{im} Q_{im}$ …………………...…………………...…………. (2)

OC_{im} = opportunity cost of monetary expenditure, for stove i

k_i = annual capital cost for the stove

M_i = the annual stove maintenance cost

FP_{im} = the price per unit of purchased fuel

Q_{im} = the amount of purchased fuel

Furthermore, in order to determine the economic feasibility and financial viability of adoption of improved biomass stoves and biogas, the investment payback period was calculated. The discounted payback (PBP) was defined as the number of years required to recover the stove investment cost and it was estimated with the following formula:

$$DPP = -\ln\left(\frac{1 - IR}{C}\right) / \ln(1 + R)$$

Where:

DPP = the discounted payback period (years)

R = discount rate (7%) - (GoK, 2017)

I = total amount invested (fuel and stove costs)

C = the annual cash inflow (fuel monetary savings)

3.3.2.5 Social (health) impacts category

In order to understand the health effects of biomass stove use, a multivariable probit regression model was run to estimate the probability of self-reported health outcomes.

The self-reported binary (No/Yes) symptoms of primary cooks' health outcomes in the past 30 days prior to the date of survey for: respiratory (breathing difficulties, nose/throat irritations, coughing and phlegm); eye irritations; and injuries in form of burns/scalds was analyzed.

Explanatory variables included (a) binary variable for cooking location (1 if outdoors; 0 if indoors); (b) binary variable of cooking place (1 separate room; 0 if located within main living house); (c) dummy variable for location (1close forest, 1 semi-arid and 1peri-urban); (d) variables at the primary cook-level include age (years) and education level; (e) household-level variables include household size, having children below 5 years of age.

The probability and marginal effects of prevalence of symptom occurrence were estimated using STATA 15 according to the equation:

$$Y_{ijn} = \beta_0 + \beta'_n x_{ijn} + \varepsilon$$

$$Y_{ijn} = \{1 \text{ if } Y_{ijn} > 0; \text{ 0 if otherwise}$$

where β_0 is the constant term β'_n is the corresponding vector of parameters to be estimated; Y_{ij} denotes a health outcome for primary cook *'i'* in household *'j'*; This latent variable was assumed in this study to be a linear combination of both household demographic, socioeconomic and geographical location characteristics (X_{ijn}) as well as the unobserved characteristics that are captured by the stochastic error term ε

3.4 Study limitations

Using the methodologies outlined in this chapter, this study will holistically unpack the factors affecting stove adoption, preferences and associated sustainability impacts. Nevertheless, the study appreciates varying issues which were beyond the scope of this study, thus creating pathways for future research works as outlined in Section 7.4.

To begin with, the study acknowledges the existence of multiple stove use, where households use more than one stove, a concept often referred to as “fuel stacking”. While the study was able to obtain an inventory of these secondary stoves, it was not possible to obtain information about their frequency of usage. Second, while this study was one-off, it appreciates the existence of external factors including climatic conditions and seasonal variations. Such factors could have substantial ramifications for fuelwood procurement patterns, per capita fuelwood consumption patterns and the associated socio-economic and environmental impacts. In addition, the study acknowledges that it is not crystal clear whether the observed results in Chapter 6 entail causal effects on health, economic activity, and GHG emissions (i.e. impacts). In this respect, the study uses the term “impact categories” to better reflect this limitation.

While this study reports an in-depth analysis of stakeholder perspectives in a complex stove adoption system, it has some limitations. The survey may not have managed to capture the views of other equally relevant stakeholders in Kenya’s stove sector due to practical challenges. For instance, some identified and important respondents from international organizations and government agencies (e.g. energy regulatory authority or Kenya Bureau of Standards) were not accessible for interviews. Nonetheless, it is appreciated that most of the participants interviewed for this study were deemed the most appropriate due to their deeper knowledge, awareness and active participation in Kenya’s stove sector.

As outlined in Section 3.2.3.3, when it comes to sampling design to identify adopters of improved biomass stoves, this study followed a random sampling aimed to minimize household selection bias across the enumeration transects. In this way, the study is able to distinctly identify the effects and associated impacts of proximity to resources (i.e. the urban center and state forest). However, such a sampling strategy was not applicable when it comes to identification of the rather sophisticated biogas stoves where a purposive snowballing procedure was followed.

As outlined in Section 3.2.2.6 of the choice experimental design, the objective of the choice experiment was to study the impact of the relationships/trade-offs between different attribute levels have upon stove preference. Therefore, since the status quo alternative was excluded in the design of the choice experiment, it is impractical to explain a systematic bias of stove preference.

CHAPTER 4

MULTI-STAKEHOLDER PERCEPTION ANALYSIS: ADOPTION, IMPACTS AND POLICY GAPS IN THE KENYAN CLEAN COOKING SECTOR

4.1 Introduction

Kenya is one of the countries in SSA where the large-scale adoption of clean cooking options has the potential to catalyze widespread sustainability transitions (Karanja and Gasparatos, 2019; World Bank, 2017). However, despite large economic growth and technology adoption (e.g. mobile penetration rate is above 80% nationally), only 14% of Kenyans have access to clean cooking options such as LPG, electricity, solar and ethanol stoves (IEA et al.,2019). This continuous reliance on traditional cooking energy is to a large extent responsible for the significant lack of progress for meeting SDG7, rendering Kenya one of the top 20 access-deficit countries to modern cooking technologies and fuels (IEA et al., 2018). This situation seems a bit paradoxical considering that Kenya has a long-established and highly developed clean cookstove sector compared to other SSA countries (Karanja and Gasparatos, 2018).

The international community, through various partnerships, has also attempted to boost financing in the Kenyan clean cooking sector. However, the Kenyan clean cookstove sector is currently at a crossroads. At the same time many different stakeholders are operating in the sector, in what often feels to be a crammed space. This includes a multitude of stove manufacturers, government agencies, research institutes, civil society organizations, and international donors, among others (Karanja and Gasparatos, 2019). Often these stakeholders hold radically different perceptions of how to enhance the adoption of clean cookstoves and improve the sustainability of the sector. This often results in uncoordinated and fragmented actions, which curtail the effective large-scale adoption of clean cooking options in the country (Johnson et al., 2016)

The aim of this chapter is to elicit the perspectives and insights of the main stakeholders involved in the Kenyan stove sector about the adoption (drivers and barriers), perceived impacts and requisite approaches to enable scaling up access to clean cooking in Kenya. The study identifies convergences and divergences in their perceptions through semi-structured interviews with 28 stakeholders that play a major role in the clean cooking sector as identified through an extensive literature review and institutional analysis (see Section 1.3). Through its multi-stakeholder perspective, this study offers a valuable addition in the literature that has mainly explored the factors influencing the adoption and the impacts of clean cooking options in Kenya through the lens of households.

Section 4.2 presents stakeholder perceptions about the factors influencing the adoption of clean cooking options (Section 4.2), the impacts of stove adoption (Section 4.3) and the way for accelerating adoption in the country (Section 4.4). Section 4.5 synthesizes the elicited perceptions from this stakeholder exercise.

4.2 Drivers and challenges of stove adoption

4.2.1 Fuel and technology characteristics

4.2.1.1 Affordability, accessibility and availability

Stove market issues were by far the most frequently mentioned barriers of stove adoption in Kenya. Many stakeholders highlighted that the upfront cost for clean cookstoves is not only high for consumers at the bottom of the energy pyramid but does not often align with their unstable income cycles characterized by multiple, variable and informal income streams (e.g. small-scale traders and craftspeople commonly known as *juakali*). For such income groups, clean cookstoves essentially becomes unreachable, as they often compete with food and other household basic necessities that would take budget preference in decision-making (personal comm: MoGYA;CCAK;BML;E-bank).

There is large variation in the upfront costs of clean cooking options. For example, in rural Kenya the average cost for an advanced biomass stove is about USD 40 (personal comm: GIZ-1;BML), while that of a biogas installation USD 1000-1500 depending on bio-digester capacity (personal comm: SES;MPL). This makes many consumers reluctant to uptake the technology for the fear that it might take a very long time to recover the money if there is no added incentive apart from saving on fuel costs (personal comm: MPL).

Several stakeholders expressed that an added barrier is the fact that some stove types come with extra and recurring fuel costs (e.g. pellets, LPG) (personal comm: MoE; CCAK). For instance, the upfront cost of a complete set of a 6 kg LPG cylinder and a burner is USD 45–60 but requires periodic refilling depending on use patterns. However, different stakeholders expressed optimism that LPG stoves have the potential to thrive in rural areas if provided in small dispensable portions (through licensed distributors and retailers at their nearest shopping center) and at affordable prices (personal comm: MoE; MoA; SEI). On the other hand, even when accessible, the high and variable costs associated with electricity have also been cited as barriers of adoption (personal comm: SEI;CCAK;KCIC).

On the other hand, the escalating direct monetary costs to procure fuelwood (partly due to scarcity) and the fuelwood savings provided by improved and advanced biomass stoves have been cited as important drivers of clean cooking adoption (personal comm: CCAK;GACC;MoE;BML). Often, indirect costs associated with fuelwood procurement and cooking can become equally important factors for cooking options decisions. For example, in many rural areas women and children lose significant amounts of productive time cooking and searching for twigs and branches depending on availability and scarcity (personal comm: CCAK;SEI). Such opportunity costs can often influence households to adopt clean cooking options, as they reduce time investment for cooking and fuelwood procurement, allowing them to pursue other livelihood and education activities (personal comm: MoGYA;GIZ-1) (see also Section 4.3.5).

4.2.1.2 Stove design, functionality and performance

There is a large consensus among stakeholders that cookstove design can affect the overall stove quality and functionality, contributing significantly in their adoption and long-term sustained acceptance (personal comm: GACC;UoN) (see also Section 4.2.4.2). In this regard many stakeholders emphasized that in rural contexts there is often a significant mismatch between products and market, which prevents mass adoption (personal comm: MoA;BML).

Many stakeholders also mentioned that design quality and good stove performance is often related/associated with convenience, ease of use and appealing appearance (personal comm: BML;GACC). Regarding convenience, stove design is often critical for meeting user needs, e.g. by allowing the preparation of local dishes and compatibility with traditional cooking utensils (personal comm: MoA) (see also Section 4.2.1.3). Furthermore, households also value convenient stove designs that have added functions such as space heating during cold seasons, portability for outdoor cooking, easy ignition, and the ability to hold larger/multiple cooking pots to cater for larger family sizes or gatherings (personal comm: MoA;CCAK;SEI). When it comes to appealing appearance, many stakeholders stressed that women (who are the most common stove buyers) tend to value highly aesthetic appeal (e.g. modern and attractive appearance including stove colours) (personal comm: MoE;BML).

On the other hand, poor design characteristics such as inconvenient stove size, instability, failure to accommodate specific cooking styles, lack of versatility in fuel use, and extensive resources for stove maintenance and renovation can be significant barrier of stove adoption (personal comm: BML;ECO2;SEI; UoN). On that regard, one of the respondents mentioned that *"...some of the designs in the market are too small in size to hold a stove for a bigger family, easy to topple or cause safety hazards in the kitchen. It is also a lot of work for the woman in the village to chop the fuelwood into tiny pieces that can fit in most of the improved wood stoves"* (personal comm: GIZ-1). Several respondents also pointed that though some of the cookstoves may be efficient, but they tend to cook very slowly (e.g. ethanol stoves) (personal comm:MoE;CCAK). Such stoves tend to require long cooking times, which may limit the type of dishes that can be cooked, reducing thus their appeal to some households (personal comm: MoA).

4.2.1.3 Sociocultural compatibility

There was a consensus among stakeholders that in order to enhance stove adoption in rural Kenya, they must be compatible with local capabilities, tastes and preferences. Many participants argued that there is a relationship between stove and the type of traditional dishes that can be cooked (personal comm: CRIT). For instance, kneading and mashing *ugal*i, (a common dish in Kenyan households) require a strong and stable stove, especially when cooking for a large family (personal comm: GIZ-1;GIZ-2).

Many other cultural practices related to taste and health were identified as deterring stove uptake and sustained use. These include:

- *"If you go to a manyatta of the Maasai community, they keep open fires to keep away houseflies. The use of clean cookstoves may not meet this crucial need unless you provide an additional solution to keep away the flies" (*personal comm: MMU*)*
- *"…there is the preference perspective where local people feel that food tastes better when cooked with smoky flavour, while other cultures use the smoke to preserve food" (*personal comm: MoA*)*

4.2.2 Demographic and psychosocial factors

4.2.2.1 Household characteristics and decisions

Some stakeholders highlighted that clean cookstove technology designers and programme implementers often over-simplify or inaccurately abstract the role of household characteristics and social complexities of rural life for stove adoption (personal comm: SEI;IFAD). For instance, women are likely to be the main "audience" of many efforts/activities to increase the awareness of (and enhance demand for) clean cooking options (personal comm: CCAK;MoGYA). However, males often make household decisions regarding expenditures and budget allocation (including for cookstoves) without necessarily using and/or directly benefiting from the stove. These stakeholders further explained that such abstractions and over-simplifications may in turn lead to misconceptions about the target market segments, including who has the purchasing power in households. In such situations, investing in a new clean stove seldom becomes a priority in the household expenditures (personal comm: MoE; ECO2;GIZ).

When it comes to the adoption of biogas technologies, some stakeholders indicated that a major challenge is lack of secure feedstock. In particular households not owning enough cows (often a minimum of 2-3 cows) cannot sustain biogas production, which deters uptake and sustained use (personal comm: SES;MPL;MoE). A similar, and possibly more important barrier to biogas adoption is the lack of stable land tenure or large landholding to place the bio-digester (personal comm: MPL).

4.2.2.2 Awareness and behavioural change

Multiple stakeholders identified awareness as a major driver and barrier of clean cooking adoption as it is often the first step to any action and progress (personal comm:). While poverty is often assumed to be a factor behind low adoption, this notion may not always correct (personal comm: KEFRI). Indeed, many potential clean cookstove users in Kenya are either completely unaware of alternative cooking technologies (i.e. do not know their existence) or are ignorant about their operation, intended benefits and personal relevance to them (personal comm: GACC;MoE;MoA). Some stakeholders asserted that in Kenyan society, there are great disparities, where on one hand are consumers that can afford a clean cookstove but they do not like it (or feel that they do not need it), and on the other hand are consumers that are willing to buy clean cooking options at very high prices (personal comm: PAC;CRIT;SEI).

Consumer behaviour was perceived as complex and that it can be challenging to catalyse new cooking practices and habits because clean cookstoves typically operate differently compared to the traditional biomass stoves, with which most consumers are accustomed to (personal comm: CCAK;SNV;PAC). With a wide range of clean cookstoves currently available in the market, consumers are now confronted with different fuel options or fuelwood preparation techniques (e.g. fuelwood chopping into very small pieces). Adopting such cooking options would require a significant shift in cooking practices and overall user behaviour change, which is not to be underestimated until the new stove becomes part of the daily household routine (personal comm: SNV;ISAK;CRIT). This for example could require the adaptation of recipes and the development of new cooking habits to make the most of the new stove (personal comm: ISAK;UoN). Another relevant awareness aspect is the critical role of consumer education on stove usability and kitchen management (e.g. ventilation, positioning of fuel/cooking pot, fuel management) (personal comm: MoGYA;KCIC;MMU). A particular stakeholder highlighted how in some areas development agencies disseminated stoves freely without explaining their benefits or mode of usage, resulting in the beneficiaries simply discarding them (personal comm: IFAD). In other cases, certain cooking technologies can pose a significant stigma in local societies (e.g. biogas technologies that utilizes animal or human waste as feedstock) (personal comm: MPL;MoE).

Several stakeholders raised that generally, as in other African cultures, Kenyans are not adaptive to new technologies and do not like "struggling" with new techniques (personal comm: CCAK;NEMA;KFS). On the contrary, the Founder of Burn Manufacturing expressed that consumer perception and behaviour change depends on consumers' satisfaction with the product design and functionality: "*…if the user is satisfied with the product, they will have the self-initiative to change their cooking habits and develop a new routine"* (personal comm: BML).

LPG was a brought up in many interviews as an example of how such aspects play a critical role in clean cooking adoption. Low adoption has been to a large extent a combined effect of the negative perceptions that food does not taste good when cooked with LPG (personal comm: MoA;SEI), low user education (personal comm: KCIC;KFS) and lack of awareness about safety issues (personal comm: MoH;SES;CCAK). Indeed, in the past, accidents involving LPG stoves have been sensationalized and increased consumer skepticism over safety issues.

4.2.2.3 Social influence and status

As already discussed in Section 4.2.1.1, costs (in terms of time, money, fuel) play a major role behind stove adoption. However, once consumers start using specific stoves, all that matters is whether the stove operates as expected (Section 4.2.1.2). In Kenya, consumers use mainly social networks such as women groups or Savings and Credit Cooperatives Societies (SACCOs) to learn about product functionality, recommend good products, and raise grievances about bad product performance (personal comm: MoGYA;ISAK;KENDBP). Bad product experiences more often than not result to negative messaging, which can hurt substantially adoption, especially in close-knit communities (personal comm: ISAK;GIZ-2). On the other hand such networks can also facilitate the adoption, for example by spreading experiences/comparisons (e.g. cleanness of kitchen walls with clean stoves compared to the black walls for kitchens with 3-stone fire). Thus such networks can forge immensely social acceptability that can either facilitate stove adoption or pose a major barrier (personal comm: GIZ-2;SEI; BML).

The element of improved social status and social prestige that comes with the adoption of some clean cookstoves cannot be ignored. Stakeholders asserted that clean cooking often conveys modernity, wealth, or sophistication, all of which can elevate the social status of adopting households (personal comm: GACC;SNV).

4.2.3 Market Development

4.2.3.1 Spatial patterns

Spatial characteristic can play some role in stove adoption as since some cookstoves designs and modifications vary according to what is demanded in specific and geographic regions. For instance, most landlords in urban areas prohibit the use of firewood, while there is limited space to operate a 3-stone fire (personal comm: MoGYA;BML). In such settings, charcoal stoves are more widely adopted as they burn more cleanly compared to wood (personal comm: SEI).

Similarly, the ever-growing number of LPG marketing companies is concentrated in urban areas where the market is already developed with a well established the distribution infrastructure, and the overall market risks are low (personal comm: KCIC). For exactly the same reasons the LPG market remains untapped and underdeveloped in rural settings, include high market risks and distribution costs (personal comm: MoE;DVL).

4.2.3.2 Community involvement and post-acquisition support

The good understanding of consumer preferences, constraints and behaviour, can influence the design of clean cooking products and interventions that meet better consumer needs and enhance the adoption and sustained use of clean cookstoves. In particular, many stakeholders asserted that central to achieving the objectives of clean cooking interventions is preventing or solving mismatches between capabilities of local communities and the characteristics and functionalities of new technologies (personal comm: SNV;GIZ-2). It was suggested that the focus of many clean stove dissemination programs actually rests on the technology itself, while not achieving the active participation of active users and misunderstanding the local context (personal comm: GIZ-1).

It was underscored that stove manufactures and innovators need to involve consumers (particularly during stove design) to facilitate the development of stoves that meet local needs and preferences (personal comm: CRIT;UoN). In particular, women involvement can be critical as they are typically the primary users of stoves, and often command a significant knowledge about local conditions and resources (personal comm: MoGYA;SEI). The stakeholders quoted regularly a study commissioned by GACC (Shankar and Onura, 2016) which identified that if/when equipped with the same entrepreneurial training, women exhibited a noteworthy latitude to sell clean cookstoves than males (e.g. SEI;KCIC;UoN). Another finding of the GACC study that resonated with many respondents is that when women sell stoves to other women, the buyers were more likely to report sustained cookstove use and the benefits of clean cookstoves, when compared to male cookstove sellers (personal comm: SEI).

Furthermore, stakeholders stressed that sustaining clean cookstove demand and use requires an iterative approach that should not end once households acquire the clean cookstoves (personal comm: GIZ-2;KCIC). Thus an extra challenge faced by the cookstoves market is to not only stimulate demand for the initial sale, but also to maintain interest in the product use throughout its lifetime (personal comm: BML). Sustained adoption can be improved when product manufacturers and distributors identify cost-effective ways and feedback mechanisms for engaging with customers (both existing and new), gauging customer satisfaction, identifying the critical points in the process when extra support is needed, and ensuring stoves operate properly (personal comm: SEI;CCAK;GACC).

The Founder of Burn Manufacturing outlined their success strategy as fostering consumer loyalty, establishing customer relationships, and building trusting relationship for the longer-term support. He stated that: "*... we often check in with our customers 6 months after purchase to measure their initial satisfaction with the stove and ask them about their usage. ...we also encourage repeat purchase behaviour if their stove is at the end* *of its useful life, we can send them SMS messages about our latest products and may offer them a purchase discount"* (personal comm: BML).

4.2.3.3 Market messaging techniques

Strategies to generate stove demand can vary across target populations due to regional differences in fuel resources, taste preferences, and other aforementioned cultural factors. Thus tailoring stove promotion messages should not be underestimated by stove manufacturers and project implementers (personal comm: KCIC;GACC;BML). Some stakeholders argued that, when considering consumer psychology, it might be better to advertise clean stoves as modern, healthy, attractive, and something that everyone *'must have'* (personal comm: BML). This is because some of the tangible positive impacts of clean stoves (Section 3.2) such as climate change mitigation, health improvement, and environment conservation are still abstract for many Kenyans (personal comm: CCAK;GIZ-1;UoN).

Out of these tangible impacts it is possible that indoor air pollution effects on health could be the easiest to communicate (personal comm: CCAK; MoH). In that respect sensitization messages should focus on easy to comprehend messages such as that 14,000 people die prematurely every year in Kenya due to indoor air pollution (Section 4). As one respondent aptly expressed: "*…let them hear the figures to visualize the impact and instil their confidence in the efficacy of the product"* (personal comm: MoH). In this respect local health services can raise awareness during clinic visits about both the health benefits of clean cooking and good cooking practices (e.g. kitchen ventilation, keep little children away from cooking areas) (personal comm: MoH;MoA;GIZ-2).

Furthermore, some stakeholders touched on how important it is to channel effectively this information in a way that both resonates to the needs of target consumers and utilizes creative marketing tools such as social marketing (e.g. SACCOs, women groups) (personal comm: CCAK;BML). Towards this end it would be important to collaborate with recognized consumer brands that inspire consumer confidence, trust and willingness to buy clean stoves (personal comm: GACC). Two further strategies to strengthen marketing outreach could be to mobilise (a) community leaders (e.g. chiefs, religious leaders), (b) local administrators, and (c) cultural icons (e.g. popular musicians and television programs) (personal comm: GACC;BML;MoE).

4.2.3.4 Supply and distribution networks

Poor distribution models often increase stove/fuel prices and reduces their availability. Improving the distribution networks can have a positive effect on clean stove adoption and sustained use, as it can encourage distributors and manufacturers to roll out their products to more markets and local distribution centres (personal comm: DVL;BML;MPL). For many low-income customers, infrastructural challenges related to lack of road access and formal addresses, and large distance from city centres, is a reality that can hinder the adoption of clean cooking options (personal comm: BML). This often complicates the last mile distribution of clean cooking options (such as LPG and pellets) contributing to unpredictable fuel supply, whereas other non-clean fuel such as kerosene is easily available (personal comm: BML;CCAK).

Some respondents advocated that investors can take advantage of the widespread adoption of mobile money payment methods in Kenya to increase the convenience of their services (personal comm: CCAK;GACC;PAC;ISAK). For instance, the PayGo Energy system enables access to LPG by providing a smart meter and a pay-as-you-go service through mobile money in order to tackle last mile delivery challenges (personal comm: CCAK; UoN). With the PayGo smart metering system, consumers are able to conveniently prepay for small amounts of cooking fuel based on their disposable income at the time (personal comm: CCAK).

4.2.3.5 Business financing mechanisms

Funding availability often restrains efforts to develop innovative clean cooking options and hinders the growth of many clean cooking enterprises (personal comm: GACC;E-bank). Many traditional financial institutions do not understand well the viability of clean cooking investments viability or the underlying business models (which are sometimes still new in the market) (personal comm: GACC;AFRISOL;SES). In addition, it was emphasized that few investors are prepared to generally support companies at their early stages, particularly those operating in unproven markets such as clean cooking (personal comm: BML;MPL;DVL).

However, through the interviews, three major financing avenues that are currently present in the Kenyan clean cookstove space were identified:

i) direct international funding to clean cooking ventures through carbon trading schemes (such as UNFCCC – Clean Development Mechanism, Gold Standard and voluntary markets) and grants from donor organisations (personal comm:MoE;SEI;UoN;ECO2).

ii) domestic funding through the Kenya Climate Innovation Centre (KCIC) that provides incubation, capacity-building services and financing to Kenyan entrepreneurs for clean energy solutions. The KCIC CEO explained that most of the entrepreneurs join the initiative at the stage of idea formulation and are provided with advisory services until they reach the growth stage. Subsequently KCIC provides them with "seed funding" to move to the project implementation stage (personal comm: KCIC)

iii) funding assistance from GIZ-EnDEV and SNV Netherlands Development Organisation that promotes result-based projects. This route provides incentives to micro-finance, SACCOs, and to any other financial institution to develop stove credits. Such efforts sensitise the financial sector on the current possibilities and potential in the cookstove sector by providing risk guarantee funds, negotiate for lower interest rates (less than 10%) and a grace period (personal comm: GIZ-1;SNV).

4.2.3.6 *Consumer finance mechanisms*

As discussed in section 4.2.1.1, costs are a major factor that can prevent the adoption and sustained use of clean cookstoves. Innovative strategies can curb such constraints by offering flexible financing and payment options to consumers (personal comm: GACC). For instance, the CEO of Sustainable Energy Strategies Ltd. commented that for about 95% of their installed biogas units, the company has to work with micro-finance institutions to help those who cannot afford the high upfront costs (personal comm: SES).

Several stakeholders believe that it is more advantageous to offer micro-credit opportunities and longer payment periods rather than giving out free stoves (personal comm: SEI;SNV;UoN). For instance, some stakeholders from the private sector have mentioned the benefits of initiatives, and in particular the partnership between Equity Bank and Micro-Energy Credits (MEC) in 2013 (personal comm: E-bank;MPL;KCIC). Through a USAID-funded project ["Developing a Sustainable Cookstove Sector" (DSCS)], Winrock supported the expansion of this program to sell improved cookstove products through the network of Equity Bank branches and retail shops, offering to bank customers improved charcoal cookstoves from Burn Manufacturing, EcoZoom and Envirofit, among others, ranging between USD 35-46 (personal comm: E-bank;BML)[4].

4.2.4 *Regulations and Legislation*

4.2.4.1 *Tax and import duties*

Some stakeholders lauded the Kenyan government for taking steps in the 2016-2017 budget to reduce import duties for improved cookstoves (from 25% to 10%) and not placing a VAT on clean cookstoves, raw materials, and their accessories (personal comm: GACC;CCAK;PAC;MoE;CRIT; BML). The budget proposal also enforced a zero VAT on clean cookstoves, in an effort to make the cooking technologies more affordable. Furthermore, the Kenyan government announced the removal of the 16% VAT on LPG and increased kerosene costs by Kshs 7.20 (USD 0.07) to disincentive its use while at the same time incentivizing the adoption of cleaner cooking fuels (personal comm: CCAK).

However, despite the efforts of the Kenyan government to improve cooking energy access, the domestic stove manufacturers and assemblers continue to face difficulties (personal comm: BML;DVL). Many of the affected stakeholders (especially from the private sector) lamented that the government strategically increased the tariff rates for raw materials from the United States, but decreased the rates from Chinese imports, even if they do not produce very strong and good quality products (personal comm: BML). Due to these circumstances, the use

[4] The program had sold by 2017 more than 11,500 improved cookstoves (cash and loan sales combined). With such a mobile lending tool, the program has been able to reach more potential customers with affordable loans for clean cookstoves (personal comm: E-bank).

of sub-par material for stove production has taken a toll on the quality of their products, affecting both stove sales but also brand/product reputation (personal comm: BML,DVL,CCAK).

4.2.4.2 Quality assurance

Several respondents brought up that various issues related to quality assurance can play an important facilitating role for stove adoption (personal comm: AFRISOL;MoE;MoH;GACC). These include aspects related to stove standards, quality control and enforcement mechanisms that are essential when rolling out new (cooking) technologies at a large-scale (personal comm: AFRISOL;MoE;SEI;UoN). Implementing verifiable and replicable stove standards and management systems is important for both the technical and operational sides of cookstoves supply and demand (personal comm: MoE;KCIC; PAC).

Some stakeholders insisted that the sustained adoption of clean cookstoves depends on reliable testing procedures and quality assurance at source (personal comm: GACC;CCAK;PAC;MoH). Towards that end, in 2005, the Kenya Bureau of Standards (KEBS) developed household stove standards (KS 1814-1:2005) (GoK, 2013b) to ensure the quality of stoves introduced in the market. However, these standards currently address thermal efficiency, durability and the testing approach, but remain silent about the volume of toxic emissions (personal comm: MoE). Similarly, the Kenya Standard (2520:2013) has established parameters to ensure the efficiency, safety, and durability of biogas stoves and digesters installed in Kenya (personal comm: MoE;SES;AFRISOL;KENDBP).

Stakeholders highlighted that many of the stove products entering the market need to be subjected to systematic evaluation of their performance and quality (personal comm: GACC;MMU;SEI). They suggested that measures such as labelling after installation (to identify and blacklist counterfeits) can build consumer trust and have a positive effect on adoption (personal comm: CCAK). For example a star ratings similar to that of household electrical appliances, would allow the consumer to make a more informed decision when selecting a cookstove (personal comm: CCAK;MoH).

However, it was noted that stove quality does not necessarily assure the delivery of good cooking energy services, as the actual technology (i.e. stove) is only one part of the cooking energy system (personal comm: BML;UoN;SEI). For instance, if wet firewood or inferior biomass is used for cooking in improved biomass stoves, then the users might still complain about poor stove performance, possibly ceasing its use. It is therefore imperative to distinguish between technical performance and user behavior, which is a key aspect of user-training and post-acquisition support as discussed above (Section 4.2.3.2).

4.3 Impacts of clean cooking adoption

4.3.1 Energy access and energy poverty

Many stakeholders asserted that clean cookstoves can catalyze access to reliable and safe energy to some the most vulnerable people in Kenya, contributing manifold in improving their quality of life (personal comm: MoH;MoGYA;GACC;PAC;AFRISOL;BML). For example, clean cookstoves can curb (or totally diminish) fuelwood demand that is gradually becoming scarce in some parts of Kenya (personal comm: BML;MoE;KEFRI;KFS). This can reduce the large recurring household expenses related to fuelwood purchases (personal comm: GIZ-1;MoA;KEFRI;CCAK). Furthermore, with stable supply-distribution systems, some interviewees advocated that LPG would be an excellent option to deliver modern energy services in rural areas, thus increasing easy access to modern energy markets and enabling households to utilize modern energy for the first time (personal comm: MoE;MoH;GACC;SEI).

This increase in adoption can have multiple benefits at different scales. At the national/regional level such cost-effective solutions could help transition to a renewable and more sustainable energy system for household energy (personal comm: MoE;NEMA). At the household level such affordable cooking options can have multiple positive effects in reducing energy poverty for a large segment of the Kenyan population (personal comm: BML;GACC;PAC;SNV;GIZ-1).

4.3.2 Environmental impact

Many stakeholders mentioned that the use of biomass energy in inefficient stoves, especially in the rural areas, is highly unsustainable and exerts pressure on the local forest resources (personal comm: KEFRI;KFS;NEMA;UoN;CCAK;GACC;SNV;SEI). Several stakeholders highlighted that unsustainable fuelwood harvesting plays a major role in deforestation and land degradation in Kenya (personal comm: KFS;IFAD;NEMA;MoE;CCAK;KEFRI). As already discussed in Section 4.3.1, clean cooking options might reduce or altogether divert the need for fuelwood and charcoal. In that respect the promotion of clean cookstoves can have positive effects in reducing the high levels of deforestation in the country (personal comm: IFAD;KFS;UoN;CRIT).

However, some stakeholders highlighted that the reduction in firewood consumption does not necessarily ensure stability of wood resources (personal comm: MPL;SES;AFRISOL). In fact it was mentioned that the use of improved biomass stoves without replanting would simply prolongs the ultimate consequences of deforestation (personal comm: DVL). Towards that end, stove promotion and adoption efforts need to be coupled with sustainable biomass production practices, such as agroforestry systems, woodlots, trees-on-farm and communal forests (personal comm: KFS;NEMA;IFAD). Furthermore, there is a need to identify and introduce the most appropriate fuelwood species that are desirable by the communities for cooking purposes (personal comm: KEFRI;MMU;UoN).

Apart from deforestation, some stakeholders also pointed to the possible benefits that modern cooking options can play in reducing GHG emissions associated with the traditional methods of charcoal production and cooking (personal comm: KEFRI;KFS). Suggestions included the modernization of charcoal kilns coupled with the adoption of efficient charcoal stoves that can reduce GHG emissions for climate mitigation (personal comm: KEFRI;NEMA;IFAD).

4.3.3 Health

Almost all stakeholders were well versed about the negative health impacts of traditional cooking practices, especially those related to respiratory and other health problems associated with indoor air pollution (personal comm: MoH; MOGYA; MoE; MoA; BML; DVL; AFRISOL;SES;CCAK;GACC;KCIC;NEMA;IFAD;GIZ-1;SEI;CRIT;UoN;KEFRI;MMU). In addition, some stakeholders also mentioned health issues related to drudgery such as headaches, back/neck pains and spine injuries for women and girls carrying heavy firewood loads (personal comm: GIZ-1;GIZ-2;SNV;SEI;ISAK;CCAK). There were also reflections about the safety concerns such as burns (e.g. little children falling in open fires) or poisonings (e.g. from kerosene stored in soft beverage bottles) (personal comm: MPL;SEI;MoA;MoH).

It was emphasized that access to modern cooking energy can substantially reduce such health complications, possibly being one of the most important impact of clean cookstove adoption (personal comm: MoH;NEMA;IFAD;SNV;PAC). Such positive impacts can manifest both through advanced/improved biomass stoves with chimneys to direct smoke outdoors (personal comm: GIZ-1;ISAK;MoE), or through a switch to clean burning methods such as LPG, biogas and ethanol stoves (personal comm: MoE;AFRISOL;KNBDP;GACC).

4.3.4 Improved livelihoods

As highlighted in Section 4.3.1, access to modern cooking energy can provide monetary savings to user households (personal comm: UoN;KEFRI). These savings can be invested to purchase basic household necessities or improve the productive capacity of households (e.g. in income-generating activities) (personal comm: GIZ-1;MoE;BML;SEI). In this sense clean cooking options can have ripple positive effects to household livelihoods (personal comm: IFAD).

Livelihood benefits can span beyond end user households. For instance, some stakeholders asserted that the introduction of clean cooking options has contributed to the development of micro-economies and the modernization of small commercial enterprises (e.g. food preparation kiosks, local restaurants) in both the rural and urban areas (personal comm: MoA; GIZ-2;CCAK;IFAD). The significant employment generation potential across the entire clean cooking value chains was often highlighted for stove producers, marketers, installers, and artisans, often in the form of small-scale entrepreneurship (personal comm: GIZ-1;ECO2). For instance, the construction of a single biogas installation involves about 20 man-days of both skilled and semi-skilled labour (personal comm: SNV;AFRISOL;SES; KNBDP).

4.3.5 Education

Stakeholders asserted that there is a strong association between the time children spend on firewood collection and the likelihood of school attendance, especially among girls (personal comm: MoA;MoGYA;GIZ-2). Furthermore, even when fuelwood collection does not cause school dropout, children are often tasked to collect firewood after school, rather than playing and attending to their school homework (personal comm: SEI). Furthermore, reduced exposure to indoor air pollution can reduce health issues (Section 4.3.3), hence they do not miss out on education (personal comm: MoH;UoN;IFAD). In this sense, many stakeholders highlighted that access to modern energy services (due to lower demand for fuelwood, Section 4.3.1) can translate into increased time for education and reduced fatigue, thus encouraging school attendance and reducing dropout rates particularly for rural children (personal comm: MoE;MOGYA;GIZ-2).

By saving on cooking fuel schools that offer feeding programs can save on costs and alleviate school budgets. Such savings can invested to improve the quality of their education services and expand their feeding programs that are often a strong incentives for poor families to send children to school (personal comm: MoA;CRIT;SNV) (see also Section 4.3.6). Some examples of institutional biogas projects in schools include the 200m^3 digester in Kaimosi Teachers College (human waste), 120m^3 digester at the University of Nairobi, Kabete campus (cowdung) and Mangú High School (sewage and dung) (personal comm: MoE).

Furthermore, some stakeholders brought in an interesting dimension that the education sector can foster an increased awareness about clean cooking, and its benefits (personal comm: IFAD;MoA). In this sense integrating cooking energy information into school curricula can educate directly children (i.e. future end-users) and indirectly sensitize parents about cooking energy issues, including the benefits of clean cooking options (personal comm: IFAD;MoE). In this sense it can provide an impetus for curbing some of the most important barriers related to the adoption of clean cooking adoption (Section 4.2 and 4.4)

4.3.6 Food security

There is a strong linkage between food and nutritional security, and how food is prepared, with the latter being directly related to cooking energy provision. Some stakeholders suggested that due to fuelwood savings, some clean cooking technologies can increase fuel availability for food preparation (Section 4.3.1). This can facilitate the regular preparation of highly nutritious meals consisting of legumes and beans that have a high cooking energy requirement (personal comm: MoA). However, it is worth noting that some clean cookstoves such as ethanol stoves, while highly efficient, they also cook slowly limiting the variety of foods cooked at home (personal comm: MPL;UoN).

Consistent to other SSA countries, very few local foods can be consumed raw in Kenya, especially those with high nutritional value such as beans, legumes and tubers. In areas with fuel shortages, local communities often resort to fast-cooking food as a coping strategy, which is however often of lower nutritional value (personal comm: MoA;CRIT). Another relevant food security dimension highlighted by stakeholders is that fewer hot meals may be prepared per day with traditional cooking devices. This can lead to the consumption of stale or leftover foods that could be contaminated, causing nutrient loss and increased risk of infection (personal comm: MoH). Undercooking to save fuel can also cause some food-related health problems, as some pulses and oils become toxic when undercooked (personal comm: UoN).

Despite the current incentives and campaigns to promote clean cooking, the sociocultural dimensions related to traditional cooking stoves should not be ignored. For example several communities in Kenya roast maize, bananas, or sweet potatoes over the traditional stoves (personal comm: MoA;SEI). For these types of food, boiling alters the nutritional value while roasting improves nutrition (personal comm: MoA).

4.3.7 Women empowerment

Many of the impacts outlined above are gender-differentiated, in that women and men are often affected differently by access to clean cooking technologies (or lack thereof). Some stakeholders clarified that energy poverty (Section 4.3.1) has a more pronounced effect to women and girls due to the large toll it takes on their time, resulting in 'time poverty' (personal comm: BML;DVL;ECO2;ISAK;GACC; CCAK;MoGYA). It was emphasized that women spend disproportionate amount of time gathering fuelwood, resulting in severe opportunity costs that prevent them from participating in other beneficial ventures including education (Section 4.3.5), income generating activities (Section 4.3.4) and self-care (personal comm: PAC;SNV;GIZ-1;MoGYA;MoA). Furthermore, due to their disproportionate involvement in fuelwood collection and cooking, females and girls face disproportionately the negative health outcomes associated with traditional cooking (Section 4.3.3) (personal comm: SES;PAC;MoH; KEFRI;CRIT;KCIC).

On the other hand, the clean cooking sector provides multiple opportunities to empower females in Kenya. At the household level the adoption of clean cookstoves can increase women's participation and decision-making power, enabling ownership of technologies and operation skills (personal comm: ECO2;MoA;AFRISOL;CCAK). At a broader level more women are currently becoming involved in clean cooking value chains as stove producers and marketers, thereby improving their working conditions, income generation and status for their families (personal comm: GIZ-2;GACC;SNV;MoE;BML).

4.3.8 Humanitarian impact

Kenya has a number of refugee camps at the borders with Somalia and Ethiopia such as the Daadab Refugee Complex, Kakuma Refugee Camp and Kalobeyei Integrated Settlement. Ensuring the nutrition and health of these refugees has been a major challenge of national and international agencies operating in these camps. While cooking has been a central factor mediating the quality of life in (and around) these humanitarian settings, it is rarely considered by the relevant agencies (personal comm: GIZ-1;KEFRI). Connected in part with the impacts discussed above, the stakeholders highlighted some of the key dimensions through which the lack of clean cooking interventions affects the daily life of refugees (and surrounding communities) in humanitarian settings of Kenya:

a) Food security: Refugees usually receive staple food such as rice or grain, which they must cook. In many cases, the refugees opt to barter the little food they have for firewood to cook for their families (personal comm: MoA;GIZ-1;SEI);

b) Health: Subpar cooking practices due to fuelwood scarcity add to the already prevalent under- and mal-nutrition in camps. In addition, indoor pollution-related illnesses are very prevalent due to cooking, but medical services are often limited to deal with such health issues (p.comm: MoH;MoA)

c) Safety and social conflict: Refugees have often tense relationships with local communities. Reliance on fuelwood for cooking increases the time spent outside camps collecting firewood, increasing the risk of physical assault (from humans and animals) and gender-based violence (including rape). Such risks and tensions can be exacerbated in areas that experience fuelwood scarcity (MoGYA;MMU);

d) Environmental dimension: Refugee camps have very high population densities compared to surrounding rural communities. Fuelwood demand from this large and dense population can put a huge added strain to local ecosystems causing extensive deforestation, to the degree that environmental degradation is one of the reasons behind the government’s intent to close Daadab camp (personal comm: KEFRI;NEMA).

4.4 Pitfalls and pathways for improving access to clean cooking in Kenya

4.4.1 User sensitization campaigns

Unanimously, and across all interviews, respondents emphasize the importance of increasing consumer awareness, as well-informed consumers will tend purchase clean cookstove/fuel, and well-trained consumers would be able to use the cookstove effectively. Many respondents suggested that the lack of end-user knowledge about the health and economic benefits of clean cookstoves and fuels can suppress demand (personal comm: MoH;SEI;SES;GIZ-2;SNV). It was highlighted that rural communities should not be expected to rapidly acquire or develop these skills (and simply *''leapfrog''* into using new cooking technologies) without the sufficient accumulation of technological knowledge coupled with appropriate social, cultural, and economic conditions (personal comm: MoE;UoN;IFAD;NEMA).

Behavioral change on the demand side can be addressed through awareness-raising campaigns especially, related to the public health benefits of clean cooking (personal comm: CCAK;ISAK; MoGYA;ECO2). In this regard, the Kenyan government can play a leading role in showing clearly the negative human health impacts of traditional cooking practices and sensitize local communities (especially in rural areas) as for done other public health issues such as HIV/AIDS and malaria (personal comm: CCAK;SEI). Typical communication strategies in urban areas can be television, newspapers, and social media and radio, word of mouth and social marketing in rural areas (personal comm: AFRISOL;BML;GACC;KENDBP). Key for countering consumers' scepticism would be the development and communication of tailored messages that will resonate with their needs and preferences of different consumer groups (personal comm: GACC;CCAK;SNV;MoH).

Interviews also highlighted the indispensable role of academic and research institutions in the sensitization process (personal comm: MoE;UoN;CCAK). Consumer research can inform the development of appropriate marketing strategies and branding techniques that can have tangible consumer benefits (personal comm: MoE;CCAK;BML).

4.4.2 Technical and industrial support

Some stakeholders asserted that a crucial factor for achieving the sustained use of clean cookstoves is the timely stove replacement after its lifetime (personal comm: GIZ-1;GIZ-2;MoE). Towards this end it is important for stove providers (whether private companies or international organisations) to have clear strategies on how to facilitate stove replacement after the end of its lifecycle (personal comm: GACC;SNV;KFS).

While the stakeholders argued that advanced stoves have lower emissions than traditional stoves (Section 4.3) they are not always convenient and or user-friendly (Section 4.2). However, while the local stove innovations tailored to local needs are often cost effective and reduce fuel consumption, they have little-to-no emission reductions (personal comm: MoE;KEFRI). Thus, some stakeholders argued that setting bar too high in terms of emission reductions might kill the local stove industry (personal comm: GIZ-1;ISAK).

Furthermore, many stakeholders emphasized that fostering local technical and marketing expertise could guarantee the development of successful local innovations in the long run (personal comm: SNV;KCIC;MoE;KEFRI). International donors and NGOs (especially local) can identify promising local innovations and strengthen their capacity by providing critical support functions related to technical assistance, innovation funding and capacity building (personal comm: KCIC;UoN;MoE).

4.4.3 Multi-stakeholder collaboration

As discussed throughout this paper, clean cooking is a multi-faceted challenge. The effective promotion, uptake and sustained use of clean cooking interventions would require the combined effort of stakeholders from different sectors, both between government agencies at different levels but also between non-government stakeholders (personal comm: CCAK;GIZ-1;UoN).

However, there are clear policy gaps that hinder stakeholder collaboration especially between different government levels. In particular the Energy Act of 2015 does not recognize household cooking energy at the county government level. Many respondents highlighted the need for stronger cooperation between stove promoters (e.g. private sector, NGOs, international organisations) and the devolved governments to establish community-based models for promoting clean cooking options (personal comm: GACC;KCIC;MoE;SES;KENDBP). Energy planning expertise from the national government should be better linked to general rural development and stove capacity development efforts, as there are few renewable energy experts and officers at the county level (personal comm: GIZ-1;MoA).

Lack of coordination is also evidenced between international organisations, NGOs and government agencies responsible for the dissemination of cookstoves (personal comm: MoE;MoGYA;KFS). Some stakeholders were concerned about the lack of statistical information about the development, dissemination and use status of clean cookstove interventions in different counties, which would be essential to track adoption/sustained use rates and identify high impact areas to be targeted in the future (personal comm: SEI;BML;ISAK). This would require a coherent monitoring and evaluation system to track progress, but this is to a large degree hampered by the failure of many entities to disclose accurately the number/type of disseminated stoves (personal comm: CCAK).

Finally, there is also a need for stronger collaboration amongst companies in the private sector (personal comm: KENDBP). For instance, an important element for creating viable LPG markets would be to establish a working dialogue between the different stakeholder groups at the national and local levels (personal comm:). Such networks should first aim to identify the reasons that limit the delivery of clean technologies to local communities, and based on the sober analysis these bottlenecks, they should find priority target areas before the implementation of large-scale interventions (personal comm:GIZ-1; AFRISOL; ISAK).

4.4.4 Enabling environment

Allied to the multi-stakeholder collaboration (Section 4.4.3) is the development of an enabling environment that fosters both growth in the clean cookstove sector, but also cross-sectoral coordination (personal comm: GACC;SNV). The Kenya Country Action Plan for cooking energy (GoK, 2016a) was perceived by many stakeholders as a good first step towards that direction, as it has a clear view on how to strengthen supply, demand and foster an enabling environment (personal comm:MoE). Achieving such an enabling environment, as discussed below, has several components ranging from financial incentives to producers, to quality standards to ensure the protection of the consumers.

Some stakeholders highlighted the need for interventions to spur the development of standards for high quality products (personal comm: CCAK;SNV;MoE;KEFRI). They also advocated for governmental support in reducing duties on clean cookstoves and fuels as a means of expanding investments in the sector, reducing stove costs and improving access (personal comm: KEFRI;E-bank;BML;MPL). Some stakeholders proposed that a well-structured subsidy could help in the development of a rural distribution system that can enhance access to clean cookstoves and fuels (personal comm: MoA;SEI).

However, the lack of robust evidence/evaluations about the impacts of interventions has curtailed the commitment of government agencies and donors to secure the necessary investment, technology development, and support for the implementation of stove interventions (personal comm: KEFRI;MMU;CRIT;DVL). Impact evaluation studies should become a norm in the sector as such exercises could check whether the intended development results were actually achieved, the pathways to impact, as well as the possible reasons for underperformance. This would provide a much needed evidence base that could guide future clean cookstove interventions in Kenya (personal comm: KEFRI;MoE).

4.4.5 Innovative finance instruments

Financial aspects underline all of the pathways discussed above. Ensuring adequate and sustained finance is a necessary step for enhancing the adoption, sustained use and positive impacts of clean cooking interventions (Section 4.4.1-4.4.4). Adequate financing is not only important to end-users for obtaining the actual stove/fuel, but practically to all stakeholders as it drives the entire clean cooking sector.

For end-users, clean cooking options must be affordable, accessible, safe and reliable in the local marketplace (see Section 4.2.1). In order to achieve strong market development and long-lasting impacts, many stakeholders highlighted that a fully commercial approach is the most important step towards ensuring the viability of clean cooking initiatives after the end of the initial support (personal comm: GACC;PAC). Some stakeholders advocated for the creation of appropriate and self-sustaining funding mechanisms to support consumers and local enterprises (see also below) to unlock market growth potential and stimulate demand for clean cooking solutions (personal comm: GIZ-1;SNV;MoE). Some of the suggested examples include the provision of appropriate incentives, well-structured subsidies, and micro-finance loans with flexible payment modalities (e.g. through the widely adopted mobile banking system *M-Pesa*, as used in the solar-lighting energy sector) (personal comm: SEI; GACC;UoN;ISAK;SES). It was also suggested that companies and NGOs can explore initiatives to scale-up existing grants and financing options, as a means of supporting cookstove entrepreneurs for developing high quality stoves in large numbers, and reducing costs passed to consumers to improve their affordability (personal comm: CCAK;PAC)

For investors and businesses limited access to working capital was cited as a critical challenge (personal comm: AFRISOL;DVL;SES;ISAK;MoA;E-bank). This owes to the fact that few investors are prepared to provide funds and technical assistance to clean cooking companies at their early stages (personal comm: KCIC;AFRISOL). For such companies it was suggested that funds can be sought from a diverse set of organizations including multilateral/bilateral donors, national/local governments and private entities (personal comm: GACC;CCAK;UoN). Possible financing mechanisms include: (a) seed funding and grant investments in order to reduce the risk to investors and bridge the gap of working capital (personal comm: KCIC;GIZ-1;SNV;MoE); (b) specialized funds from the government (e.g. rural energy funds often used to support rural electrification) (personal comm: MoE); (c) climate funds from the Global Environmental Facility (GEF), Clean Development Mechanism (CDM), Climate Investment Funds (CIFs) (personal comm: NEMA;KEFRI;UoN). It was further emphasized that the nature and sustainability of financing models and subsidies for cookstove promotion programs are often complex and require longer-term government and donor commitment in order to respond better to sustained user demand (personal comm: SEI;PAC;GIZ-1;CRIT).

4.5 Discussion

4.5.1 Synthesis of stakeholder perceptions

Figure 4-1 synthesizes the main drivers and barriers of clean cooking adoption alluded by the different stakeholders (Section 4.2). As expected, there is some variation between stakeholder groups about specific drivers and barriers, reflecting to some extent their unique interests and role in the clean cooking value chain. For example, private sector stakeholders tended to mention more consistently issues related to stove/fuel affordability and business financing, while stakeholder from government, academia/research and NGOs focused more on issues related to awareness and behavioral change. Donors and international development organizations strongly highlighted community involvement and participation in stove development (Table 4-1)

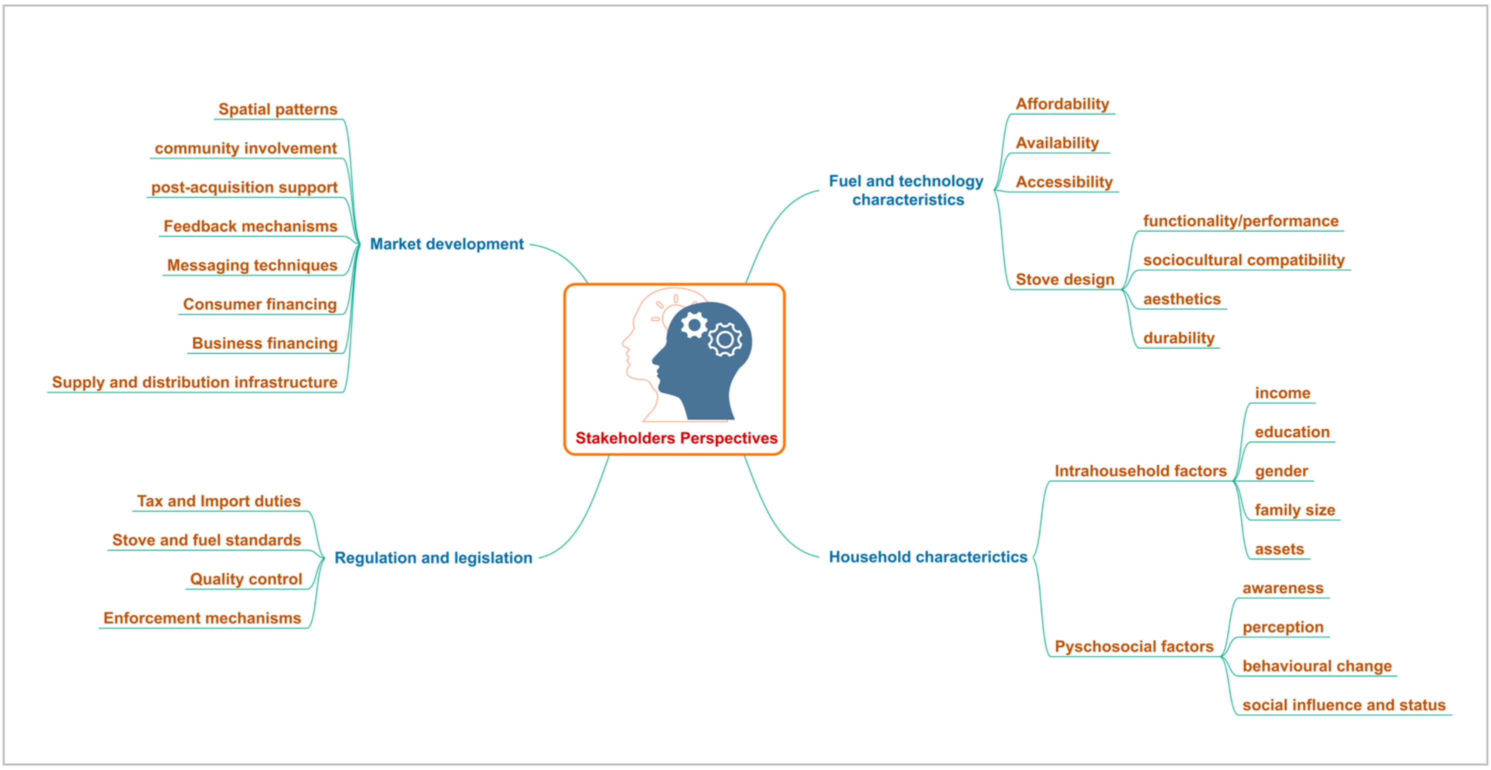


Figure 4-1:Main stakeholder perceptions about drivers and barriers of stove adoption

Table 4-1: Stakeholder perceptions about the drivers and barriers of clean cooking adoption

Dimension	Driver/barrier	Private Sector (n=7)	Donors and international organizations (n=4)	NGOs (n=6)	Academia & Research (n=5)	Government (n=6)	All n=28
Fuel and technology characteristics (Section 4.2.1)	Affordability, accessibility/availability	5	1	2	1	3	12
	Stove design	2	1	2	2	2	9
	Sociocultural compatibility	1	2	0	2	2	7
Demographic and psychosocial factors (Section 4.2.2)	Household characteristics and decisions	3	2	1	1	2	9
	Awareness and behavioural change	3	2	5	5	6	16
	Social influence and status	1	2	3	1	1	8
Market development (Section 4.2.3)	Spatial patterns	2	0	1	1	2	6
	Community involvement	0	3	1	3	1	6
	Post-acquisition support	1	0	3	0	0	3
	Messaging techniques	1	2	3	1	1	8
	Supply and distribution networks	3	0	4	1	0	8
	Business financing models	7	2	2	2	1	14
	Consumer financing mechanism	4	1	2	2	0	9
Regulation and legislation (Section 4.2.4)	Tax and import duties	2	0	3	1	1	7
	Quality assurance	4	0	4	3	2	13

However, despite this variation in possible drivers and barriers of clean cooking adoption, there is a large degree of consensus about what stakeholders consider as the most important of these barriers and drivers of adoption. By far, stove affordability (n=10) and awareness (n=9) were identified as the most important factors by practically all stakeholder groups (Table 3). The other top-ranked barriers/drivers reflect again the specific roles of some stakeholders within the clean cooking sector and include: (a) behavioral change (3 NGO and 1 private sector stakeholders), (b) reliable supply/distribution networks (1 NGO stakeholder), (c) business financing mechanisms (1 private sector stakeholder), (d) stove design (1 academia/research stakeholder), (e) community involvement (1 donor stakeholder), (f) quality assurance (1 government stakeholder).

Table 4-2: Stakeholder perceptions about the most important drivers and barriers of clean cooking adoption

Dimension	Driver/barrier	Private Sector (n=7)	Donors and international organizations (n=4)	NGOs (n=6)	Academia & Research (n=5)	Government (n=6)	All (n=28)
Fuel and technology characteristics	Affordability	3	2	2	2	1	10
	Stove design	0	0	0	1	0	1
Demographic and psychosocial factors	Awareness	2	1	0	2	4	9
	Behavioral change	1	0	3	0	0	4
Market development	Community involvement	0	1	0	0	0	1
	Supply and distribution Networks	0	0	1	0	0	1
	Business financing mechanisms	1	0	0	0	0	1
Regulation and legislation	Quality assurance	0	0	0	0	1	1

This broad consensus can forge a shared understanding between stakeholders about the priority areas to target when establishing clean cooking interventions and promotion efforts. Experience from Kenya and other SSA contexts suggests that consumer awareness can be tied to the influence of campaigns (communication channels), peer effects and social networks (Kumar and Igdalsky, 2019; Rhodes et al., 2014; Vulturius and Wanjiru, 2017). Affordability is often determined by the household socioeconomic status and purchasing power (Bruce et al., 2018; Karanja and Gasparatos, 2019; Sovacool et al., 2015), which can be directly impacted by income and availability of incentives to offset part of the upfront stove cost (Mutua and Kimuyu, 2015; Treiber et al., 2015). Community involvement and post-acquisition consumer support can play a key role in ensuring consumers' full transition from old cooking habits and to stay motivated with the new technology (Johnson et al., 2016; Lambe et al., 2015; Mudombi et al., 2018).

It was suggested that the promotion and adoption of local stove innovations can be the most immediate pathway for steering a transition to clean cooking, as they closely resonate to local cooking cultural sensibilities, especially in the rural areas (see also similar findings in Hooper et al., 2018; Johnson et al., 2016; Tamire et al., 2018). However, enabling a successful transition would undoubtedly require a certain level of change in behaviour, cooking habits, cultural traditions, housing design or other related household practices (Jürisoo et al., 2017). Such examples include aspects of the home environment (e.g. ventilation through chimneys, windows, eaves) and behaviour (e.g. stove use patterns, use of dry fuelwood) (WHO, 2016). Most stakeholders were well-versed with the main sustainability impacts of stove adoption and use in Kenya.

Practically all stakeholders identified the positive effect of clean cooking interventions on health. Many stakeholders also evoked the positive effects of clean cooking for women empowerment, energy access, environmental protection and livelihoods (Table 4-4). These were also largely identified as the ***most important*** impacts of clean, which can possibly identify major themes to ensure policy coherence and marshal the support of the different stakeholders in clean cooking efforts.

It should be noted that humanitarian impacts and impact on food security and nutrition, seem to be the least known among stakeholders (Table 4-3) despite the large body of knowledge emphasizing how traditional cooking technologies/practices affect food preparation and life in/around refugee camps (Barbieri ET AL., 2017; Gunning, 2014; Lehne et al., 2016; Owen et al., 2013). In any case, the links between clean cooking and food security remains some of the least studied impact areas in the existing literature (Anderman et al., 2015; Kituyi and Kirubi, 2003; Sola et al., 2016).

Table 4-3: Stakeholder perceptions about the impacts of clean cooking adoption

Impacts	Private Sector (n=7)	Donors and international organizations (n=4)	NGOs (n=6)	Academia & Research (n=5)	Government (n=6)	All n=28
Energy access and energy poverty (Section 4.3.1)	2	2	3	2	6	15
Environmental impact (Section 4.3.2)	2	2	2	5	2	13
Health (Section 4.3.3)	4	4	6	5	5	24
Improved livelihoods (Section 4.3.4)	3	4	2	2	2	13
Education (Section 4.3.5)	0	3	0	3	4	10
Food Security and nutrition (Section 4.3.6)	3	1	1	3	2	9
Women empowerment (Section 4.3.7)	4	3	5	2	3	17
Humanitarian impact (Section 4.3.8)	0	1	0	3	4	8

Table 4-4: Stakeholder perceptions about the most important impacts of clean cooking adoption

Impacts	Private Sector (n=7)	Donors and international organisations (n=4)	NGOs (n=6)	Academia & Research (n=5)	Government (n=6)	All n=28
Energy access and energy poverty	4	1	2	1	1	9
Environmental impact	0	0	0	1	2	3
Health	1	1	3	2	3	10
Women empowerment	2	2	1	1	1	7

4.5.2 Impact trade-offs with adoption of clean cooking technologies

Apart from establishing stakeholder knowledge about clean cooking impacts (and their importance), interviews were also instrumental in identifying possible trade-offs from the adoption of clean cooking practices including:

a) Deforestation: In many parts of Kenya where fuelwood demand already exceeds the available supply, the adoption of improved biomass stoves offers only a short-term solution, and simply prolongs the ultimate consequences of deforestation (personal comm: DVL);

b) Cultural change and social cohesion: The adoption of clean cooking options may alter the preparation of traditional dishes (cultural change), and social interactions in cooking places and firewood collection areas (social cohesion) (personal comm: SEI,MoA);

c) Clay mining: The uncontrolled mining of clay and pottery sand to mould the fuelwood stove liners may have negative environmental impacts through land degradation, soil erosion, proliferation of mosquito breeding sites, and vulnerability to landslides (personal comm: GIZ-1);

d) Livelihoods: The wide adoption of clean cooking options can have negative livelihood outcomes through the loss of jobs and income from fuelwood and charcoal value chains that dominate livelihoods in some rural and urban contexts (personal comm: BML;KEFRI;CRIT).

e) Waste management: Life-cycle effects are rarely considered during stove manufacturing and promotion, and especially the negative environmental impacts of stove disposal after the end of their life (this applies to both low cost/efficiency cookstoves from scrap metal and advanced stainless-steel stoves) (personal comm: BML)

4.6 Summary

This Chapter provides a comprehensive outlook of the perspectives of 28 stakeholders actively engaged in ongoing clean cooking activities in Kenya about the drivers, challenges, perceived impacts and future pathways of the sector, as well as their interactions in the clean cooking sector. The Chapter has identified that various stakeholders are involved in the clean cooking sector in Kenya, each holding distinct interests and agendas. It is important to understand better these entrenched positions in order to ensure the wide stakeholder support in efforts that aim the wide promotion and adoption of clean cooking options.

Due to the radically different roles of the interviewed stakeholders within the sector there is some variations in their perspectives. However, there is a good level of consensus about the main barriers and impacts of clean cooking options in Kenya. In particular, there is a good shared understanding about the need for establishing solid funding mechanisms, not only to facilitate consumer affordability but also to ensure financial sustainability of the entire clean cooking system. These offer a good base to explore appropriate financial instruments in a coordinated fashion, unlock market growth potential and stimulate consumer demand for clean cooking options.

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CHAPTER 5

ADOPTION OF CLEAN BIOENERGY COOKING TECHNOLOGIES IN KIAMBU AND MURANGA COUNTIES

5.1 Introduction

While Kenya has been striving to modernize its household energy system, the significant fiscal challenges associated with expansion of clean cookstoves have been an impediment. Several studies, albeit fragmented, have alluded that clean cooking technologies can have multiple positive sustainability impacts (see Section 1.4). Nonetheless, against these ramifications are considerations relative to the dynamics of stove adoption and sustained use at household level.

In Section 1.2, the study identified that there exists a myriad of highly engineered, efficient and aesthetically-pleasing clean cooking options (both domestic and imported). However, their large-scale uptake in Kenya has been slow and complex (IEA et al., 2018). In order to promote policies and programs to enable scaling up adoption and long-term/sustained use, the inherent bottlenecks and enablers at the household level must be understood (IEA et al., 2019; IEA, 2016). Understanding the effect of these factors is crucial for: (a) informing the development and implementation of stove interventions that maximize sustainability impacts of clean bioenergy stoves; and (b) for policy makers to facilitate an enabling environment for adoption and investment in the clean cooking sector.

In this respect, the aim of this Chapter is to: (a) estimate empirical information about factors affecting adoption of biogas and improved biomass stoves in Kenya (Sections 5.3 and 5.4); (b) elicit trade-offs and relative strengths of stove-specific attributes inherent to stove choice behavior through a discrete choice analysis (Section 5.5); and (c) identify user perception about enablers and barriers affecting initial stove acquisition and sustained use by mapping the converging and diverging patterns emanating from ethnographic surveys (Section 5.6).

5.2 Basic household descriptive statistics

The household descriptive statistics are documented to outline stove adoption patterns (Table 5-1 and 5-2), the distribution of surveyed population is presented in form of percentages for categorical variables (Table 5-3), while continuous variables for the targeted users of improved biomass stoves, biogas stoves and traditional biomass stoves, are outlined in form of mean and standard deviation in Table 5-4 and Table 5-5 for Kiambu and Muranga, respectively. The significance levels of two-sample independent t-tests are presented in relation to geographical locations across the enumeration transect zones and by stove use.

5.2.1 Household stove adoption patterns

When it comes to distribution of households by stove use (see Table 5-1), the results show that 61.5% of surveyed Muranga residents use traditional biomass stoves while 38.5% have adopted improved biomass stoves. None of the interviewed households were found to use modern stoves as the primary household stove. In Kiambu, there was an observed higher diversity of stove use since 51.5% of the surveyed residents use traditional stoves while 30.7% had adopted improved biomass stoves. Other stove types used in the surveyed Kiambu households include charcoal stoves (7.2%), LPG (10.0%) and electric stoves (0.6%).

However, there is a broad variation of household distribution in terms of stove use patterns across the enumeration transects. In the Muranga transect, it was observed that proportion of adoption of improved biomass stoves increase with increasing distance away from the state forest towards the semi-arid interior where 44.6% of the surveyed population use improved biomass stoves as compared to 32.9% of their close forest counterparts. This is perhaps due to the observed fuelwood scarcity (see results in Section 6.2) and notable availability of local artisans producing improved biomass stoves in this transect zone.

A similar pattern is observed in the Kiambu transect where 32.3% of the peri-urban residents use improved biomass stoves as compared to 27.1% of the households located at close vicinity to the forest. In addition, Table 5-1 indicate that, about 43.1% of the surveyed population in the peri-urban interface use non-fuelwood stove types including LPG, charcoal, kerosene and electricity. This is possibly attributable to infrastructural development for modern stove market which is enhanced by the vicinity to the capital city.

Table 5-1: Distribution of stove use for the randomly sampled households across the enumeration transects

Study area	Transect zone	Sample size	Traditional Biomass Stoves	Improved Biomass Stoves	Other *(LPG, charcoal, electricity)*
Muranga (n=200)	Close forest	70	67.1%	32.9%	0.0%
	Mid-transect	65	61.5%	38.5%	0.0%
	Semi-arid	65	55.4%	44.6%	0.0%
	Total	**200**	**61.5%**	**38.5%**	**0.0%**
Kiambu (n=200)	Close forest	70	72.9%	27.1%	0.0%
	Mid-transect	65	50.8%	30.8%	18.5%
	Peri-urban	65	24.6%	32.3%	43.1%
	Total	**200**	**51.5%**	**30.7%**	**18.8%**

Table 5-2 provides a stove matrix identifying that the concept of *"fuel stacking"* or multiple-stove use is commonly practiced in the study areas. From the results, households that were found to solely rely on a single stove include: 91% of the surveyed biogas users, 29.1% of improved stove users and 47.1% of traditional stoves users. Other households were found to own at least two stoves. The most common secondary stove used include LPG which is used by 35.1% of improved biomass stove users, 7.9% of traditional stove users, and 6.2% of biogas stove users. Charcoal was found to be the second most common secondary stove used by 27.7% of improved biomass stove users, 11.1% of traditional stove users and 1.0% of biogas users.

Table 5-2: Multiple stove use patterns in the sampled households

		Primary stove		
		Biogas	Improved Biomass Stove	Traditional Biomass Stove
Secondary stove use	One stove only	91.00%	29.12%	47.13%
	LP Gas	6.19%	35.13%	7.86%
	Charcoal Stove	1.00%	27.68%	11.05%
	Improved Biomass Stove	0.30%	-	27.89%
	Kerosene Stove	0.51%	5.15%	6.14%
	Electric Stove	1.00%	0.74%	0.00%
	Traditional Biomass Stove	0.00%	1.47%	-
	Biogas Stove	-	0.74%	0.00%

5.2.2 Description of household demographic and socio-economic characteristics.

When it comes to demographic attributes, the results suggest that more than 80% of the surveyed households are patriarchal. In terms of education, majority of the household heads were found to have acquired post-primary education, but the mean average of education is highest among biogas adopters (4.48) where 46% have completed secondary school. The results in Table 5-4 and Table 5-5 indicate that the average age of the household heads in Muranga and Kiambu is 41.18 and 40.96, respectively. The average household size was found to be 4.14 in Kiambu and 4.08 in Muranga. The average household size for biogas adopters was the lowest at 3.37, which is below the national average of 4.40 (KNBS, 2017).

Distribution of household heads' occupation and sources of income, about 72% and 64% are farmers in Muranga and Kiambu, respectively. Operation of self-run businesses was the second highest occupation carried out by 11% and 16% in Muranga and Kiambu residents, respectively.

When it comes to households' distributions in relation to their monthly income, Kiambu residents were found to earn an average monthly income of KES. 20240 (app. US$205) which is about two times higher compared to that of Muranga. Biogas adopters have the highest mean monthly income of KES. 36590 (app. US$370), which is expected since biogas is a high investment technology. By geographical locations, households located in the peri-urban zone were found to have the highest average monthly income of KES. 25125 (US$250). The semi-arid zone residents have the lowest monthly income of KES. 6686 (US$67) which is below the revised international poverty line of US$1.90/capita/day (World Bank, 2016). Comparison of income means using a two-sample independent t-test suggest significant income disparity across stove user groups ($p<0.05$). The universal patterns depicted in the results show that traditional stove users have lower income as compared to adopters of improved biomass stoves.

Kiambu county is a dairy farming area where cattle ownership serves a key wealthy indicator. The results suggest that the average TLU (total livestock unit) for the county is 1.83 but biogas adopter had almost 3 times as much. This discrepancy is expected since the sustainability of biogas production is predicated on sufficient supply of cow-dung feedstock. In addition, land ownership is particularly pertinent for installation of bio-digester and for long-term farm investment including planting trees. The results in Table 5-3 reveal that, more than 70% of the surveyed households acquired their land through inheritance. The rest of the households have either purchased the land or operate as tenants paying some form of monthly or annual rent or hold a land-leasing agreement with the owners.

Table 5-3: Distribution of households by basic household characteristics

		Muranga (n=200)	**Kiambu (n=200)**	**Biogas (n=100)**
Education (household head)	No formal school=0	5.6%	3.5%	0.0%
	Some primary school =1	14.0%	8.5%	2.0%
	Completed primary school =2	27.2%	46.5%	12.0%
	Some secondary school =3	22.6%	29.0%	31.0%
	Completed secondary school =4	25.1%	10.6%	46.0%
	University/college education =5	5.5%	1.9%	9.0%
Occupation (household head)	Farmer	71.7%	64.3%	59.0%
	Civil servant	10.1%	3.4%	12.0%
	Company employee	0.9%	4.9%	4.0%
	Self-run business	11.2%	15.9%	16.0%
	Retired	2.1%	6.2%	2.0%
	Casual labourer	4.0%	5.3%	7.0%
Household Income (KES)	Quartile 1 [≤20000]	58.7%	26.7%	1.7%
	Quartile 2 20001-30000]	33.8%	28.8%	18.0%
	Quartile 3 [30001-40000]	5.9%	35.3%	35.3%
	Quartile 4 [>40000]	1.6%	9.2%	45.0%
Land tenure	Inherited	75.7%	86.9%	73.0%
	Purchased	16.2%	8.2%	24.0%
	Leased	3.2%	3.5%	3.0%
	Rented	4.8%	1.5%	0.0%

Table 5-4: Descriptive statistics of household characteristics by stove use and geographical location (mean ± SD) in Kiambu

Study Groups		Household head			Household composition					
		Gender	Education	Age	Children	Adults	Total	Farm size (acres)	Livestock (TLU)	Income
Total Kiambu		**0.86 ± 0.35**	**3.49 ± 1.46**	**40.96 ± 12.27**	**1.46 ± 1.23**	**2.67 ± 1.24**	**4.14 ± 1.73**	**1.66 ± 1.36**	**1.833 ± 1.77**	**20240 ± 13024.75**
Close forest *(n=70)*	**Total average**	**0.86± 0.35**	**3.06± 1.45**	**41.6± 13.07**	**1.61± 1.21**	**2.77± 1.32**	**4.39± 1.93**	**2.10± 1.67**	**2.54± 2.16**	**19382.86 ± 13629.08**
	Improved Biomass (n=19)	0.95±0.23	3.53±1.31	35.26±11.11	0.95±1.02	2.58±0.76	3.53±1.07	1.36±1.14	1.42±1.15	18421.05±9947.45
	Traditional stove (n=51)	0.82±0.38	2.82±1.41	41.12±13.43	1.86±1.18	2.84±1.47	4.71±2.08	1.67±1.41	1.32±1.40	13627.45±6545.10
	t-test	n.s	0.063	0.072	0.004	n.s	0.022	n.s	n.s	0.022
Mid-transect *(n=55)*	**Total average**	**0.85± 0.36**	**3.33± 1.41**	**41.77± 13.20**	**1.53± 1.32**	**2.75± 1.19**	**4.28± 1.55**	**1.54± 1.13**	**1.60± 1.55**	**16355± 9449.89**
	Improved Biomass (n=22)	0.86±0.35	3.23±1.57	41.91±12.64	1.55±1.50	3.09±1.23	4.64±1.61	1.78±2.18	1.73±1.74	16704.55±13241.04
	Traditional stove (n=33)	0.82±0.39	3.12±1.19	42.91±14.20	1.58±1.27	2.48±0.90	4.06±1.39	1.34±0.96	1.16±1.11	13787.88±8087.44
	t-test	n.s	n.s	n.s	n.s	0.040	n.s	0.084	0.091	0.036
Peri-urban *(n=35)*	**Total average**	**0.87± 0.34**	**4.17± 1.28**	**39.42± 10.22**	**1.22± 1.14**	**2.48± 1.19**	**3.70± 1.59**	**1.27± 0.97**	**1.24± 1.09**	**25125± 14014.71**
	Improved Biomass (n=19)	0.89±0.31	3.32±1.11	46.84±11.47	1.58±1.30	3.05±1.58	4.63±2.11	1.34±1.07	1.20±1.10	18736.84±10066.95
	Traditional stove (n=16)	0.69±0.48	3.75±1.18	46±17.27	1.06±0.99	2.07±0.92	3.13±1.25	2.02±2.48	0.85±0.89	15968.75±8161.84
	t-test	0.003	n.s	0.036	n.s	0.035	0.018	0.075	n.s	0.058
	Biogas (*n=100*)	0.83±0.38	4.48±0.89	41.94±9.46	1.03±1.05	2.34±0.87	3.37±1.20	2.45±2.00	4.71±3.29	36590±13061.69

Table 5-5: Descriptive statistics of household characteristics by stove use and geographical location (mean ± SD) in Muranga

Study Groups		**Household head**			**Household composition**				
		Gender	Education	Age	Children	Adults	Total	Farm size (acres)	Income
Muranga		**0.815 ± 0.38**	**3.37 ± 0.93**	**41.18 ± 11.48**	**1.72 ± 1.25**	**2.36 ± 0.48**	**4.08 ± 1.13**	**1.79 ± 1.90**	**10157.75 ± 6419.89**
Close forest *(n=70)*	**Total average**	**0.8±0.40**	**3.37±0.97**	**43.53±11.76**	**1.81±1.35**	**2.30±0.27**	**4.11±1.38**	**2.12±2.63**	**14276.43±8448.30**
	Improved Biomass	0.76±0.43	4.00±0.91	40.28±9.58	1.64±1.18	2.16±0.41	3.80±1.25	2.37±3.89	12900±9169.70
	Traditional stove	0.82±0.38	3.02±0.81	45.33±12.55	1.91±1.44	2.37±0.15	4.28±1.44	1.36±0.96	9485.56±579.53
	t-test	n.s	0.000	0.085	n.s	n.s	0.092	0.081	0.000
Mid-transect *(n=65)*	**Total average**	**0.85±0.36**	**3.26±0.95**	**38.71±10.58**	**1.43±0.84**	**2.23±0.30**	**3.66±0.92**	**1.72±1.44**	**9193.85±4062.44**
	Improved Biomass	0.73±0.46	3.95±0.84	37.95±10.43	1.27±0.70	2.27±0.44	3.54±0.83	2.11±1.61	10840.91±5770.17
	Traditional stove	0.90±0.29	2.91±0.81	39.09±10.76	1.51±0.90	2.21±0.21	3.72±0.95	1.49±1.31	8351.16±2520.42
	t-test	0.059	0.000	n.s	n.s	n.s	n.s	0.079	0.018
Semi-arid *(n=65)*	**Total average**	**0.8±0.40**	**3.48±0.87**	**41.12±11.68**	**1.91±1.44**	**2.55±0.74**	**4.46±1.71**	**1.51±1.22**	**6686.15±1721.09**
	Improved Biomass	0.82±0.39	3.86±0.75	41.79±12.58	1.46±1.17	2.53±0.76	4.00±1.42	2.16±2.71	7107.143±1857.70
	Traditional stove	0.78±0.42	3.19±0.84	40.62±11.10	2.24±1.55	2.56±0.74	4.81±1.82	1.39±1.04	6367.57±1560.64
	t-test	n.s	0.002	n.s	0.030	n.s	0.012	n.s	0.086

5.3 Factors affecting adoption of improved biomass stoves and biogas stoves

Following the methodology and estimation methods outlined in Section 3.3.2.2, this section present results for probit regression models and the marginal effects *(dy/dx)* for the factors predicting adoption of improved cookstoves and biogas in Table 5-6 and 5-7 respectively. The results are discussed based on the conceptual framework presented in Figure 3-1 where stove adoption was hypothesized to be predicated on a set of demographic attributes, economic, ecological and institutional factors affecting stove adoption.

5.3.1 Demographic factors

The results show that male-headed households have a significantly positive effect on adoption of biogas. The marginal effects suggest that male headship increase the probability of biogas adoption by 6.4% as compared to female headship. However, male-headed households have an inverse relationship with adoption of improved biomass stoves. Although this association is not statistically significant, the effect is possibly attributable to a fact that since women often disproportionately bear the burden of fuelwood procurement and cooking tasks (see results in Section 6.2.2), they might have a higher incentive for fuelwood-saving stoves.

The age of the household head has a significantly negative effect on adoption of improved biomass stoves. This implies that younger household heads have a greater probability of adopting clean cooking technologies. It is expected that younger heads can be typically less risk-averse and more willing to try new technologies while older people can view the modern, improved stoves as non-traditional and therefore, oppose their acquisition.

The estimation results further indicate that household size and dependency ration have a negative effect on adoption of both biogas and improved biomass stoves. For improved biomass stoves, the results show that a unit increase in household size and dependency ratio significantly decrease adoption by 9.3% and 5.6%, respectively. In this study, household size was instrumented as a measure of degree of labour availability for fuelwood collection which can negatively affect adoption. Besides, it is expected that the larger the household size, the greater the pressure to spend on other fundamental household expenses such as food.

5.3.2 Socioeconomic factors

A unit increase in the level of household income (see Table 5-3) was found to significantly increase probability of biogas adoption by 7.4% and that of improved biomass stoves by 11.3%. Biogas stove is a high investment cooking technology for digester installations where stove costs and income are critical in decision making. When it comes to non-income poverty predictors, the study revealed that multidimensionally poverty and multidimensional energy poverty reduces the probability of adoption of improved biomass stoves by 9.8% and 14.2% respectively, ($p<0.05$).

Education level of the household head had a significantly positive influence on adoption of improved biomass stoves and biogas stoves with a marginal effect of 6.2% and 2.2%, respectively. The theoretical expectation is that educated heads have improved awareness and can better understand the health and economic benefits of stove use compared to those with no formal education.

Since Kiambu County is dairy farming economy, the effect of livestock ownership was investigated. The biogas model show that a unit increase in the number of total livestock units (TLU), significantly increased the probability of biogas adoption by 2.5%. When it comes to land ownership, the positive significance of the marginal effects suggests that households with a secure land tenure have a 5.3% higher probability of biogas adoption as compared to those operating on rented land. In theory, having a secure land and space to construct the biogas system is prerequisite for bio-digester installation and for proper management/storage of the bio-slurry.

Finally, it is expected that integrating and planting trees on farm (agroforestry) facilitate reliable access and sustainable supply of fuelwood for biomass stove users. The estimation results suggest that agroforestry practice has a positively significant effect on adoption of improved biomass stoves by a factor of 15.5% as compared to households that have not planted any trees. The coefficient for agroforestry was not only strongly significant ($p<0.01$), but the magnitude of its coefficient ranks highest across the hypothesized variables emphasizing its relative importance for adoption of improved biomass stoves.

5.3.3 Institutional factors

Access to credit has a strong positive significance effect ($p<0.01$) on adoption of improved biomass stoves and biogas. The estimated marginal effects indicate that, households with access to credit through formal and/or informal institutions had a 9.5% and 14.4%, higher probability of adoption of biogas and improved biomass stoves, respectively than households without access to credit services. It is expected that credit access eases the liquidity constraints for the households to finance the upfront costs. This is particularly salient for biogas stoves whose investment cost is substantially high for most rural households.

Theoretically, it is expected that farmers who are exposed to information about new technologies by extension agents through training and other forms of information delivery have higher chances to adopt new technologies. The study findings indicate that, households that receive extension visits have a higher probability of adopting biogas and improved biomass stoves by 4.1% and 8.7%, respectively, as compared to households that do not receive such extension services.

In addition, the estimation results suggest that households participating in social groups have a significantly higher probability of adopting biogas and improved biomass stoves by 3.1% and 12.2%, respectively, as compared to non-participating households. It is hypothesized that belonging to a social group enhances social capital allowing information exchange. During ethnographic surveys, it was observed that, women are often involved in social groups often referred to as *"table-banking", "merry-go-round" or "chamaas"* where they pool modest amount of money to support each other in rotations to purchase basic household assets.

5.3.4 Ecological factors

For the household that depend on self-collected fuelwood from open-access areas, the results suggest that adoption of improved biomass stoves increase by 4.2% with each additional kilometer walked from the homesteads to the most frequent fuelwood collection woodland. It can be inferred that fuelwood scarcity can incentivize household to adopt fuelwood-saving cookstoves as compared to those with abundant and accessible biomass within their localities.

It is imperatively acknowledged that the actual distance to the state forest (Aberdare forest reserve) or to the urban center (Nairobi city) from the communities located in the different geographical segments could have an implication on adoption of improved biomass stoves. However, the diagnostic test for multicollinearity between distance to the forest and actual walking distance from the villages to the fuelwood collection area was significantly strong ($r=0.93$, $p<0.01$). Therefore, the distance to the state forest is omitted from the regression analysis presented in Table 5-6. When it comes to distance to the urban center, each additional 10 kilometers away from the city center decreases the probability of adoption of improved biomass stoves by 0.57%, however, this effect is not statistically significant.

As outlined in Table 5-1, geographical location across the transect has significant ramifications on stove adoption. In Muranga, the estimation results suggest that household's location at close proximity to state forests reduce the probability of adoption by 15.2% ($p<0.05$). On the other hand, household's location at the vicinity of the urban center (peri-urban zone) increase the chance of adoption of improved biomass stoves by 9.5% ($p<0.05$). In Section 5.2.2, the study found that peri-urban residents have the highest household income across the enumeration transect zones which can enhance their purchasing power for modern cookstoves as established in Section 5.3.1.2 above. Furthermore, the study perceives urbanization as an indicator for higher accessibility to modern fuels (improved market infrastructure) and awareness about modern products including clean cooking options.

On the other hand, while a household's location in the fuelwood scarce (semi-arid) zones was found to increase adoption by 3.9%, this effect is however not statistically significant. Reflecting on the fuelwood scarcity experienced in this transect zone (see also results in Section 6.3), it means the residents walk for longer distances in search of fuelwood (a factor that this study has established to have a significantly positive effect on adoption).

However, the average income was found to be lowest in this zone which can negatively affect their stove purchasing ability (see Section 5.2.2).

Table 5-6: Probit estimation results for factors affecting adoption of improved biomass stoves

Domain	Variables	Coef.	Robust SE	p-value	dy/dx
Demographic factors	Gender	-0.309	0.210	n.s	-0.063
	Age	-0.020	0.008	**	-0.004
	Household size	-0.455	0.227	**	-0.093
	Dependency ratio	-0.270	0.083	***	-0.055
Socio-economic factors	Education	0.303	0.083	**	0.062
	Income	0.268	0.016	***	0.113
	Multidimensional poverty	-0.479	0.250	*	-0.098
	Multidimensional energy poverty	-0.692	0.411	*	-0.142
	Farm size	0.123	0.048	**	0.025
	Land tenure	0.028	0.207	n.s	0.058
	Agroforestry	0.813	0.204	***	0.166
Institutional factors	Credit access	0.731	0.180	***	0.149
	Social group membership	0.602	0.205	***	0.123
	Extension visits	0.443	0.196	**	0.091
Ecological factors	Distance to woodland (km)	0.080	0.031	**	0.036
	Distance to urban center (10 km)	-0.027	0.133	n.s	-0.006
	Close forest: Muranga	-0.769	0.170	**	-0.211
	Mid-zone: Muranga	-0.188	0.310	n.s	-.0039
	Semi-arid zone: Muranga	0.307	0.044	*	0.063
	Close forest: Kiambu	-0.297	0.286	n.s	-0.061
	Peri-urban zone: Kiambu	0.491	0.200	**	0.098
	Intercept	-1.047	0.270	*	-
	Pseudo R^2	59.47%			
	Observations	360			

Table 5-7: Probit estimation results for factors influencing adoption of biogas

	Variables	Coef.	SE	p-value	dy/dx
Demographic factors	Gender (male =1)	2.997	1.361	***	0.064
	Age	-0.022	0.034	n.s	-0.000
	Household size	-0.191	0.320	n.s	-0.006
	Dependency ratio	-1.204	0.936	*	-0.049
Socio-economic factors	Education	1.042	0.517	*	0.022
	Income	4.039	1.593	**	0.074
	Land tenure	2.333	1.183	**	0.053
	Farm size (acres)	1.699	0.562	**	0.025
	Stable dwelling	0.984	1.480	n.s	0.022
	Water access (km)	-2.882	2.433	n.s	-0.057
	Livestock ownership (TLU)	1.297	0.404	***	0.025
Institutional factors	Credit access	4.827	1.619	***	0.095
	Social group	1.572	0.397	*	0.031
	Extension visits	2.057	0.925	**	0.041
	Intercept	-30.720	13.050	**	
	Pseudo R^2	65.73%			
	Observations	260			

Significance codes: *p<0.1, **p<0.05, ***p<0.01

5.4 Direct, indirect and total effects of productive resources on adoption of clean bioenergy cooking technologies: A path analysis

Upon identifying and assessing the hypothesized demographic, socio-economic, institutional and ecological factors of adoption in Section 5.3.1 and presented in Table 5-6 and Table 5-7, the second task for this Chapter is to use a path analysis technique to determine the direct, indirect and total effects of the statistically significant productive resources (i.e. socioeconomic and institutional factors) on stove adoption mediated by income resource.

In this pursuit, a list of 8 predictors of improved biomass stoves adoption (Table 5-8) and 7 predictors of biogas stoves (Table 5-8) were identified. In order to better understand the gender effects on stove adoption, correlation between gender of the household head and the identified productive resources was estimated within the path analysis model.

5.4.1 Path analysis for adoption of Improved Biomass stoves

The estimated path coefficients and residual coefficients for adoption of improved biomass stoves are shown in the path diagram in Figure 5-1 along with their paths (arrow directions). First, the estimation results suggest that that the selected variables in the path model explain 58% of the variance on adoption and 41% of the variance on income. All the coefficient for direct effects on adoption of improved biomass stoves are statistically significant at 1-5% significance levels.

The results in Table 5-8 suggest that agroforestry practice (i.e. planting trees on farm) has the highest positive direct effect (0.337) and total effects (0.443, 23.9% mediated by income) on adoption of improved biomass stoves. Ranking by decreasing magnitude of the coefficients of total effects (after agroforestry practice), the other important variables influencing adoption of improved biomass stoves include: female household headship (0.295, -13.6% mediated by income); household income level (0.275); credit access (0.272, 17.3% mediated by income); education level (0.238, 25.6% mediated by income) and social group membership (0.205, 18.5% mediated by income). On the other hand, energy poverty (-0.146) and multidimensional non-income poverty (-0.248) have negative total effects on adoption.

The estimation results for gender correlations with productive resources as established in this path analysis suggest that:

a) Female-headed households have a negative correlation with almost all of the identified productive resources that positively affect adoption of improved biomass stoves. These include: agroforestry practice (-0.165); education (-0.163); farm size (-0.104); and access to extension visits (-0.136). The results also show existence of a significantly inverse association between female-headed households and household income which reduce women's total effects on adoption of improved biomass stoves by 13.6%.

b) Female-headed households were found to have a positive correlation with multidimensional poverty (0.110) and multidimensional energy poverty (0.235). Similarly, these are variables observed to have a significantly negative effect on adoption of improved biomass stoves.

c) Promisingly, female headed households were found to have a positive correlation with access to credit services (0.303) and participation in social groups (0.208). Variables that have a significantly positive effect on adoption of improved biomass stoves.

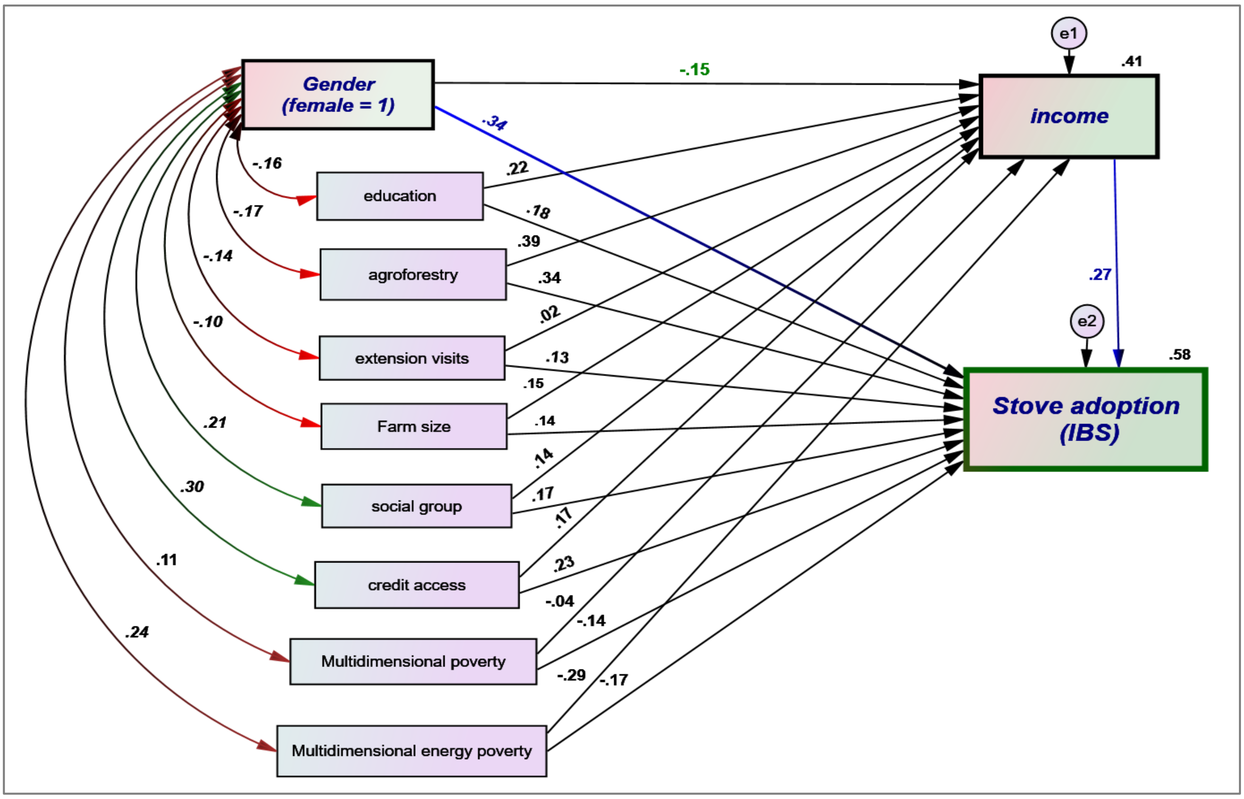

Figure 5-1: Path diagram showing the effects (*direct and indirect*) of the selected productive resources on adoption of improved biomass stoves and correlations with female-headed households.

Table 5-8: Direct, indirect and total effects of selected variables on adoption of improved biomass stoves

Variables	Correlation coefficient (female head)	**Effects on adoption of improved biomass stoves**			
		direct effect (on adoption)	Indirect effect (via income)	Total effects	% of total effects explained by income effect
agroforestry	-0.165	0.337	0.106	0.443	23.9%
gender (female head=1)	-	0.336	-0.040	0.295	-13.6%
income	-	0.275	-	0.275	-
credit access	0.303	0.225	0.047	0.272	17.3%
education	-0.163	0.178	0.061	0.238	25.6%
social group membership	0.208	0.167	0.038	0.205	18.5%
farm size	-0.104	0.14	0.041	0.181	22.7%
extension visits	[-.0.136]	0.133	0.006	0.139	4.3%
multidimensional poverty	0.110	-0.135	-0.011	-0.146	7.5%
energy poverty	0.235	-0.169	-0.079	-0.248	31.9%
e_1		-	0.573		
e_2		0.052	-		
Intercepts		-.212	1.027		
R^2		57.7%	40.6%		

5.4.2 Path analysis for adoption of biogas stoves

The estimated path coefficients and residual path coefficients for direct, indirect and joint effects of the selected productive resources on adoption of biogas stoves are presented in Table 5-9 and the path diagram on Figure 5-2.

The estimation results suggest that the selected variables in the path model explain 62.4% of the variance on biogas adoption and 26.3% of income variance. All of the coefficient for direct effects on adoption of biogas stoves are statistically significant at 1-5% significance levels.

The results show that the household income level has the highest positive direct and total effects on biogas adoption (0.335). Ranking by decreasing magnitude of the coefficients of total effects (after income), the next most important variables influencing adoption include: livestock ownership (0.334, 23.7% mediated by income); farm size (0.287, 20.2% mediated by income); access to credit service (0.281, 28.8% mediated by income); education level of the household head (0.254, 30.3% mediated by income); and male household headship (0.251, 15.1% mediated by income).

Other variables with positive effect on adoption of biogas (albeit weak effect) include land tenure (0.108, 22.0% explained by income) and access to extension visits (0.085, 36.5% mediated by income).

The gender correlations results from this path analysis model suggest that: (a) male headed households have a positive association with income which increase their total effects on biogas adoption by 15.1%; (b) male-headed households have a significantly positive correlation with all the variables that were identified to have a positive effect on biogas adoption except social group participation (-0.024), of which was found to be statistically insignificant. These findings shed light about the gender disparities where women have limited access to income and important productive resources which curtail their probability for adoption of clean bioenergy stoves as established in Section 5.3.

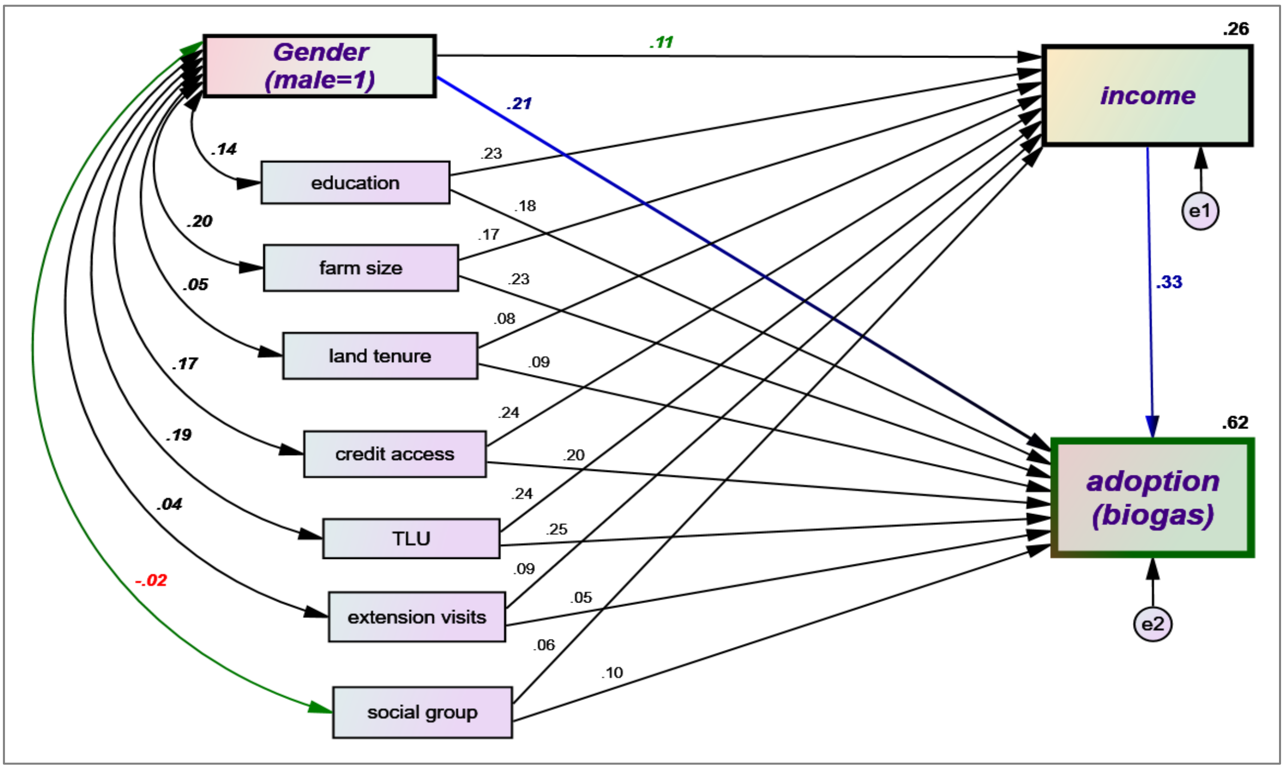

Figure 5-2: Path diagram showing the effects (*direct and indirect*) of the selected productive resources variables on adoption of biogas and correlations with male-headed households.

Table 5-9: The direct, indirect and total effects of selected independent variables on adoption of biogas

Variables	Correlation coefficient (male head)	**Effect on adoption of biogas stoves**			
		direct effect (on adoption)	Indirect effect (via income)	Total effects	% of total effects explained by income effect
income	-	0.335	0	0.335	-
livestock ownership	0.194	0.255	0.079	0.334	23.7%
farm size	0.201	0.229	0.058	0.287	20.2%
credit access	0.171	0.200	0.081	0.281	28.8%
education	0.143	0.178	0.077	0.254	30.3%
gender (male=1)	-	0.213	0.038	0.251	15.1%
social group	[-0.024]	0.100	0.020	0.119	16.8%
land tenure	0.052	0.092	0.026	0.108	22.0%
extension visits	0.045	0.054	0.031	0.085	36.5%
e1		-	0.718		
e2		0.263	-		
Intercepts		-0.704	0.820		
R^2		62.4%	26.3%		

5.5 Stated preference and trade-offs in stove choice behavior

This section identifies household preferences and trade-offs related to stove-specific attributes and functions estimated from the discrete choice experiment. First, the study looks into the user perceptions about their desirable characteristics for their "dream" stove. A comprehensive discrete choice analysis is then used to test and quantify the relative strengths and trade-offs of the different stove-specific features in stove preference.

5.5.1 Household perception about the ideal or desirable stove characteristics

As described in Section 5.2.1, the concept of multiple-stove use commonly referred to as "fuel-stacking" is eminent in most of the surveyed households (see Table 5-2). Deliberated through an open-ended question, the study probed for respondents' perceptions about the ***main*** desired stove feature for their household.

As illustrated in Figure 5-3, the surveyed respondents stated their desire for a stove that: is affordable (41.5%), reduce fuelwood consumption (23.6%), emit less smoke (15.9%), cook faster (10.7%), and is safe to use (5.3%). This finding is indicative of a relatively broader component in the cookstoves landscape i.e. that most households are not fully satisfied with the functioning, design and/or performance of their primary stove types for their cooking needs.

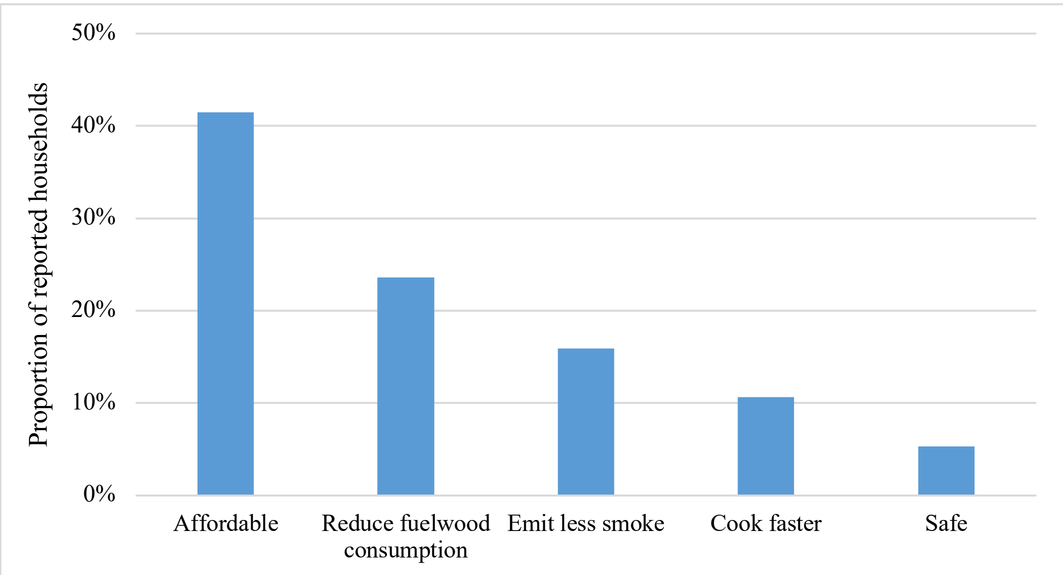

Figure 5-3: Respondents perception about ideal stove characteristics

5.5.2 *Estimation results for discrete choice experiment*

This section present results from the discrete choice experiment designed for two main alternatives: LPG and improved charcoal stoves as outlined in Section 3.2.2.6. Stated preferences and trade-offs relative to stove-specific attributes are estimated using a combination of conditional logit and mixed logit models. The maximum likelihood estimates for the mixed logit models are presented to account for preference heterogeneity (McFadden and Train 2000). As described Section 3.3.2.3, the utility parameters for the selected stove-specific attributes were specified as random parameters, assuming a normal distribution in the surveyed population in the mixed logit model. The constant for LPG alternative (i.e. ASC) is included to capture the average effects of unincluded factors on utility of LPG relative to charcoal alternative.

5.5.2.1 *Trade-offs between stove-specific attributes on stove preference (main effects)*

The estimation results for the main effects of stove-specific attributes on utility of LPG preference over charcoal alternative are presented in Table 5-10.

Table 5-10: Estimation results for general effects of stove-specific attributes on stove preference

	Conditional Logit	*Mixed Logit*	
Stove attributes		*Mean coefficient*	*Standard deviation*
Alternative Specific Constant	0.098	0.134	
	(0.184)	(0.220)	
Stove price	-0.020***	-0.023***	0.009*
	(0.003)	(0.003)	(0.005)
Fuel usage cost	-0.040*	-0.061*	0.138***
	(0.025)	(0.027)	(0.030)
Indoor pollution	-0.333***	-0.408***	0.066
	(0.064)	(0.073)	(0.021)
Environmental impact	0.549***	0.693***	0.496***
	(0.089)	(0.106)	(0.135)
Log likelihood	-1989.04	-1926.31	
Wald test	123.72***	125.47***	
Observation	360		
Note:	*standard errors in parenthesis.* *p<0.1; **p<0.05; ***p<0.01		

To start with, the positive ASC (α) coefficient signifies that all factors held constant, the respondents evaluated and generated higher utility for preference of LPG than the charcoal stove alternative. However, the ASC coefficient was not statistically significant suggesting that there was no bias of respondents leaning towards the LPG alternative.

All the coefficients for the effects of stove-specific attributes were statistically significant at 1-5% levels. The standard deviation coefficients of parameter distributions from the mixed logit model suggest that stove price, fuel usage cost, and environmental impact are indeed heterogeneous across the surveyed populations. However, although the mean coefficient for indoor pollution was strongly significant ($p<0.01$), its standard deviation coefficient was not statistically significant. This implies that higher levels of indoor air pollution are expected to generate a negative utility for the respondent, regardless of their socio-economic status or geographic location.

As expected, the coefficients for stove price and fuel usage cost were significantly negative. This implies that, a unit increase in stove price and fuel usage cost generated negative utility or reduced respondents' probability for LPG preference. In other words, the respondents were significantly sensitive to monetary attributes which negatively affected their likelihood for preference of the modern LPG alternative. However, based on the relative magnitude of the coefficients, fuel usage cost was found to affect decision making 3 times more than the stove price. This pattern can be explained that a lower usage cost reduces the overall cost of a cookstove in the long term, hence the stronger magnitude of utility.

When it comes to the effects of non-monetary attributes on stove preference, the results indicate that, a given increase in the levels of indoor air pollution generates a negative utility for the respondents. On the other hand, the positive sign for environmental impact signifies that respondents were positively influenced by environmental conservation which increased likelihood for selection of LPG stove alternative.

5.5.2.2 Effects of household geographical location and socio-economic characteristics on stove preference

In order to investigate the possible sources of heterogeneity in stove preferences, household socio-economic variables and geographical location (i.e. proximity to the urban center and the state forest) were interacted with ASC. Estimation results in Table 5-11 suggest that ASC coefficients are significantly positive ($p<0.01$) implying the surveyed population's preference for the modern LPG alternative. In this case, the standard deviations in the mixed logit model are insignificant confirming that the heterogeneity of the stove-specific attributes is incorporated explicitly to the interacted variables.

5.5.2.3 Effects of household geographical location on stove preference

Although the respondents, on the whole, preferred the modern LPG over the charcoal alternative, the relative utility was not universal for all individuals relative to their location across the enumeration transect zones.

The negative coefficient for the respondents located at close proximity to the forest and for those located farther away from the forest towards the semi-arid interior imply their significant preference for the charcoal stove alternative *($p<0.01$)*. However, based on the magnitude of their coefficients, the utility for the charcoal alternative by residents located at close proximity to the forest was found to be about 40% higher as compared to that of the semi-arid zone. This is perhaps due to the biomass abundance for the households living at the vicinity of the state forest as compared to those farther away where biomass scarcity is high (see also results in Section 6.2.1).

On the other hand, the utility coefficient for the peri-urban transect zone was significantly positive *($p<0.01$)* signifying their likelihood for LPG preference. It is expected that the transitional state of a peri-urban interface alters the households decision-making environment. Households located in the peri-urban transect zone have limited open-access areas for free fuelwood collection (see Section 6.2.1) but may have better access and awareness about modern cooking technologies (see Section 5.2.1) as compared to their rural counterparts (see Section 5.2.2).

The results further suggest that the likelihood for preference of LPG over charcoal alternative decrease with each additional kilometer walked from the homesteads to the most frequent fuelwood collection woodland ($p<0.05$). This finding contradicted the theoretical expectation that fuelwood scarcity would motivate desire to switch to non-solid fuels. Nevertheless, this finding is in harmony with utility generation observed in semi-arid zone where a significant likelihood for preference of charcoal alternative was observed.

5.5.2.4 Effects of intra-household characteristics on stove preference

By demographic characteristics, the interaction effects suggest that a unit increase in the level of income increases the likelihood for LPG preference *($p<0.05$).* This finding is consistent with the energy ladder theory whereby households tend to switch to modern fuels as their wealth increases.

In addition, the estimation results signify that a given increase in the education level of the respondent was also found to increase utility generation for LPG alternative ($p<0.05$). The theoretical expectation was that education improves awareness and cognitive ability about the inherent benefits of stove choices. This is possibly because highly educated individuals are more likely aware of environmental impacts and the health dangers of indoor air pollution.

From a gendered perspective, the results suggest that male respondents are more likely to prefer LPG alternative than females ($p<0.05$). This observation is perhaps attributable to the fact that, while men are more involved with household budget affairs, the burden of the sustained stove use falls more on women as they are often solely involved in fuel procurement and cooking tasks (also see results in Section 6.2.2). This hypothesis is consistent with the path analysis findings (Section 5.3.2.1) where women were found to have an inverse association with income which reduce their total effects on stove adoption by about 14%.

Table 5-11: Conditional and mixed logit models for interaction-effects on stove preference

Attribute	*Conditional Logit*	*Mixed Logit*	
Alternative Specific Constant	0.519*	0.546	
	(0.273)	(0.631)	
Price	-0.023***	-0.024***	0.006
	(0.003)	(0.005)	(0.062)
Usage cost	-0.065**	-0.064**	0.001
	(0.026)	(0.032)	(0.061)
IAP	-0.389***	-0.394***	0.004
	(0.067)	(0.123)	(0.014)
Environment	0.460***	0.472**	0.013
	(0.096)	(0.254)	(0.060)
ASC Interactions with geographical location			
Kiambu region	0.246**	0.249**	
	(0.109)	(0.129)	
Close forest	-0.513***	-0.514***	
	(0.147)	(0.148)	
Peri-urban	0.324***	0.326***	
	(0.140)	(0.145)	
Semi-arid	-0.306***	-0.309***	
	(0.116)	(0.132)	
ASC Interaction with household characteristics			
Education	0.126***	0.213**	
	(0.033)	(0.092)	
Gender (male=1)	0.214***	0.222*	
	(0.082)	(0.138)	
Income	0.110***	0.112**	
	(0.039)	(0.042)	
Improved biomass stove use	0.067	0.067	
	(0.108)	(0.111)	
Distance to woodland (km)	-0.063**	-0.064**	
	(0.026)	(0.033)	
Log likelihood	-1947.38	19747.37	
Wald test	186.46***	75.30***	
Observations	360		

Note: *standard errors in parenthesis.* $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

5.5.2.5 *Marginal willingness to pay for stove-specific attributes*

In order to better understand how trade-offs are made between stove-specific attributes, the marginal willingness to pay (MWTP) was estimated. The MWTP was estimated to establish the value of money households are willing to forfeit in order to obtain a further (additional) non-monetary attribute, based on the stove price coefficient (Ryan et al., 2008). Table 5-12 present the estimated coefficients from conditional and mixed logit models illustrating the trade-offs between the stove-specific attributes. The effect of indoor pollution and environmental impact are presented in their respective categorical impact levels as outlined in Table 3-8.

Table 5-12: Estimation results for of stove-specific attributes only

		Conditional Logit	Mixed Logit	
Stove attributes			*Mean coefficient*	*Standard deviation*
Stove price		-0.020^{***}	-0.026^{***}	[0.002]
		(0.002)	(0.003)	(0.004)
Fuel usage cost		-0.055^{**}	-0.080^{***}	0.187^{***}
		(0.021)	(0.027)	(0.026)
Indoor pollution	No smoke	0.505^{***}	0.511^{***}	0.435^{*}
		(0.085)	(0.104)	(0.268)
	High smoke	-0.344^{***}	-0.478^{***}	[0.305]
		(0.081)	(0.089)	(0.173)
Environmental impact	Low impact	[-0.146]	-0.309^{**}	1.090^{***}
		(0.094)	(0.149)	(0.106)
	High impact	0.724^{***}	1.123^{***}	0.403^{**}
		(0.082)	(0.110)	(0.192)
Log likelihood		-1969.61	-1876.46	
Wald test		164.22^{***}	186.29^{***}	
Observations		360		

Note: standard errors in parenthesis. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$ [] for non-significant variables

Estimation results in Table 5-12 show that all the mixed logit coefficients for stove-specific attributes are statistically significant at 1-5% levels and in the expected signs. The surveyed respondents are negatively sensitive to a given increase in (a) stove price; (b) monthly fuel usage cost; (c) high smoke emission; and (d) low environmental impact (cutting trees). On the other hand, the positive coefficient for low smoke emission and high environmental impact imply that the surveyed respondents were enticed by a stove demonstrating clean indoor air quality and increased conservation of trees from stove use.

The standard deviation coefficients of random parameter distributions from the mixed logit model suggest with the exemption of stove price and high smoke emission, all the stove-specific attributes exhibit preference heterogeneity across the surveyed populations. In other words, regardless of socio-economic status or geographical location across the enumeration transect, the respondents are affected the same way by a given increase in stove prices and high smoke emission.

The relative magnitude of the MWTP estimates are statistically significant confirming the presence of substantial heterogeneity for all the stove-specific attributes in stove preferences. Table 5-13 presents estimations on the amount of money households are willing to forfeit in order to obtain a further (additional) non-monetary attribute, based on the stove price coefficients.

Table 5-13: Estimation for marginal willingness to pay for additional attributes

		Marginal willingness to pay (US$)		
Stove attribute		*Conditional logit model*	*Mixed logit model (mean)*	*Standard deviation*
Indoor pollution	No smoke emission	25.25	19.65	10.59
	High smoke emission	-17.20	-18.88	16.31
Environmental impact	Low impact (less trees conserved)	-07.30	-11.88	38.74
	High impact (more trees conserved)	36.20	43.19	27.68

Note: 1 USD = 100 Kenya shillings

The results from the mixed logit model reveal that for an average household in the surveyed population:

(a) Zero smoke emission increases their WTP by US$19.65 at a standard deviation on US$10.59;

(b) High smoke emission reduces their WTP by US$18.88 at a standard deviation of US$16.31;

(c) Environmental degradation (cutting down trees) reduces their WTP by US$11.88 at a standard deviation of US$38.64;

(d) Environmental conservation increases the MWTP by US$43.19 at a standard deviation of US$27.68

These results lay more emphasis about trade-offs between stove-specific attributes where the surveyed population place the highest relative valuation and importance on environmental conservation followed by reduced smoke emission level. However, in realistic terms, when compared to the monthly income levels of the surveyed communities (see Tables 5-4 and 5-5), the estimated MWTP is far reaching particularly for the semi-arid residents who earn about US$60.00 a month.

5.6 Ethnographic mapping of perception of acquisition and sustained use of biogas and improved biomass stoves.

This section outlines the emerging patterns from the ethnographic surveys identifying convergences and divergences of drives and barriers of stove uptake and consistent use.

5.6.1 Perception about factors influencing stove acquisition/uptake

During the ethnographic surveys, the users of biogas and improved biomass stoves were probed about the reasons that motivated them to adopt the respective cooking technologies for their households. As illustrated in Figure 5-4, the study identified that despite the varying reasons for adoption in relation to stove type, there also exists common drivers of adoption.

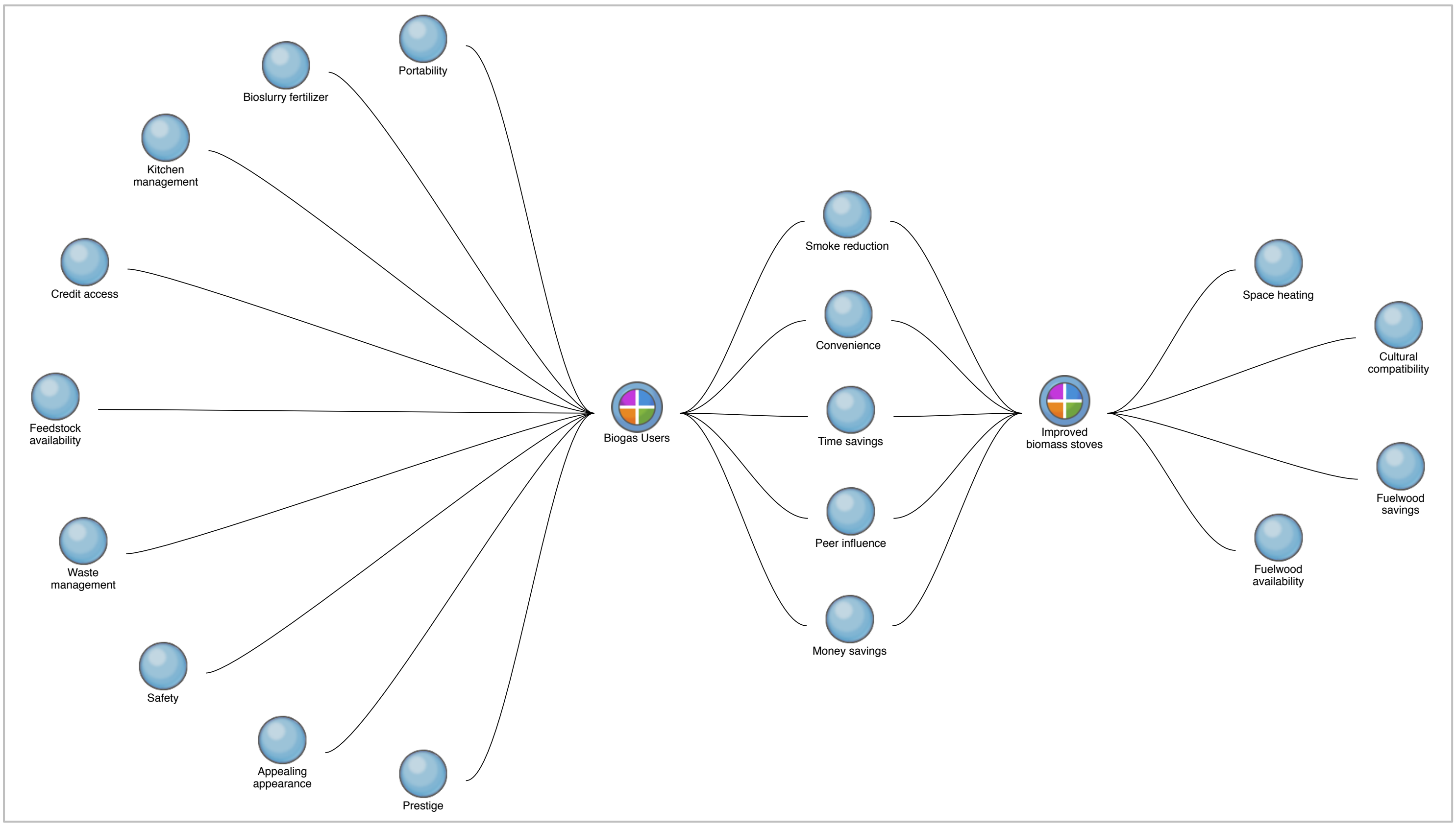

Figure 5-4: Mapping of drivers of adoption of improved biomass and biogas stoves (source: thesis author)

The converging enablers of adoption as expressed by users of improved biomass stoves and biogas stoves include: (a) smoke reduction; (b) convenience of use in terms of ability to multi-task cooking with other household activities; (c) time savings was consistently mentioned by households that often collect fuelwood from off-farm sources located farther away from their homesteads; (d) money savings which was largely emphasized by households relying on fuelwood purchased from the market; and (e) peer effects or social influence from friends, family or neighboring households that have adopted improved biomass or biogas stoves.

Biogas stove users had additional diverging reasons that motivated them to invest in the cooking technology. These reasons include: stove portability, kitchen hygiene/cleanliness and safety which was particularly mentioned by households that have small children. Others highlighted about access to credit services offered by micro-financing institutions or farmer organizations. Utilization of bio-slurry for improved crops and fodder production was strongly highlighted as a key motivating and decision-making factor that influenced households to invest in biogas. To a large extent, this driver (bio-slurry utilization) was particularly mentioned by men whereas women expressed their interest in biogas as safe, non-smoky and appealing/prestigious cooking technology.

> *"... I was very interested in the bio-digester effluent because I could grow organic crops and fodder for my cows. I do not need to buy and use chemical fertilizers anymore."* (male, farmer, Kikuyu-Kiambu*)*

When it comes to specific drivers motivating adoption of improved biomass stoves, the respondents expressed opinion about space-heating as a co-benefit especially during the cold seasons or for simply warming their house in the evenings. Fuelwood availability was also mentioned as a motivating driver for adoption of improved stoves predominantly where households practice agroforestry or have established woodlots for sustainable supply of fuelwood.

Cultural appropriateness offered by the design of improved biomass stoves was largely emphasized by the respondents. They explained that, even after the stove-switch, they have been able to continue using their cultural cooking pots and enjoying their cultural dishes and cooking practices e.g. smoking fish, smashing *ugali* and roasting maize, bananas, etc.

5.6.2 Perception about barriers of sustained/consistent stove use

Ethnographic surveys were also conducted with quitters or dis-adopters of biogas and improved biomass stoves. This included groups of households that had earlier acquired but discontinued to use the cooking technologies but switched back to their old cooking methods. This exercise was conducted to understand the barriers of sustained or consistent stove use.

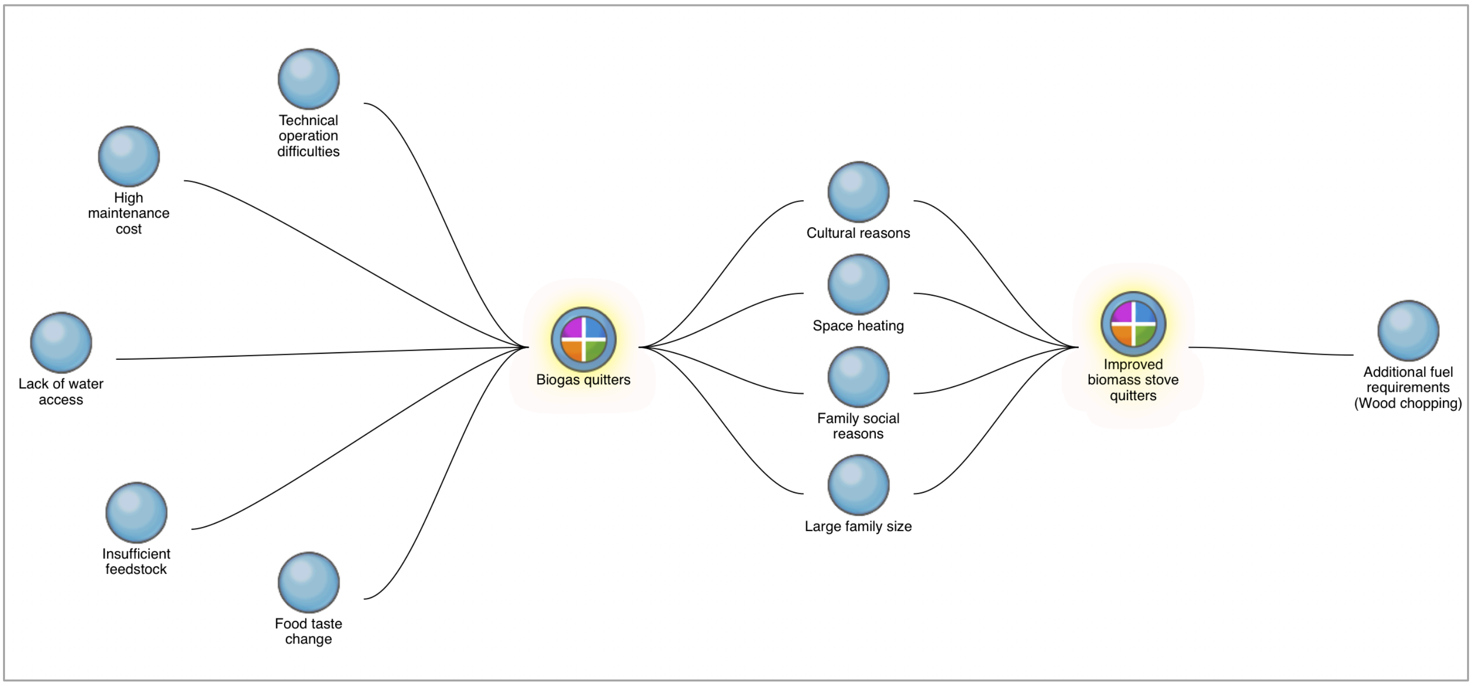

Figure 5-5: Mapping of barriers of sustained use of improved biomass and biogas stoves (source: thesis author)

As illustrated in Figure 5-4, the identified common challenges/barriers of consistent stove use include: (a) cultural reasons; (b) family or social reasons; (c) need for space heating; and (d) large family sizes requiring large cooking pots.

In general, stove technological appropriation emerged strongly as a fundamental issue affecting sociocultural norms. For instance, adoption of clean cookstoves (especially biogas) was said to alter household social life since design of traditional stoves (spacious and portable) permit to serve as household gathering point and space heating/warming:

> *"… whenever I'm cooking in the evening, my children are fond of sitting around the cookstove to keep warm, storytelling, singing or listen to their grandmother tales. We cannot enjoy such activities with biogas stove, so we occasionally cook with the three-stone stove."* (female, housewife, Lari - Kiambu)

Furthermore, the women asserted that, the use of biomass stoves has important ramifications for their social life since they are able to enjoy chatting with other people during fuelwood collection activities.

Further scrutiny of the ethnographic narratives with improved biomass stoves quitters revealed their dissatisfaction with the additional requirement of having to chop the fuelwood into smaller pieces that can fit in the stove.

Similarly, biogas quitters had additional specific reasons that made them switch-back to traditional cookstoves which revolved around operation of bio-digester sub-system including: (a) lack of sufficient feedstock; (b) technical operation difficulties; (c) lack of reliable water access; and (d) high maintenance costs.

For (a) and (b), the following comments are quoted conversation with 2 respondents in Kiambu:

"…*the farm worker failed to use the sieve to filter out biomass debris from the feedstock. The bio-digester piping blocked, and I did not have the money to have it repaired.* (Female, teacher, Gatamaiyo-Kiambu)

"… I was very happy with the biogas stove. However, my cows got sick and died. I no longer have cow-dung to put in the bio-digester for production of biogas." (Male, Farmer, Kigumo-Kiambu).

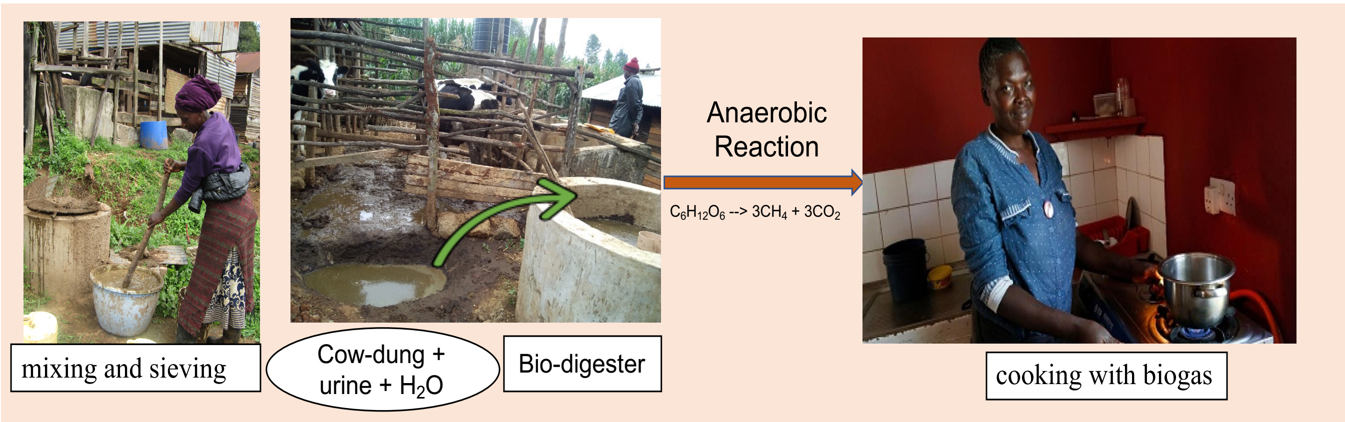

Figure 5-6: Illustrative diagram for bio-digester operation procedures (source: thesis author)

5.6.3 Perception about barriers/challenges of adoption of clean cookstoves

Further ethnographic surveys were also conducted with exclusive users of traditional bioenergy cookstoves to understand the reasons that inhibit their adoption of clean cookstoves (see Figure 5-7). The survey started by inquiring whether the respondents are aware of "better" cooking technologies of which they all responded to the affirmative. However, they were generally found to be less knowledgeable and appreciative of the benefits of clean cookstoves.

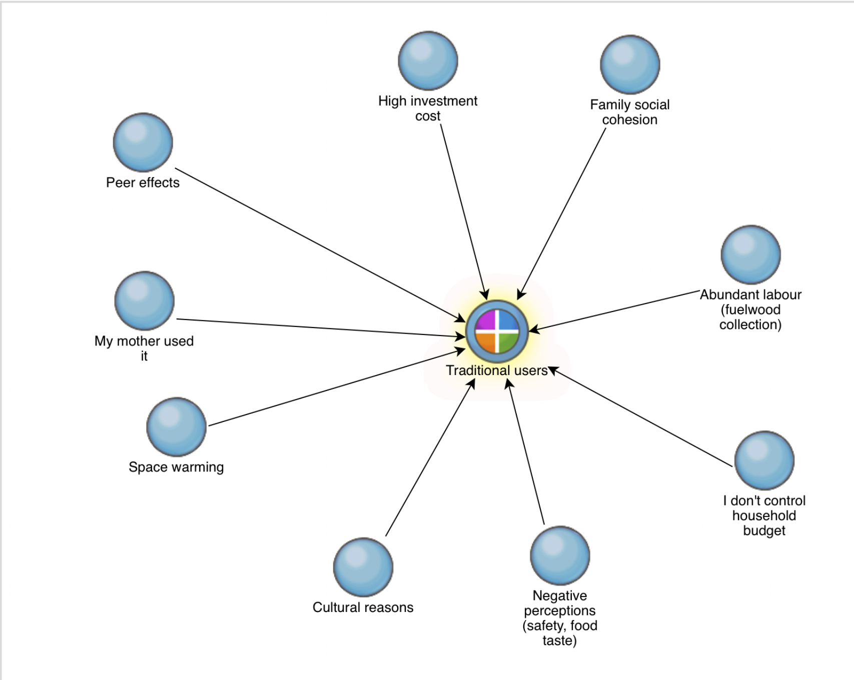

Figure 5-7: Mapping of barriers of adoption for traditional stove users (source: thesis author)

To start with, it was noted that most of the stated barriers of adoption of clean cookstoves by traditional stove users were also mentioned as barriers/challenges for consistent stove use by adopters of biogas and improved biomass stoves (see Section 5.5.2). In other words, these are perceived benefits of traditional biomass stoves which include: (a) family social reasons; (b)space warming; and (c) cultural reasons.

It was observed that majority of traditional stove users perceive clean cookstoves as either too expensive for them to afford, while others feel that it is within their cultural prerogative to use traditional biomass stoves. The study deduced that the perceived norms for non-adoption of clean cooking technologies include situations where traditional stove users are influenced by inter-generational transmission of socio-cultural norms and peer effects:

> *"I use three-stone stove in my household because I found my mother using it. After I got married, I found my mother-in law cooking with it, and most of my friends use it too"* (Female, shopkeeper, 29 years)

Consistently, majority of the interviewed women quoted, *"I do not control household budget"* as the reason for not adopting clean cookstoves for their households. The ethnographic narratives further revealed that, although women bear the greatest responsibilities in terms of fuelwood procurement and cooking tasks, they often consult their husbands on matters of household budgetary issues, including the decision to purchase a stove.

The study further deduced other strong effects of negative perceptions and skepticism with regard to the functionality and performance of clean cookstoves. The most prominent negative perceptions revolved around issues of safety concerns, change in food taste and negative hearsays (often untrue):

"… cooking with biogas makes the kitchen to smell and the food to taste like cow-dung manure" (Female, farmer, 48 years)

"… I would consider buying gas (LPG) but I am afraid it might explode while cooking or the children might tamper with it and burn the house" (Female, housewife, 36 years)

Figure 5-8: Photo of a woman cooking with traditional biomass stove (source: thesis author)

5.7 Synthesis of main findings about factors affecting stove adoption and preferences

This study utilizes multiple data methods to present a case that households' adoption of clean cookstoves is a complex process subject to a spectrum of factors and dynamics. This section synthesizes main findings gathered from the regression estimation model, path analysis, discrete choice analysis and ethnographic surveys. The aim is to synthesize emerging and cross-cutting patterns with respect to: (a) the observed general factors affecting stove adoption and preference; and (b) observed patterns relative to geographical locations as depicted by the enumeration transects.

5.7.1 Patterns of stove adoption and preference in relation to intra-household factors

To begin with, the probit estimation results identify that income significantly increase the probability of adoption of improved biomass and biogas stoves (see also Osiolo 2017; Uhunamure et al., 2019; Mwirigi et al., 2014; Nguu et al., 2011). Similarly, the discrete choice analysis established that a unit increase in household income level increases the likelihood for preference of the modern, LPG alternative. This finding is consistent with the energy ladder theory which allude that households tend to switch to modern fuels as their wealth increases (Treiber et al., 2015; Kroon et al., 2013; Masera et al., 2000; ESMAP, 2003). When it comes to trade-offs in decision-making, discrete choice analysis consistently identifies significant sensitivity to monetary attributes (i.e. stove price and monthly fuel usage cost). In a more nuanced perspective, ethnographic mapping identifies high investment costs and the recurring maintenance costs as key barriers of stove acquisition and sustained use (Sections 5.6.2 and 5.6.3).

Second, without disputing the notion that ordinary Kenyan household is typically patriarchal, the study identifies gender as a cross-cutting factor affecting stove adoption and preference. To start with, the probit regression models suggest that male headed households have a significantly positive effect on adoption of the modern biogas stoves (Section 5.3.1). A similar pattern is observed in the discrete choice analysis where males are more likely to prefer LPG alternative than females (Section 5.5.2.2). This is perhaps attributable to their positive correlation with income and almost all of productive resources that positively affect adoption as identified through the path analysis (see Table 5-9). On the other hand, the path analysis further reveals that female heads have limited access to productive resources and have a negative association with income which reduce their total effects on adoption of improved biomass stoves by a factor of 14% (see Table 5-8). This implies that in the long-term, reduction in fuel cost will have maximum welfare benefit on women, who are often disproportionately involved in fuelwood procurement activities and cooking tasks.

During ethnographic surveys, women consistently spoke about their lack of control of household budget as the key reason deterring them from adopting "better" cooking methods (see also Clough, 2012; Mengistu et al., 2016). Promisingly, the path analysis model suggest that women stand better opportunities for adoption of improved biomass stoves in terms of access to credit services and participation in social groups (Section 5.4.1). Previous studies identify that households participating in social groups are more likely to engage in social learning about a technology hence raising their likelihood to adopt it (Kisaka-Lwayo and Obi, 2012; Person et al., 2012; Vulturius and Wanjiru, 2017; Miller and Mobarak, 2016).

Finally, the Chapter has shed light on the role of education as an indicator of awareness about benefits and dangers of traditional cooking methods. The probit regression models suggest that more educated household heads have a significantly positive effect on adoption of both the improved biomass stoves and biogas stoves. Several studies report that educated households heads can better process information and understanding about the benefits of clean cooking options as compared to those with no formal education (Andadari et al., 2014; Fraser et al., 2006; Malla and Timilsina, 2014).

5.7.2 Patterns of stove adoption and preference across enumeration transect zones

In addition to the intrahousehold factors discussed above, it is consistently observed that local biomass availability/accessibility (distance from the state forest) and the transitional state of a peri-urban interface (proximity to the urban center) alter the decision-making environment when it comes to stove choices.

The regression analysis reveal that households located in the peri-urban zone have a statistically significant positive effect on adoption of improved biomass stoves while those located at close proximity to the forest have a negative effect on adoption (Section 5.3.4). Considering the trade-offs and interaction terms with ASC, this finding is consistent with discrete choice analysis which points out that demand for the modern LPG stoves is significantly positive in the peri-urban zone while households located in the rural interior prefer the charcoal alternative. This finding confirm previous studies which present urbanization as a key indicator for greater accessibility to modern fuels (improved market infrastructure) and awareness about modern products, including clean cookstoves (Pattanayaket al., 2012; Shen et al., 2015). This would mean that a reduction in stove price and fuel cost will have maximum welfare benefit on households located farther away from the state forest (i.e. in fuelwood scarce zones).

Perhaps, the consistent discrepancy across the transect zones could be largely attributable to income differences between the transect zones (a factor discussed in Section 5.7.1 above as an important driver of adoption and choice behaviour). In Section 5.2.2, it was established that peri-urban residents have significantly high income while those located farther away from the state forest towards the semi-arid interior have the lowest income (see Tables 5.5 and 5.4). Several studies suggest that households located at close vicinity to the city have higher chances for employment and income diversification opportunities as compared to their rural counterparts (Hollada et al., 2017; Karimu, 2015b). Consequently, other things being equal, it can be inferred that a given increase in stove price and fuel costs will have the most negative impact on the low-income groups (i.e. those located in the semi-arid interior as alluded in the above paragraph).

In addition, while biomass availability appears to have a significant effect on stove adoption and preference, the physical accessibility is equally important. The estimation results from the probit model indicate that adoption of improved biomass stoves increases by 4.2% ($p<0.05$) with each additional kilometer walked from the homesteads to the most frequent woodland. On the contrary, the likelihood for preference of the modern LPG alternative significantly decrease with increasing distance to fuelwood collection area. It can be conveniently argued that while fuelwood scarcity can incentivize household to adopt fuelwood-saving cookstoves, affordability and sensitivity to monetary attributes (due to low income) remain a key barrier for adoption of modern stove alternatives.

5.8 Summary

This chapter has utilized multiple analytical methods to understand stove adoption patterns which are discussed in four distinct and interconnected phases. Sections 5.3 and 5.4 have provided estimation results for the hypothesized variables affecting adoption of improved biomass stoves and biogas stoves. The discrete choice analysis (Section 5.5) has illustrated the relative strengths of stove-specific attributes on stove preference and how trade-offs are made across different market segments and user profiles. A systematic mapping of qualitative narratives from ethnographic surveys have provided more nuanced insights and user perspectives about stove adoption.

A holistic synthesis of the emerging patterns for stove adoption and preference (Section 5.7) identifies that stove adoption is not universal for all individuals but is largely affected by intrahousehold characteristics, institutional factors, geographical location (i.e. proximity to the urban center and the state forest).

However, the ethnographic mapping of user perception (Section 5.6) has revealed that, even though households are positive towards modern cooking technologies, there are other contextual factors beyond the stove-specific attributes, geographical location and intrahousehold attributes that affect stove uptake and sustained use. These include: (a) socio-cultural dimensions; (b) peer effects and intergeneration transmission of cooking options; (c) negative perceptions and skepticisms about modern cooking technologies; and (d) technological appropriation in terms of compatibility with local cooking pots and stability when cooking local dishes such as preparing *"ugali",* a popular local dish which requires rigorous mashing.

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CHAPTER 6

IMPACT CATEGORIES OF CLEAN BIONERRGY COOKING TECHNOLOGIES IN KIAMBU AND MURANGA COUNTIES

6.1 Introduction

Although the availability of fuelwood is found to be mostly sufficient at global and national scales (Openshaw, 2010; Tobergte and Curtis, 2013) unsustainable woodfuel harvesting causes pressures at the local level (IEA, 2010; Drigo et al., 2015). Some studies have reported on the ramifications of such fuelwood supply-demand imbalances including accelerated deforestation and land degradation (Githiomi and Oduor, 2012; Kiruki et al., 2017; Ruuska, 2013). There also exists an expectation that adoption of clean cooking options can help address the woodfuel supply deficit, and its associated negative socioeconomic impacts (GoK, 2013a; 2015; Birundu et al., 2017; Mahiri and Howorth, 2001)

This chapter is based on a fundamental hypothesis that the dynamics of household fuelwood procurement and consumption patterns vary in relation to: (a) utilization technology (improved biomass stoves vs. traditional stoves); (b) proximity to accessible woodland; (c) fuelwood market prices; and (d) characterization of intra-household factors.

The impact categories assesed in this study emanate from fuelwood consumption savings (greenhouse gas emissions), time investment and money savings (opportunity costs) and stove user behavior and cooking area characteristcis (self-reported health symptoms). In this respect, Section 6.2 highlights the identified fuelwood sourcing dynamics, while Section 6.3 provide the estimated quantities of household fuelwood consumption; Section 6.4 evaluates the opportunity cost of unpaid time use *(collection and cooking*) and monetary expenditure; Section 6.5 estimates the potential greenhouse gas emission (CO_2) from fuelwood savings; Section 6.6 highlights about the prevalence and determinants of self-reported health symptoms associated with bioenergy stove use; and Section 6.7 provides a synthesis of key findings for the chapter.

6.2 Dynamics of fuelwood procurement patterns

This section identifies the main fuelwood collection sources based on household's proximity to resources (i.e. the state forest and the urban center). The intrahousehold dynamics with regard to allocation of labour by gender, desirable fuelwood quality and preferred fuelwood species are identified. The section further describes fuelwood procurement drudgery with regard to time investment and walking distance from homesteads to the most frequent fuelwood collection woodland. In order to better understand the intensity and magnitude of fuelwood shortage in the surveyed population, the various strategies and mechanisms applied by households to strategize shortage are identified.

6.2.1 Fuelwood collection sources

In the study areas of Kiambu and Muranga counties, numerous and varying fuelwood collection sources exist for households. It was observed that the choices made by households about where to collect, how often to collect and how much time to spend on collection is based on their geographical location across the transect and fuelwood availability within their localities. Figure 6-1 illustrates the main fuelwood sources across the enumeration transect based on the proximity to the state forest reserve and the urban center.

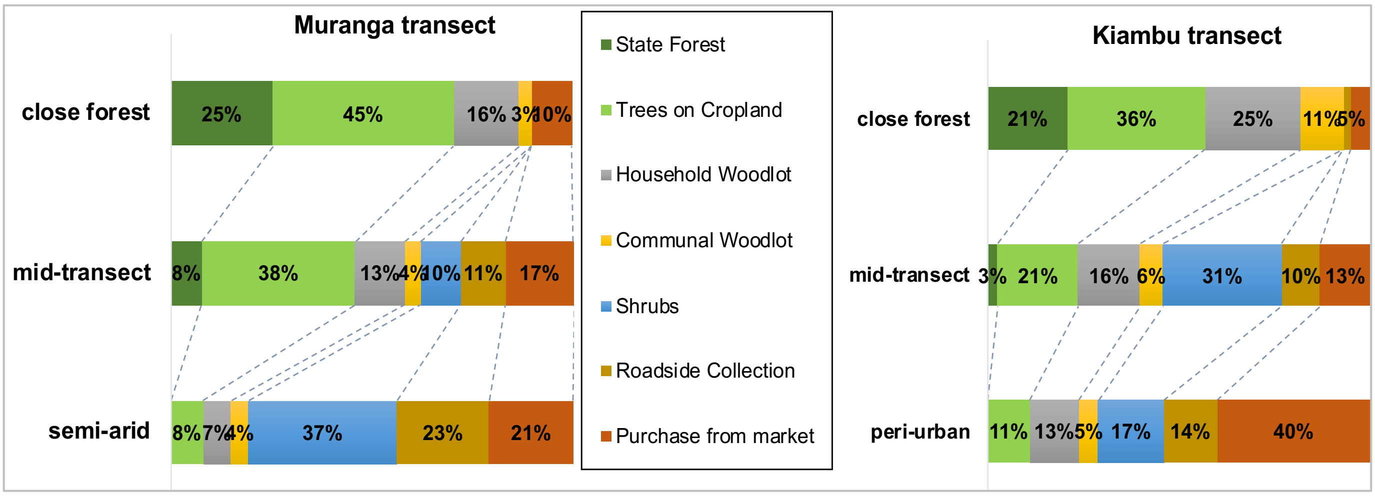

Figure 6-1: Distribution of reported fuelwood collection sources in Muranga and Kiambu transects

As illustrated in Figure 6-1, households located at close proximity to the state forest extract most of their fuelwood from their farms (i.e. agroforestry practice) where they plant trees either on cropland or in form of farm woodlots. It was further observed that "legal" inaccessibility can significantly limit the availability of fuelwood even for neighborhoods located at close proximity to the state forest. In each transect, less than 30% of the surveyed households reported to obtain access to the state forest for fuelwood extraction. During ethnographic surveys, it was identified that these populations often require some form of official licensing provided by the local forest office at a modest monthly fee of about KES.100 (US$ 1) plus a commitment to maintain the forest tree nursery and participate in tree planting activities.

As fuelwood become scarce (i.e. increasing distance away from the state forest towards the semi-arid interior), the reliance on state forest resources and on-farm sources tend to decrease (Figure 6-1). In the semi-arid transect zone, households were found to rely more on fuelwood sourced from the open-access, off-farm sources including shrubs, roadside collection and communal woodlots while 21% purchase fuelwood from the local market and traders. Ethnographic survey results identified that natural barriers such as (a) difficult landscape terrain (b) steep topography; (c) climatic and seasonal variations often limit the availability, accessibility and affordability of fuelwood for the local communities.

In the case of peri-urban interface (at close vicinity to the capital city), a different fuelwood procurement pattern was observed where both the on-farm and off-farm fuelwood sources tend to decrease and about 40% of the households rely on commercial fuelwood market. In this zone, the ethnographic and observation surveys identified that: (a) fuelwood is mostly supplied by the local furniture and construction workshops in form of wood-cuts; (b) fuelwood is readily available in small, affordable quantities in local market; and (c) there is easy market access to cooking fuel alternatives such as LPG, charcoal and kerosene to substitute or reduce household demand fuelwood (see also results in Section 5.2).

6.2.2 Intrahousehold gender differences in fuelwood sourcing

In the study areas, fuelwood procurement was observed to be a clear-cut gendered issue particularly when it comes to the freely collected fuelwood, where women and girls were found to disproportionately undertake fuelwood collection duties (see Figure 6-2). The findings indicate that adult female and young girls bear 68% and 15% of fuelwood collection burden, respectively.

For the households practicing agroforestry, 78% reported that the trees are often planted and managed by men. On the other hand, 67% of the households that mainly rely on fuelwood purchased from the market reported that men contribute the money. It was identified that in most instances, men are often responsible for household budgetary allocations.

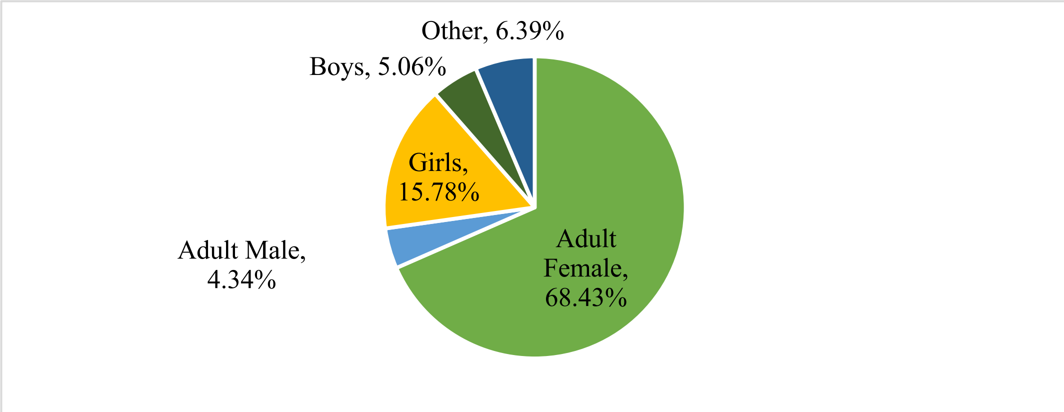

Figure 6-2: division of fuelwood procurement household labour, by gender

6.2.3 Desired quality and species preferences for fuelwood

Generally, respondents in ethnographic surveys described that most trees species found in the study areas can be used for fuelwood, but the burning quality varies from species to species. It was derived that the most appreciated fuelwood species for cooking include those that: (a) are locally available and physically accessible; (b) have dense wood with low moisture content that can dry quickly; (c) produce wood that splits with ease using household available tools; (d) that produce wood that does not produce sparks when burning; (e) burns slowly with a lot of heat and little smoke; and (f) does not give unpleasant food taste or odor.

According to the interview with the local forest officers (Mr. Maingi, Muranga Forest Office; Mr. Omamo, Central Highlands Forest Station, Kiambu), the locally available tree species that produce desirable and high-quality fuelwood include: *Casuarina equisetifolia, Acacia mearnsii, Acacia polyacantha, Acacia xanthophloea, Acacia spectabilis, Eucalyptus camaldulensis, Leuceana leucocephala,* and *Sesbania sesban.* These species are highly preferred as they produce dense fuelwood with high heat intensity.

Other fast-maturing exotic tree species, such as *Grevillea robusta, Eucalyptus grandis,* and *Eucalyptus saligna,* are commonly planted on farmlands as woodlots where they are regularly pruned for fuelwood needs. Indigenous tree species such as *Albizia gummifera*, *Cajanus cajan*, *Markhamia lutea*, *Prunus africana,* and *Vitex keniensis* were reportedly planted on farmland. Several other trees species identified in the study areas hold spiritual, cultural and religious significance for the local communities and cannot used for fuelwood.

6.2.4 *Fuel procurement drudgery and time investment*

6.2.4.1 *Self-reported safety risks experiences during fuelwood procurement activities*

Fuel gathering is a labor-intensive activity, which is not only not only time consuming (particularly for women, Section 6.2.2), but also exposes them to various safety risks during fuel gathering activities. When it comes to means of transporting fuelwood from the collection area to the homesteads, 82% of the surveyed respondents reported to carry the fuelwood loads on their back, while the rest use motor cycle (8%), hand-wheelbarrows (7%) and donkeys (4%). In the study areas, ethnographic surveys identified that an adult back-load weighs about 25-30kg, which is carried on often hilly and steep terrain, particularly in the case of Muranga.

Some of the reported safety risks (see Figure 6-3) include: (a) hilly/steep terrain in the fuelwood collection sites which increases the risk of falling when carrying the heavy back-loads; (b) conflicts at the fuelwood collection woodland which often occur as fuelwood become more scarce, where local communities have to scramble over the limited available resources; (c) injuries and bruises especially on arms and legs when walking and collecting fuelwood on often thorny shrubs; (d) attack by wild animals and snake encounters; (e) threats from forest guards and private forest owners; and (f) instances of sexual-based harassments particularly for the young girls.

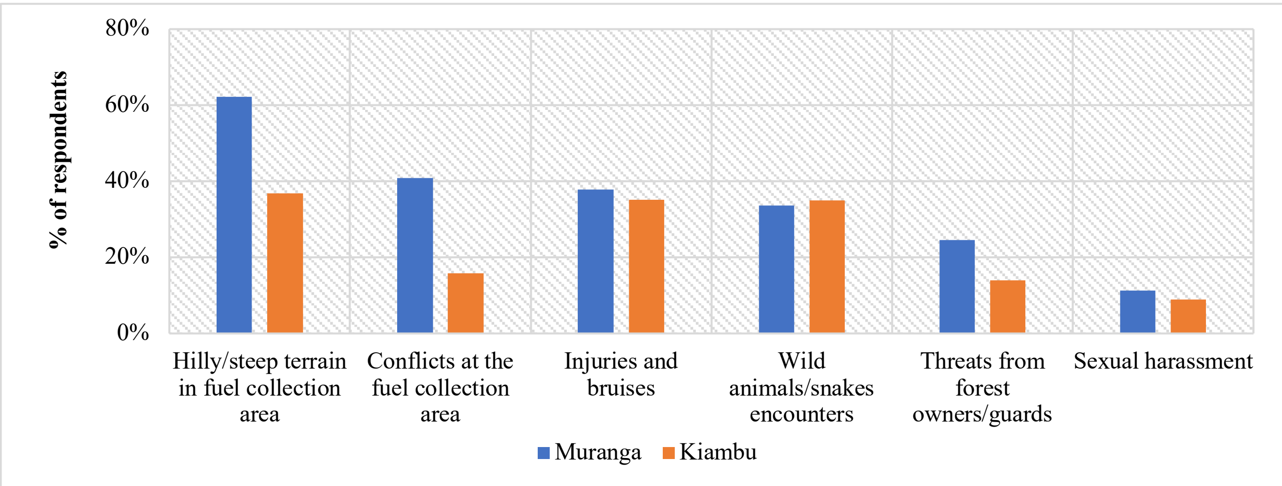

Figure 6-3: Distribution of self-reported safety risks experienced in fuelwood sourcing activities

Off-farm fuelwood collection sources such as shrubs, roadside and community woodlots have limited or no regulation (open access), akin to result to "tragedy of the commons" with depletion of the available fuelwood. The inadequacy of available fuelwood spurs local conflicts between the collectors themselves or with the owners of the collection points. Further ethnographic scrutiny points out that similar conflicts are also experienced in cases where local communities attempt to illegally extract fuelwood (without a license) from the state forest which lands them into conflict with the forest guards and officers.

Figure 6-4: Photo of women in the study areas transporting fuelwood in Gatamaiyo, Kiambu (source: thesis author)

6.2.5 Household fuelwood scarcity coping strategies

In principle, it can thus far be conveniently said that fuelwood scarcity is an extremely complex system, subject to a number of dynamics including proximity to resources (i.e. urban center and the state forest) and intra-household factors. In order to better understand the magnitude of fuelwood scarcity in the surveyed areas, this study identified different coping mechanisms applied by households to strategize fuelwood shortage (30 days prior to the date of survey). These mechanisms are hereby summarized into four categories: (a) food-related coping strategies; (b) increased procurement time/effort; (c) market-based strategies; and (d) stove/fuel substitution.

Results in Table 6-1 indicate that households often avail themselves a range of options to adapt their fuelwood consumption patterns. The intensity (i.e. reported proportion) of the identified coping mechanisms was found to vary by household's geographical location across the transect and by stove use. Households located at close proximity to the forest had the lowest reporting of applied coping strategies. This is perhaps due to biomass abundance experienced in this transect zone where fuelwood is often procured from both on-farm sources and extraction from the state forest (see Section 6.2.1).

In the semi-arid zone, traditional stove users were found to be the most affected by fuelwood scarcity as depicted by the proportion (%) of their coping strategies. Majority of the surveyed households in this zone reported to apply food-related coping strategies such as cooking fewer meals in a day (95% traditional stove users and 71%

improved stove users), cutting fruit trees for fuelwood such as mango and avocado trees (55% traditional stove users and 36% improved stove users). On the other hand, some of the reported drudgery-related coping mechanisms include walking for longer distances in search of fuelwood (90% traditional stove users and 84% improved stove users) while others reported to increase fuelwood collection labour by reallocating collection duties to school-going children (95% traditional stove users and 86% improved stove users).

In the peri-urban zone, results show that households often opt to substitute fuel or stove type (96% traditional stove users and 91% improved stove users) by switching to non-fuelwood types such as LPG, kerosene and charcoal. Food-related coping strategies applied in the peri-urban transect zone include omitting to cook heat-intensive foods such as legumes (84% traditional stove users and 56% improved stove users) and resort to eating dry foods such as bread or ready-made foods from the street food-vendors (90% traditional stove users and 83% improved stove users). Market-based coping mechanisms were also found to be commonly applied in the peri-urban zone including purchasing fuelwood from the local market and traders (87% traditional stove users and 73% improved stove users).

In addition, there were some other notable fuel and time-saving practices including: (a) use of appropriately sized cooking pots for stability especially when it comes to cooking “ugali” which require rigorous mashing; (b) use of tight-fitting lids to fasten the cooking process; and (c) change of meal preparation procedures (e.g. soaking, cutting food into smaller pieces and simmering food).

Table 6-1: Fuelwood scarcity coping strategies in relation to geographical location and stove use

	Close forest		**Peri-urban**		**Semi-arid**	
	Traditional stove	Improve stove	Traditional stove	Improve stove	Traditional stove	Improve stove
Food-related strategies						
– Cook fewer meals	33%	15%	83%	38%	95%	71%
– Undercook food to save fuelwood	12%	8%	20%	14%	55%	36%
– Omit cooking heat-intensive foods	18%	9%	84%	56%	90%	64%
– Cut fruits or fodder trees for fuelwood	26%	15%	15%	7%	84%	79%
– Eat dry or ready-made foods	23%	22%	90%	83%	95%	71%
Increased time/effort input						
– Walk for longer distances in search of fuelwood	23%	11%	50%	19%	90%	84%
– Increase fuelwood collection time	46%	35%	52%	45%	91%	76%
– Allocation of fuelwood collection duties to children	16%	13%	63%	50%	95%	86%
Market-based strategies						
– Purchase fuelwood from market	45%	54%	87%	73%	43%	30%
– Hire fuel collection labor	18%	32%	17%	25%	67%	43%
Substitution of stove/fuel use						
– Substitute fuel/stove use	54%	41%	96%	91%	26%	43%
– Use of inferior biomass (e.g. crop residues)	25%	17%	46%	35%	81%	66%

6.2.6 Time investment in fuelwood procurement and cooking tasks

In this study, the measure of fuelwood scarcity and physical accessibility of biomass resources was based on time investment for fuelwood collection activities and cooking. This was estimated based on a round-trip walking distance and average walking time invested by household member (particularly women. Section 6.2.2) from their homesteads to the main fuelwood collection site (see Table 6-2)

To begin with, the results from a Pearson correlation analysis indicate that there exist a strong and significantly positive correlation between increasing distance away from the state forest (enumeration transect zones) and distance (kilometers) travelled to the main collection woodland area (r=0.93, $p<0.01$).

In the case of Muranga transect, households located at close proximity to the state forest were found to walk for an average of 0.88 Km (0.97 hours/collection trip) while the semi-arid region residents walked nearly 3 times longer distance (2.64 hours/collection trip). Similarly, the frequency of weekly fuelwood collection trips was also highest in the semi-arid region where households cover an estimated average of 5 collection trips in a week. This pattern reveals the consequential drudgery with increasing fuelwood scarcity and limited physical accessibility within the household localities.

Kiambu transect exhibited a slightly different pattern. Compared to the households close to the forest who cover an average of 0.98km, the walking distance increased at the mid transect by 38% and then decreased in the peri-urban region at an estimated average of 0.80km. This is perhaps due to the limited open-access woodlands for fuelwood collection, high reliance on commercial fuelwood; and the regular substitution with alternative fuel options in the peri-urban interface (see Section 6.2.1).

When it comes to time investment in cooking activities, the time spent by the households was also found to vary by geographical location and by stove use. On average, while the close-forest residents in Muranga spend 12.22 hours/week, the semi-arid region spend 23% longer cooking time (see Table 6-2). From ethnographic surveys, it was observed that the variety of fuelwood collected in this zone are often in form of twigs (diameter less than 2cm) and small branches (diameter 2-4cm). Respondents described the burning quality of such fuelwood types as poor as compared to that used by households located at close proximity to the forest which is often in form of logs, stumps and heavy branches.

On average, the adoption and use of improved biomass stoves was found to reduce respectively, the fuelwood procurement and cooking time by 22% and 24% in Kiambu; and 26% and 27% in Muranga. The study also estimated the time reduction potential for biogas stove users in Kiambu who were found to spend 1.5 hours/week in bio-digester operations and 9.03 hours/week cooking time. Respectively, this time reduction represents an average of 79% and 36% less of the time consumed by traditional biomass stove users in Kiambu.

Table 6-2: Household time expenditure in relation to enumeration transects and stove use

	Muranga transect				Kiambu transect			
	Close-forest	Mid-transect	Semi-arid	Total average	Close-forest	Mid-transect	Peri-urban	Total average
Average return distance (meters**)**	**877.71**	**1241.67**	**2615.71**	**1578.36**	**984**	**1578.33**	**797.5**	**1119.94**
Average walking time (minutes/ trip)	41.86	68.50	117.07	75.81	51.2	98.75	63.75	71.23
Average collection time	16.29	32.15	41.26	29.9	21.2	31.37	29.5	27.36
Total time (hours/trip	**0.97**	**1.68**	**2.64**	**1.76**	**1.21**	**2.17**	**1.55**	**1.67**
Number of weekly fuelwood collection trips								
Average	**3.49**	**4.40**	**5.67**	**4.09**	**3.15**	**4.64**	**3.31**	**3.79**
Traditional stove	3.75	4.74	6.14	4.7	3.66	5.32	4.50	4.39
Improved stove	2.31	3.53	4.57	3.47	2.43	4.24	3.10	3.41
Total fuelwood collection time (hours/week)								
Average	**3.38**	**7.38**	**14.96**	**7.96**	**3.8**	**10.06**	**5.14**	**6.23**
Traditional stove	3.63	7.95	16.2	8.28	4.42	11.54	6.99	7.21
Improved stove	2.24	5.92	12.06	6.11	2.93	9.20	4.82	5.60
Bio-digester operations (hours/week)								**1.50**
Total cooking time (hours/week)								
Average	**12.22**	**14.07**	**15.80**	**14.03**	**12.38**	**14.14**	**10.79**	**12.44**
Traditional stove	13.88	16.45	18.26	16.2	14.06	15.88	12.47	14.14
Improved stove	10.55	11.68	13.33	11.85	10.69	12.39	9.10	10.73
Biogas cooking time (hours/week)								**9.03**
Total weekly time (*cooking + fuel procurement*)								
Average	**15.60**	**21.45**	**30.76**	**21.99**	**16.18**	**24.2**	**15.93**	**18.67**
Traditional stove	17.51	24.4	34.46	24.48	18.48	27.42	19.46	21.35
Improved stove	12.79	17.6	25.39	17.96	13.62	21.59	13.92	16.33
Biogas								**10.53**

Table 6-3: Statistical mean differences between improved and traditional stove types within same transect zone

	Muranga			Kiambu		
Transect zones	close-forest	mid-transect	semi-arid	close-forest	mid-transect	Peri-urban
Weekly trips	n. s	0.013	0.002	0.039	0.020	0.000
Fuelwood procurement time	0.058	0.000	0.002	0.000	0.032	0.063
Cooking time	0.011	0.000	0.005	0.000	0.014	0.000
Total time	0.047	0.006	0.000	0.010	0.000	0.000

Table 6-4: Statistical test for mean differences in relation to stove use between transect zones

(one-way ANOVA with post-hoc Bonferroni test, p<0.10)

	Muranga						Kiambu					
Stove types	Traditional stoves			Improved stoves			Traditional stoves			Improved stoves		
Transect zones	**A - B**	**A - C**	**B - C**	**A - B**	**A - C**	**B - C**	**D - E**	**D - F**	**E - F**	**D - E**	**D - F**	**E - F**
Weekly trips	n. s	0.001	0.071	0.066	0.004	0.000	0.002	0.083	n. s	0.000	0.028	0.017
Fuelwood procurement time	0.009	0.000	0.084	0.045	0.005	0.013	0.035	0.000	0.056	0.031	0.000	0.042
Cooking time	0.038	0.000	0.032	0.007	0.000	0.071	0.008	0.012	n. s	n. s	0.105	n. s
Total time	0.047	0.000	0.041	0.016	0.000	0.056	0.019	0.050	0.021	0.007	0.010	0.082
***Key:* transect zones**	**A** – close forest **B** – mid-transect **C** – semi-arid						**D** – close forest **E** – mid-transect **F** – peri-urban					

6.3 Fuelwood consumption patterns

Following methodology outlined in Section 3.3.2.4.1, this section presents results for per capita fuelwood consumption for households relying on: (a) self-collected fuelwood; and (b) purchased fuelwood from local markets. In each case, estimation results from an Ordinal Least Square (OLS) model are also presented to show the factors affecting per capita fuelwood consumption.

Out the surveyed 360 fuelwood users in the study area, 67% (240 households) primarily rely on self-collected fuelwood (discussed in Section 6.3.1), while 33% (120 households) depend on fuelwood purchased from the local market.

6.3.1 Estimation of per capita consumption of self-collected fuelwood

Table 6-5 presents the mean and statistical significance of per capita consumption for self-collected fuelwood in Muranga and Kiambu districts. The overall per capita fuelwood consumption was 2.62 kg cap^{-1} day^{-1} (4.78 tons household^{-1} year^{-1}) in Muranga and 2.24 kg cap^{-1} day^{-1} (4.09 tons household^{-1} year^{-1}) in Kiambu transect.

Based on stove use, the results reveal an average per capita fuelwood consumption rate of 2.97kg cap^{-1}day^{-1} (5.42 tons household^{-1} year^{-1}) for traditional stove users and 1.86 kg cap^{-1} day^{-1} (3.39 tons household^{-1} year^{-1}) for users of improved biomass stoves. This implies an average fuelwood saving of 37.3% for adopters of improved biomass stoves in Muranga. The highest per capita consumption rates recorded in the region at close proximity to the forest at an average of 3.41 kg cap^{-1} day^{-1} (6.22 tons household^{-1} year^{-1}) while the semi-arid region yielded lower fuelwood consumption rate by 44%.

In Kiambu, the results indicate an average fuelwood consumption rate of 2.96 kg cap^{-1} day^{-1} (5.40 tons household^{-1} year^{-1}) for traditional stove users and 1.80 kg cap^{-1} day^{-1} (3.29 tons household^{-1} year^{-1}) for users of improved biomass stoves. This consumption represents a mean fuelwood saving of about 40%. The per capita consumption rates for the region close to the forest yielded an average of 3.07 kg cap^{-1} day^{-1} (5.60 tons household^{-1} year^{-1}) while peri-urban residents consumed 60% less.

Table 6-6 suggest that, in both study areas, there are significant differences of per capita consumption observed between most of the transect zones (*p<1-5%*). This possibly owes to the observed broad disparity of fuelwood availability for households at the vicinity of the state forest and those located in the semi-arid interior and peri-urban regions (see Section 6.2). Overall, consumption of self-collected fuelwood between improved biomass stoves and traditional stoves was statistically significant.

Table 6-5: Average per capita consumption for self-collected fuelwood (kg cap^{-1} day^{-1})

Muranga transect					**Kiambu transect**				
	Traditional Stove	Improved Biomass Stove	Total average	sig		Traditional Stove	Improved Biomass Stove	Total average	sig
Average	2.97	1.86	2.62		**Average**	2.96	1.80	2.24	
close forest	3.59	2.60	3.41	**	**close forest**	3.36	2.69	3.07	***
mid-transect	2.78	1.93	2.54	**	**mid-transect**	2.67	1.85	2.15	**
Semi-arid	2.23	1.45	1.90	***	**peri-urban**	2.11	1.20	1.34	**

Table 6-6: Statistical test for mean difference in relation to stove use between transect zones for per capita consumption of self-collected fuelwood

	Muranga transect						**Kiambu transect**					
Stove types	Traditional stoves			Improved stoves			Traditional stoves			Improved stoves		
Transect zones	**A - B**	**A - C**	**B - C**	**A - B**	**A - C**	**B - C**	**D - E**	**D - F**	**E - F**	**D - E**	**D - F**	**E - F**
Per capita consumption (self-collected fuelwood)	0.044	0.000	0.008	0.005	0.000	n. s	0.000	0.000	0.000	n. s	0.009	0.023
Key: transect zones	**A** – close forest **B** – mid-transect **C** – semi-arid						**D** – close forest **E** – mid-transect **F** – peri-urban					

6.3.1.1 Factors affecting per capita consumption of self-collected fuelwood

First, OLS estimation results in Table 6-7 suggest that income has significantly negative association with consumption of self-collected fuelwood. This result confirms the theoretical expectation that with increasing income, there are high instances of multiple stove/fuel (combination of fuelwood-use with LPG, charcoal or kerosene) which can directly contribute to the reduced fuelwood consumption in that regard. Besides, the results further show significant effects fuel stacking where owning an LPG stove in the household was found to have a negative association with consumption of self-collected fuelwood ($p<0.01$).

Female-headed households were found to have negative association with per capita fuelwood consumption. This is possibly because, due to their disproportionate involvement in fuelwood collection and cooking tasks (Section 6.2.2), women have accumulated local knowledge about fuelwood-saving techniques (see Section 6.2.5). Household size was found to have a significantly positive association with per capita fuelwood consumption. This confirms the theoretically expectation where large household sizes not only depict more food being cooked (thus more fuelwood consumption) but also increased availability of labour for fuelwood collection.

The estimation results indicate that, each additional kilometer walked from the homesteads to the most frequent woodland has a negative association with fuelwood consumption ($p<0.01$). Practicing agroforestry was also found to reduce per capita fuelwood consumption. This is shows that, although planting trees on cropland provide fuelwood security, the households consume it sparingly to sustain the supply.

By geographical location, the OLS model suggest that households' location at close proximity to the forest has a significantly positive effect on consumption of self-collected fuelwood while semi-arid location has a negative association with fuelwood consumption. This is possibly attributable to differences in fuelwood abundance and shortage experienced in these localities.

Table 6-7: Estimated OLS model results for per capita consumption of self-collected fuelwood

Variables	Per capita fuelwood consumption, $kgday^{-1}$	
Income	-0.245*	(0.145)
Female head	-0.624*	(0.390)
Household size	0.184*	(0.106)
Dependency ratio	-0.567	(0.399)
Agroforestry	-0.263**	(0.108)
Walking distance (km)	-4.766***	(1.050)
Perceived scarcity	-0.388	(0.591)
Fuel stacking: LP gas	-1.065***	(0.374)
Close forest	2.503*	(0.342)
Semi-arid	-0.971*	(0.365)
Peri urban	-0.183	(0.468)
Constant	8.290***	(1.136)
Observations	240	
Adjusted R^2	0.562	
Note:	*p<0.1; **p<0.05; ***p<0.01	

6.3.2 *Estimation of per capita consumption of purchased fuelwood*

In addition to the walking distance to the collection woodland (Section 6.3.1), the study further looked at the effects of fuelwood market prices as a relative measure of fuelwood scarcity.

Generally, the per capita fuelwood consumption rates were found to vary by household's proximity to resources (i.e. state forest and urban center) and with stove use. Table 6-8 presents the mean and statistical significance of per capita consumption for self-collected fuelwood in Muranga and Kiambu districts. Table 6-9 provide the statistical mean difference in relation to stove use between transect zones for per capita consumption of purchased fuelwood

Data from the household surveys coupled with interviews with local market traders reveal that, the average unit cost of fuelwood KES. 3.61±1.75 per kg in Muranga while Kiambu had an average cost of KES. 3.79±1.67 per kg. The unit cost of fuelwood increased with increasing distance away from the state forest (see Table 6-8). The average unit price was KES. 4.97±0.26 per kg in peri-urban zone while the average cost was highest in the semi-arid zone at KES. 5.13±0.43 per kg.

In Muranga, the average fuelwood consumption for traditional stove users relying on commercial markets was 2.06 kg cap^{-1} day^{-1} (3.76 tons $household^{-1}$ $year^{-1}$), while those using improved biomass stoves consumed about 40% less fuelwood. Overall, the per capita consumption was lowest for households located in the semi-arid zone at an average of 1.20 kg cap^{-1} day^{-1} (2.21 tons $household^{-1}$ $year^{-1}$) while the households at close vicinity to the forest consumed about 41.3% more fuelwood.

Kiambu transect exhibited a similar pattern to that of Muranga, with an average consumption rate of 1.92 kg cap^{-1} day^{-1}(3.50 tons $household^{-1}$ $year^{-1}$). The consumption rate was about 32.8% less in the peri-urban region as compared to their close-forest counterparts who consume an average of 2.38 kg cap^{-1} day^{-1} (4.34 tons $household^{-1}$ $year^{-1}$).

Overall, consumption of self-collected fuelwood between improved biomass stoves and traditional stoves was statistically significant. Table 6-9 indicate that, in both study areas, there are significant differences of per capita consumption between most of the transect zones in relation to stove use. Significant differences were consistently observed in mean comparison of fuelwood consumption between close forest and semi-arid zones of Muranga ($p<0.05$) and close forest and peri-urban zones of Muranga ($p<0.05$). This possibly owes to the wide disparity in local fuelwood market prices, fuelwood substitutions and accessibility to open-access areas for fuelwood collection.

Table 6-8: Average per capita consumption for purchased fuelwood, kg cap^{-1} day^{-1}

	Muranga transect					Kiambu transect				
	Traditional Stove	Improved Biomass Stove	Total average		Fuelwood prices (KES/kg)		Traditional Stove	Improved Biomass Stove	Total average		Fuelwood prices (KES/kg)
Average	2.06	1.23	1.65		3.61	Average	2.38	1.45	1.92		3.79
close forest	2.47	1.64	2.06	***	2.13	close forest	2.84	1.92	2.38	***	2.56
mid-transect	2.03	1.17	1.67	***	3.57	mid-transect	2.26	1.28	1.77	***	3.85
Semi-arid	1.54	0.87	1.21	***	5.13	peri-urban	2.04	1.15	1.60	**	4.97

Table 6-9: Statistical mean difference in relation to stove use between transect zones for per capita consumption of purchased fuelwood

	Muranga transect						Kiambu transect					
Stove types	Traditional stoves			Improved stoves			Traditional stoves			Improved stoves		
Transect zones	**A - B**	**A - C**	**B - C**	**A - B**	**A - C**	**B - C**	**D - E**	**D - F**	**E - F**	**D - E**	**D - F**	**E - F**
Per capita consumption (purchased fuelwood)	n. s	0.021	n. s	n. s	0.003	n. s	0.035	0.000	n.s	0.000	0.070	0.048
Key: transect zones	**A** – close forest **B** – mid-transect **C** – semi-arid						**D** – close forest **E** – mid-transect **F** – peri-urban					

6.3.2.1 Factors affecting per capita consumption of purchased fuelwood

According to the OLS regression results (see Table 6-10) per capita fuelwood consumption of purchased fuelwood was found to have a significantly positive association with income, household size and dependency ratio. This result confirms the theoretical expectation that larger household sizes translate to increased income pockets for fuelwood purchase. On the other hand, while an increase in dependency ratio translate to reduced household income pockets, it is also expected to decrease availability of active labour for fuelwood collection hence increasing reliance and consumption of purchased fuelwood.

As expected, a unit increase in local fuelwood prices has a negative effect on fuelwood consumption. The estimation results further suggest that, households located in the peri-urban region have a positive effect on consumption of purchased fuelwood. This is possibly due to the limited free-collection sources (Section 6.2) and the high reliance on modern fuels by households located at close vicinity to the urban center. The semi-arid zone indicates a positive association (but not statistically significant) with consumption of purchased fuelwood. This is perhaps due to low income levels observed in this region (Section 5.2) which can possibly weaken their purchasing power for commercial fuelwood.

Table 6-10: Estimated OLS model for per capita consumption of purchased fuelwood

Variables	**per capita fuelwood consumption, kgday^{-1}**		
Income	0.035	(0.074)	**
Female head	-0.145	(0.207)	n.s
Household size	0.172	(0.046)	***
Dependency ratio	0.877	(0.508)	***
Perceived increase in market price	-0.213	(0.201)	n.s
Market price per kg fuelwood	-0.574	(0.247)	***
Fuel stacking: LP gas	-0.130	(0.166)	n.s
Close forest	-0.454	(0.282)	n.s
Semi-arid	0.185	(0.354)	n.s
Peri urban	0.979	(0.304)	**
Constant	2.423	(0.680)	***
Observations	120		
Adjusted R^2	0.639		

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

6.4 Economic Impact Category

Following the methodology outlined in Section 3.3.2.4.2, the opportunity costs of unpaid time use in fuelwood collection and cooking activities is estimated in relation to stove use (i.e. improved biomass stoves vs. traditional stoves; biogas vs. traditional stoves) and geographical location (i.e. enumeration transect zones). This opportunity cost of time used in fuelwood procurement is equivalent of amount of money the person (usually women) might otherwise have earned by working as unskilled/casual agricultural labour. For the household dependent on fuelwood purchased from the local fuelwood markets, the opportunity cost on monetary expenditure is estimated.

6.4.1 Opportunity cost of unpaid time use (self-collected fuelwood)

Tables 6-11 and 6-12 summarizes the estimated opportunity cost of unpaid time use in fuelwood procurement and cooking activities in Kiambu and Muranga transects, respectively. Following inquiries at the local labour officers in Murang'a and Kiambu county offices, a local farm casual laborer is paid an average of KES.200 (US$2) for work done for 5 hours from 8am-1pm equivalent to a rate of $0.4/hour (KES.100 = 1US$ at the period of this survey, 2017).

As established in Table 6-4, the average total time consumed for fuelwood procurement and cooking is statistically significant across the transects and in relation to stove use *($p<0.05$).* Based on replacement cost generalist approach, users of traditional stoves who performed the longest hours in fuel procurement and cooking activities could earn an average of US$444.01/year in Kiambu and US$509.11/year in Muranga.

The adoption and use of improved biomass stoves and biogas stove was found to reduce this opportunity cost of unpaid time use by an average of 24% and 51%, respectively in Kiambu. Among traditional stove users, the opportunity cost was reportedly highest in the mid-transect zone (US$570.34/year) and lowest in the transect zone at close proximity to the forest (US$.384.38/year). In Muranga, adoption and use of improved biomass stoves was found to reduce opportunity cost of unpaid time use by an average of 27% while incurring an annual stove investment cost of US$3.15. Among traditional stove users, the opportunity cost was reportedly highest in the semi-arid region (US$716.77/year) and lowest in the transect zone at close proximity to the forest (US$.364.21/year).

The study further prompted the interviewed women about the main activities they could engage in if they did not have to spend time in the woodland collecting fuelwood. From the results, the interviewed women reported that they could otherwise engage themselves in income generating activities (28%) such as basket weaving, food preparation kiosks, hair dressings etc., participate in social activities (26%) such as women groups and leisure activities (23%). Others reported that they could engage in child and elderly care (7%), home care (6%),

Table 6-11: Estimation of opportunity cost of unpaid time use by stove use across the Kiambu transect.

		Traditional stove				**Improved biomass stove**				**Biogas**
		Close forest	Mid-transect	Peri-urban	Average	Close forest	Mid-transect	Peri-urban	Average	
	Cost of stoves (US$)	0.00	0.00	0.00	0.00	15.00	15.00	15.00	15.00	1000.00
	estimated lifetime (years)	-	-	-	-	5.00	5.00	5.00	5.00	10.00
k_i	Annual capital cost (US$)	0.00	0.00	0.00	0.00	3.00	3.00	3.00	3.00	100.00
m_i	Annual maintenance cost (5% of annual capital cost)	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	5.00
	Total annual cost for stove (US$/year)	**0.00**	**0.00**	**0.00**	**0.00**	**3.15**	**3.15**	**3.15**	**3.15**	**105.00**
FT_i	Fuel procurement time (hours/week)	4.42	11.54	6.99	7.21	2.93	9.20	4.82	5.60	1.50
CT_i	Cooking time (hours/week)	14.06	15.88	12.47	14.14	10.69	12.39	9.10	10.73	9.03
	Total unpaid time use (hours/week)	18.48	27.42	19.46	21.35	13.62	21.59	13.92	16.33	10.53
W	Local wage rate (cost of spent time) (US$/hour)	0.40				0.40				0.40
	Total weekly opportunity cost (US$/week)	7.39	10.97	7.78	8.54	5.45	8.63	5.57	6.53	4.21
OC	**Total annual opportunity cost (US$/year)**	**384.38**	**570.34**	**404.77**	**444.01**	**283.20**	**409.00**	**297.60**	**339.56**	**219.02**

Table 6-12: Estimation of opportunity cost of unpaid time use by stove use across the Muranga transect.

		Traditional stove				**Improved biomass stove**			
		Close forest	Mid-transect	semi-arid	Average	Close forest	Mid-transect	Semi-arid	Average
	Cost of stoves (US$)	0.00	0.00	0.00	0.00	15.00	15.00	15.00	15.00
	estimated lifetime (years)	-	-	-	-	5.00	5.00	5.00	5.00
k_i	Annual capital cost (US$)	0.00	0.00	0.00	0.00	3.00	3.00	3.00	3.00
m_i	Annual maintenance cost (5% of annual capital cost)	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15
	Total annual cost for stove (US$/year)	**0.00**	**0.00**	**0.00**	**0.00**	**3.15**	**3.15**	**3.15**	**3.15**
	per capita fuelwood consumption (*self-collected*) (kg/capita/week)	25.13	19.43	15.59	20.79	18.22	13.48	10.86	13.09
FT_i	Fuel procurement time (hours/week)	3.63	7.95	16.20	8.28	2.24	5.92	12.06	6.11
CT_i	Cooking time (hours/week)	13.88	16.45	18.26	16.20	10.55	11.68	13.33	11.85
	Total unpaid time use (hours/week)	17.51	24.40	34.46	24.48	12.79	17.60	25.39	17.96
W	Local wage rate (cost of spent time) (US$/hour)	0.40				0.40			
	Total weekly opportunity cost (US$/week)	7.00	9.76	13.78	9.79	5.12	7.04	10.16	7.19
OC	**Total annual opportunity cost (US$/year)**	**364.21**	**507.52**	**716.77**	**509.11**	**266.01**	**366.07**	**503.11**	**373.62**

6.4.2 Opportunity cost of monetary expenditure

Tables 6-13 and 6-14 below summarizes the estimated opportunity cost of monetary expenditure incurred by households reliant on purchased fuelwood from the local market and traders in Kiambu and Muranga transects, respectively (refer to Section 6.3.2). The economic and financial feasibility of clean bioenergy stoves was determined by estimating the stove investment payback period.

As established in Table 6-9 the average per capita consumption of purchased fuelwood is statistically significant in relation to stove use (i.e. improved biomass stoves vs. traditional stoves) *($p<0.05$).* On the other hand, there was a consistent observation in mean comparison of fuelwood consumption between close forest and semi-arid zones of Muranga ($p<0.05$) and close forest and peri-urban zones of Muranga ($p<0.05$). This possibly because of the broad disparity in local fuelwood market prices between these transect zones.

For the traditional stove users in Kiambu, the opportunity cost of monetary expenditure was found to be highest in the peri-urban region (US$185.03/year) and lowest in the transect zone at close proximity to the forest (US$132.68/year). In the case of Muranga, the opportunity cost of monetary expenditure recorded highest in the semi-arid region (US$144.18/year) and lowest in the transect zone at close proximity to the forest (US$96.02/year).

From an economic and financial feasibility perspective, the results further suggest that, with adoption of improved biomass stoves at an investment cost of US$.15.00 and annual stove cost of US$3.15, traditional stove users that purchase fuelwood can save an estimated average of US$64.38/year in Kiambu and $54.68/year in Muranga. On average, this annual monetary saving implies a discounted payback period of about 8 months in both study areas.

In Kiambu, the results further indicate that if traditional stove users invest in biogas stove at a capital cost of US$1000.00 and an annual stove cost of US$105.00/year, they would save an average of US$.164.76/year incurred on fuelwood purchase. This monetary saving implies an average discounted payback period of 8.23 years or a simple payback period of 5.10 years.

Table 6-13: Estimation of opportunity cost of monetary expenditure by stove use across the Kiambu enumeration transect.

		Traditional stove				**Improved biomass stove**				**Biogas**
		Close forest	**Mid – transect**	**Peri – urban**	**Average**	**Close forest**	**Mid – transect**	**Peri – urban**	**Average**	
	Cost of stoves (US$)	0.00	0.00	0.00	0.00	15.00	15.00	15.00	15.00	1000.00
	Estimated lifetime (years)	–	–	–	–	5.00	5.00	5.00	5.00	10.00
k_i	Annual capital cost (US$)	0.00	0.00	0.00	0.00	3.00	3.00	3.00	3.00	100.00
m_i	Annual maintenance cost *(5% of annual capital cost)*	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	5.00
	Total annual cost for stove (US$/year)	**0.00**	**0.00**	**0.00**	**0.00**	**3.15**	**3.15**	**3.15**	**3.15**	**105.00**
Q_{im}	Household fuelwood consumption (kg/household/year)	5183.00	4124.50	3723.00	4343.50	3504.00	2336.00	2098.75	2646.25	0.00
F_{im}	Average fuelwood cost (US$/kg)	0.026	0.039	0.050	0.038	0.026	0.039	0.050	0.038	–
OC_i	**Total annual cost for fuel (US$/year)**	**132.68**	**158.79**	**185.03**	**164.76**	**89.70**	**89.94**	**104.31**	**100.38**	**0.00**
	Annual savings (improved stoves) (US$/household/year)	–				**42.98**	**68.86**	**80.73**	**64.38**	–
	Discounted payback period (years)	–				**0.87**	**0.73**	**0.71**	**0.77**	**8.23**

Table 6-14: Estimation of opportunity cost of monetary expenditure by stove use across the Muranga enumeration transect.

		Traditional stove				Improved biomass stove			
		Close forest	**Mid – transect**	**Semi –arid**	**Average**	**Close forest**	**Mid – transect**	**Semi – arid**	**Average**
	Cost of stoves (US$)	0.00	0.00	0.00	0.00	15.00	15.00	15.00	15.00
	Estimated lifetime (years)	–	–	–	–	5.00	5.00	5.00	5.00
k_i	Annual capital cost (US$)	0.00	0.00	0.00	0.00	3.00	3.00	3.00	3.00
m_i	Annual maintenance cost *(5% of annual capital cost)*	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15
	Total annual stove cost (US$/year)	**0.00**	**0.00**	**0.00**	**0.00**	**3.15**	**3.15**	**3.15**	**3.15**
Q_{im}	Household fuelwood consumption (kg/household/year)	4507.75	3704.75	2810.50	3759.50	2993.00	2135.25	1587.75	2244.75
F_{im}	Average fuelwood cost (US$/kg)	0.021	0.036	0.051	0.036	0.021	0.036	0.051	0.036
OC_i	**Total annual cost for fuel** (US$/household/year)	**96.02**	**132.26**	**144.18**	**135.72**	**63.75**	**76.23**	**81.45**	**81.04**
	Annual fuel savings (US$/year)	–				**32.26**	**56.03**	**62.73**	**54.68**
	Discounted payback period (years)	–				**0.91**	**0.76**	**0.74**	**0.78**

6.5 Environmental Impact Category

6.5.1 GHG emission reduction potential

Following the methodology outlined in Section 3.3.2.4.1 this analysis compares CO_2 emissions from fuelwood savings (see Section 6.3.1) in switching from traditional biomass stoves to improved biomass stoves. The study further considers potential displacement of GHG emissions through adoption of biogas to replace/substitute amount of fuelwood consumed by traditional biomass stoves (5.39 tons/household/year). Table 6-15 and Table 6-16 summarizes the estimated GHG emissions by stove use across the Kiambu and Muranga enumeration transects, respectively. The general observation is that, the higher the per capita fuelwood consumption (see results in Section 6.3.1), the higher the amount of GHG emissions. In other words, the GHG emissions varied by geographical locations (across the enumeration transects) and by stove use.

In Kiambu, traditional stoves were found to have an average GHG emission of 5.03 tCO_2e/year. The results suggest that, adoption and use of improved biomass stoves has an average fuelwood saving of 40% or 2.11 tons/household/year (see Table 6-15).

When converted to CO_2 emission reductions, adoption of improved biomass stove will lead to an emission reduction of 1.97 tCO_2e/year. It can also be inferred that, if biogas is adopted to displace the average fuelwood consumption by traditional stoves (5.39 tons/household/year), it would equally displace GHG emission of 5.03 tCO_2e/year.

In Muranga, traditional stoves were found to have an average GHG emission of 4.40 tCO_2e/year. From the results, the adoption and use of improved biomass stoves has an average fuelwood saving of about 37.3% of fuelwood or 2.02 tons/household/year (see Table 6-16). When converted to CO_2 emission reductions, the results suggest find that improved biomass stoves have a GHG emission reduction potential of 1.64 tCO_2e/year.

Table 6-15: Estimation of GHG emission reductions in Kiambu

		Traditional Biomass Stoves				Improved Biomass Stoves			
Parameter	**Description**	**Close forest**	**Mid-transect**	**Peri-urban**	**Average**	**Close forest**	**Mid-transect**	**Peri-urban**	**Average**
B $_{baseline}$	Per capita fuelwood consumption (tons/household/year)	6.12	4.86	3.84	5.39	4.90	3.37	2.18	3.28
B_y	Quantity fuelwood saved (tons/household/year)	0.00	0.00	0.00	0.00	1.22	1.49	1.66	2.11
f-NRB	Fraction of non-renewable fuelwood in *Kiambu*	53.40%				53.40%			
NCV	Net calorific value fuelwood (TJ/t)	0.0156				0.0156			
EF	Emission factor of fuelwood (tCO_2/TJ)	112.00				112.00			
	Total GHG emissions (tCO_2e/stove)	**5.71**	**4.53**	**3.58**	**5.03**	**4.57**	**3.14**	**2.04**	**3.06**
ER_y	GHG emission reduction potential (tCO_2e/stove)	**0.00**	**0.00**	**0.00**	**0.00**	**1.14**	**1.39**	**1.55**	**1.97**

Table 6-16: Estimation of GHG emission reductions in Murang’a

		Traditional Biomass Stoves				Improved Biomass Stoves			
Parameter	**Description**	**Close forest**	**Mid-transect**	**Semi-arid**	**Av.**	**Close forest**	**Mid-transect**	**Semi-arid**	**Av.**
B $_{baseline}$	Per capita fuelwood consumption (tons/household/year)	6.53	5.06	4.06	5.41	4.73	3.51	2.64	3.39
B_y	Quantity fuelwood saved per stove (tons/household/year)	0.00	0.00	0.00	0.00	1.80	1.55	1.42	2.02
f-NRB	Fraction of non-renewable fuelwood in *Murang’a*	46.60%				46.60%			
NCV	Net calorific value fuelwood (TJ/t)	0.0156				0.0156			
EF	Emission factor of fuelwood (tCO_2/TJ)	112.00				112.00			
	Total GHG emissions (tCO_2e/stove)	**5.32**	**4.12**	**3.30**	**4.40**	**3.85**	**2.86**	**2.15**	**2.76**
ER_y	GHG emission reduction potential (tCO_2e/stove)	**0.00**	**0.00**	**0.00**	**0.00**	**1.47**	**1.26**	**1.16**	**1.64**

6.6 Social Impact Category

6.6.1 Self-reported health symptoms

Following the methodology outlined in Section 3.3.2.6, this section present results for self-reported primary cooks' health outcomes in the past 30 days prior to the date of survey for: (a) respiratory (breathing difficulties, nose/throat irritations and coughing); (b) eye irritations; and (c) injuries in form of burns/scalds. In order to better understand the health effects of stove use and fuel use, the marginal effects of multivariable probit regression models are also presented and discussed to estimate the probability of health outcomes. The main focus is on: (a) demographic characteristics of the primary cook; (b) household socioeconomic characteristics; (c) geographical location across the transect; and (d) kitchen characteristics in terms of ventilation design and cooking area (i.e. outdoors or indoors)

6.6.1.1 Cooking area/kitchen housing characteristics and stove user behavior

To begin with, out of the surveyed households, only 12% of traditional stove users and 3% of improved biomass stove users cook outdoors (see Figure 6-5). For the households cooking indoors, the study evaluated housing characteristics and ventilation structures that may affect indoor-air pollution concentration levels. The findings indicate that more than 80% of the interviewed households reportedly cook in a separate room from the main house while more than 60% have their kitchens rooms with structured with windows and eave spaces. In addition, about 70% of the surveyed improved biomass stove users and less than 20% of traditional stove users have installed a chimney/hood structures to direct smoke outdoors.

In addition, out of the surveyed respondents that have children below 5 years in their households, 83.7% reported to spend time with them by carrying them on their backs, or hold them on their laps, or simply have them around the cooking area.

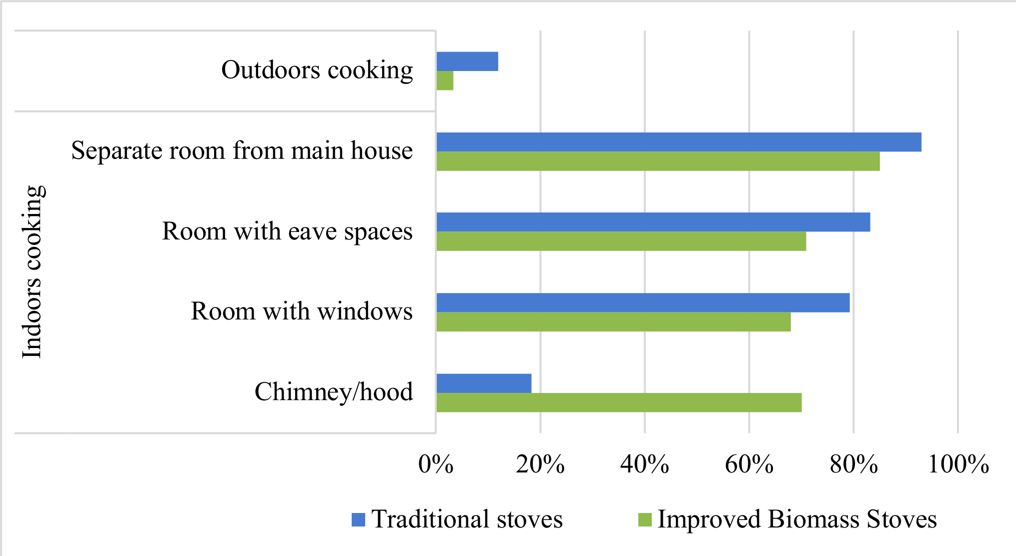

Figure 6-5: Distribution of kitchen ventilation structures and cooking area by stove use

6.6.1.2 Prevalence of self-reported health symptoms in relation to stove us

The self-reported health data indicate a substantially high occurrence of the assessed symptoms (see Figure 6-6). Prevalence of eye irritations (96%), coughing and phlegm (82%), nose/throat irritations (75%), headache (62%), dizziness (60%), burns/scalds (43%) and breathing difficulties (39%), were reported by traditional stove users in relation to cooking. However, the prevalence of these symptoms did not exhibit a consistent pattern but varied by stove use. The use of improved biomass stoves was found to reduce proportion of symptoms prevalence by nearly two-fold.

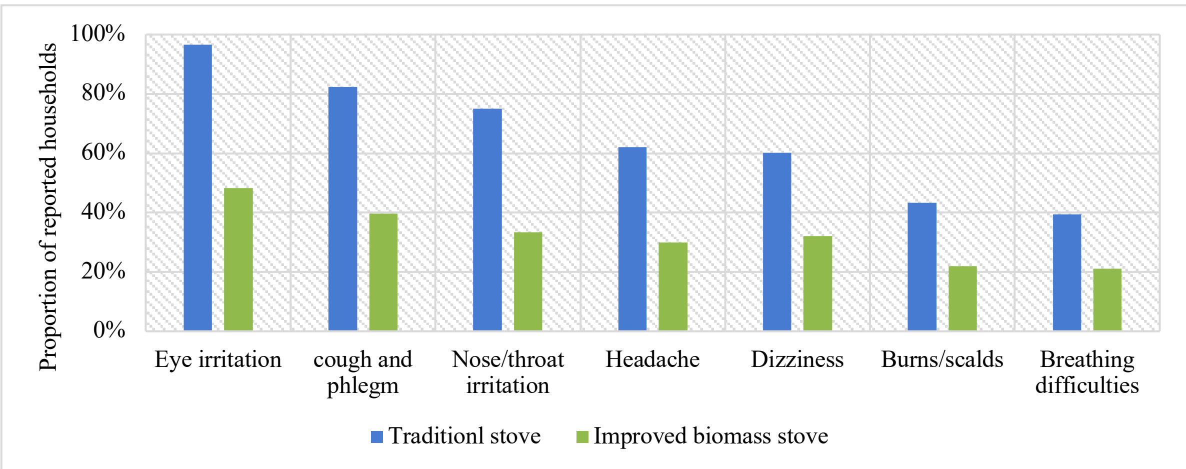

Figure 6-6: Distribution of prevalence of self-reported smoke-related health symptoms

6.6.1.3 Factors affecting prevalence of self-reported cooking-related health symptoms

The study leveraged the heterogeneity by assessing the association of risk factors with prevalence of each of the assessed health symptoms. The considered risk factors include demographic characteristics, geographical location, stove use, cooking area and ventilation structures. The marginal effects of the multivariable probit regression models were estimated to investigate the set of predictors that best explain probability of symptom occurrence (see Table 6-17)

At the primary cook level, the negative marginal effect for age suggest that a 10-year increase in age significantly increase the prevalence of eyes irritation by 7% but reduce the probability of prevalence for burns and scalds by 3% and that of all the probed symptoms by 4%. This is perhaps due to the expected dwindling eye health for older cooks, but on the other hand, they may have also accumulated protective knowledge against burns and scalds. It was also found that, with exemption of prevalence of dizziness, a unit increase in the primary cook's level of education significantly reduce the marginal effects of incidence of the overall probed symptoms ($p<0.01$) as compared to less educated cooks. This effect of education is attributable to improved awareness about protective behaviors and best practices to reduce smoke concentration levels.

When it comes to demographic factors, the estimation results suggest that, a unit increase in household size significantly increase ($p<0.05$) the probability of eyes irritation by 3.4%, coughing and phlegm by 4.0%, headache by 4.2% and prevalence of all symptoms by 2.7%. The theoretical expectation is that large family sizes translate to increased cooking frequency and preparation of large-size meals which increase exposure period to biomass pollutants. In addition, households with children below 5 years have significantly positive association with incidences of eye irritations ($p<0.05$), coughing/phlegm and burns/scalds ($p<0.05$). During ethnographic surveys, a common behavior was noted where mothers tend to spend time with their young children by either carrying them on their backs or holding them on their laps while cooking. Such practices can potentially expose the vulnerable children to smoke and possible accidents in the cooking area.

By the virtue of stove use patterns, the results suggest that, each additional hour spent in the cooking area significantly increase ($p<0.05$) the probability of incidences of eyes irritation by 4.5%, nose/throat irritations by 6.7%, burns and scalds by 6.8% and prevalence of experiencing all the probed symptoms by 11.8%. When it comes to the marginal effects of multiple stove/fuel-use, the results show that combined use of fuelwood with LPG reduces the probability of incidence of eyes irritations by 6.9%, coughing by 19.5% and that of reporting all the symptoms by 6.6%. Although the extent of impact is expected to vary depending on frequency of usage, clean-burning fuels such as LPG are said to substantially emit low levels of indoor pollutants.

When it comes to prevalence of health symptoms by geographical location (i.e. transect zones), households' location at close proximity to the forest was found to significantly reduce probability of incidences of eyes irritation by 12.3%, headaches by 8.2% and the overall incidences by 10.7%. On the other hand, the marginal effects of location in the semi-arid interior increase the probability of prevalence of coughing eyes irritation by 19.2%, coughing/phlegm by 6.1%, headache by 11.8% and the prevalence overall incidences by 19.0%. The observed pattern between close-forest and semi-arid is possibly attributable to the quality of fuelwood used in the areas. As established in Section 6.2, growing fuelwood scarcity makes households to recourse to use of inferior and low-quality biomass such as twigs, leaves and smoky fuelwood species. In addition, ethnographic surveys noted that fuelwood scarcity also compel households to use the locally available wet or "green" biomass that tend to emit a lot of smoke.

In the case of the marginal effects for the peri-urban zone, the estimation results indicate a significant reduction in prevalence of eyes irritation by 16.7%, coughing/phlegm by 9.5% ($p<0.05$) and breathing difficulties by 25.1%. This is to suggest that, although the peri-urban zone has limited fuelwood collection sources (Section 6.2), the local markets provide high quality fuelwood including off-cuts from furniture workshops. Besides, results in Section 5.2 indicated high incidences for modern stove use for households at close vicinity to the urban center which can positively contribute to reduce prevalence of the probed health symptoms.

To investigate the effects of housing design and characteristics, the estimation results suggest that respectively, cooking in a separate room from the main house and having installed a chimney/smoke hood have a negative association with eyes irritations (13.3%, 14.0%), coughing/phlegm (18.5%, 10.6%). On the other hand, cooking outdoors and in a ventilated kitchen structured with windows and/or eaves spaces was found to respectively reduce the probability of prevalence of eyes irritation (5.0%, 9.6%), dizziness (26.3%, 20.8%), and breathing difficulties (by 13.9%, 16.5%). The theoretical expectation is that cooking outdoors and in well ventilated kitchen structures reduce exposure and concentration levels of biomass smoke and other health damaging pollutants.

Table 6-17: Marginal effects (in Probit models) estimation results for determinants of prevalence of self-reported health symptoms

Variables	Eyes irritation	Coughing and phlegm	Nose/ throat irritations	Headache	Dizziness	Burns/ scalds	Breathing difficulties	All symptoms
Demographic characteristics								
Age (cook)	0.007** (0.005)	0.043 (0.003)	0.083 (0.013)	0.008 (0.036)	0.105 (0.059)	-0.003** (0.0044)	0.0072 (0.0034)	-0.004** (0.007)
Education level (cook)	-0.077** (0.014)	-0.060** (0.020)	-0.055** (0.018)	0.067** (0.018)	-0.019 (0.020)	-0.045** (0.019)	-0.061*** (0.019)	-0.066*** (0.017)
Household size	0.034** (0.014)	0.040** (0.016)	0.005 (0.042)	0.042** (0.017)	-0.028 (0.052)	0.064 (0.050)	0.030 (0.043)	0.027** (0.043)
Children ≤ 5 years	0.093** (0.052)	0.085** (0.041)	-0.044 (0.140)	0.053 (0.042)	-0.060 (0.073)	0.104** (0.067)	0.047 (0.041)	0.084 (0.066)
Stove use								
Exposure period (hours)	0.045* (0.020)	0.066 (0.052)	0.067** (0.024)	-0.031 (0.056)	-0.038 (0.083)	0.068** (0.054)	-0.021 (0.052)	0.118* (0.081)
Fuel stacking: LP gas	-0.069* (0.054)	-0.195* (0.038)	0.067 (0.036)	-0.012 (0.038)	-0.249 (0.058)	-0.058 (0.031)	-0.067 (0.037)	-0.066** (0.039)
Geographic location								
Close forest	-0.123* (0.016)	-0.053 (0.088)	0.107 (0.091)	-0.082* (0.019)	-0.076 (0.035)	-0.040 (0.099)	-0.016 (0.091)	-0.107* (0.107)
Semi-arid	0.192* (0.021)	0.061* (0.076)	0.202 (0.077)	0.118** (0.081)	-0.087 (0.033)	-0.012 (0.070)	0.106 (0.079)	0.190* (0.010)
Peri urban	-0.167** (0.062)	-0.095** (0.090)	-0.054 (0.286)	0.173 (0.284)	-0.075 (0.031)	0.156 (0.290)	-0.251** (0.106)	-0.178 (0.060)
Housing characteristics								
Separate room from main house	-0.133** (0.052)	-0.185** (0.041)	-0.044 (0.040)	0.053 (0.042)	-0.060 (0.073)	0.083 (0.010)	0.047 (0.041)	-0.184** (0.066)
Smoke hood/chimney	-0.140*** (0.041)	-0.106* (0.056)	-0.038 (0.048)	-0.141*** (0.055)	0.122** (0.056)	-0.092 (0.016)	-0.210** (0.049)	-0.102 (0.094)
Outdoors	-0.050* (0.083)	-0.261 (0.049)	-0.113 (0.041)	0.012 (0.048)	-0.263* (0.108)	0.030 (0.042)	-0.139** (0.056)	-0.401** (0.084)
Ventilation (windows/eave spaces)	-0.096** (0.048)	-0.039 (0.027)	-0.137** (0.067)	-0.033 (0.035)	-0.208* (0.083)	-0.017 (0.049)	-0.165** (0.042)	-0.042 (0.064)
Observations	360	360	360	360	360	360	360	360

6.7 Results Synthesis

This section provides a comprehensive synthesis of emerging patterns in relation to stove use, both between and within transect zones. In order to identify the patterns, the main focus is on: (a) comparison of impact mechanisms of same stove types between transect zones (Section 6.7.1); (b) comparison of socioeconomic and environmental impacts of same stove types between transect zones (Section 6.7.2); and (c) comparison of economic and environmental impacts between stove types (traditional biomass stoves vs. improved biomass stoves) within transect zones (Section 6.7.3). However, due to the purposive sampling procedure followed for selection of biogas stoves as outlined in Section 3.2.2, it becomes statistically impractical to synthesize such patterns.

6.7.1 Comparison of impact mechanism patterns in relation to stove use BETWEEN transect zones

Table 6-18: comparison of impact mechanisms in relation to stove use between transect zones

	Muranga transect			**Kiambu transect**		
Reference zone	mid-transect	semi-arid	semi-arid	mid-transect	peri-urban	peri-urban
	close-forest	mid-transect	close-forest	close forest	mid-transect	close-forest
Fuel procurement time (see Table 6-2)						
Traditional biomass stove	54.3%	48.6%	77.6%	61.7%	-65.1%	36.8%
Improved biomass stove	62.2%	50.9%	81.4%	68.2%	-90.9%	39.2%
Cooking time (see Table 6-2)						
Traditional biomass stove	15.6%	9.9%	24.0%	11.5%	-27.3%	-12.8%
Improved biomass stove	9.7%	12.4%	20.9%	13.7%	-36.2%	-17.5%
Total time (see Table 6-2)						
Traditional biomass stove	28.2%	29.2%	49.2%	32.6%	-40.9%	5.0%
Improved biomass stove	27.3%	30.7%	49.6%	36.9%	-55.1%	2.2%
Fuelwood consumption (*self-collected*) (see Table 6-5)						
Traditional biomass stove	-29.1%	-24.7%	-61.0%	-25.8%	-26.5%	-59.2%
Improved biomass stove	-34.7%	-33.1%	-79.3%	-45.4%	-54.2%	-124.2%
Fuelwood consumption (*purchased*) (see Table 6-8)						
Traditional biomass stove	-21.7%	-31.8%	-60.4%	-25.7%	-10.8%	-39.2%
Improved biomass stove	-40.2%	-34.5%	-88.5%	-50.0%	-11.3%	-67.0%

Table 6-18 indicate that in Muranga transect, the mean difference changes for fuelwood procurement time is highest between semi-arid and close-forest zones. The time investment in fuelwood procurement for semi-arid zone is 77.6% higher for traditional stove users and 81.4% higher for improved stove users as compared to their respective close-forest counterparts. The differences are statistically significant ($p<0.01$) (see Table 6-4). This is attributable to the long walking distance covered by residents in the semi-arid zone which was found to be about

3-times longer (2.7km) from their homesteads to the fuelwood collection area. The results confirm existing studies in other parts of SSA which report that fuelwood shortage is local specific (Drigo et al., 2015) and that households tend to increase time expenditure and walking distance with decline in physically accessible collection areas within their localities (Egeru et al., 2014; Scheid et al., 2019; ESMAP,2003) (see also Section 6.2.5).

In Kiambu transect, the mean difference for fuelwood procurement is lowest between peri-urban and close-forest zones. The time investment in fuelwood procurement for peri-urban zone 36.8% lower for traditional stove users and 39.2% lower for improved stove users as compared to their respective close-forest counterparts. The differences are statistically significant ($p<0.05$) (see Table 6-4). This discrepancy is attributable to the limited open-access areas for fuelwood collection in the peri-urban zone (See Section 6.2). The finding is consistent with recent studies by (Duguma, 2019; Njenga and Mendum, 2018) which report that peri-urban interface often has poor resource base for fuelwood collection which also exacerbate fuelwood market prices.

A consistent pattern is observed when it comes to cooking time in the Muranga transect. Users of traditional biomass stoves and improved biomass stoves in semi-arid zone spend 24.0% and 20.9% more time, respectively, as compared to their close-forest counterparts. The differences are statistically significant ($p<0.05$) (see Table 6-4). This variation is possibly attributable to inferior and low-quality biomass used in the semi-arid zones in form of twigs and small-branches while close-forest residents often use logs and trunks which were reported to have better burning quality (see section 6.2.3). This result confirms findings by (Scheid et al., 2019; Liyama et al., 2014; Sola et al., 2014; Drigo et al., 2013) which report that in order to strategize fuelwood shortage, households tend to switch to inferior types of biomass including crop residues and animal dung (see also Section 6.2.5)

On the other hand, the peri-urban interface exhibits a different pattern since users of traditional biomass stoves and improved biomass stoves respectively spend 12.8% and 17.5% ***less*** time as compared to their close-forest counterparts. The mean difference is statistically significant between traditional stove users ($p<0.05$) but improved biomass stoves was not significant (see Table 6-4). This discrepancy is possibly attributable to: (a) limited access to open areas for fuelwood collection (Section 6.2); (b) the high prevalence of multiple-fuel/stove use such as LPG, kerosene and charcoal noted in the peri-urban zone (Section 5.2); and (c) eating of dry and ready-made food from street vendors (Section 6.2.5), issues which can reduce the overall time investment (see also Njenga et al., 2017; Alem et al., 2016; Rahut et al., 2016).

When it comes to per capita fuelwood consumption, the general pattern observed is that fuelwood consumption tends to decrease with increasing distance away from the state forest (percentage changes is negative for all groups). For self-collected fuelwood in Muranga transect, users of traditional biomass stoves and improved biomass stoves in semi-arid zone have 61.0% and 79.3% less fuelwood consumption rate compared to the close-forest households. Their mean between the two transect differences are statistically significant ($p<0.05$) (Table

6-4). In the case of Kiambu transect, users of traditional biomass stoves and improved biomass stoves in peri-urban zone have 59.2% and 124.2% less fuelwood consumption rate compared to the close-forest households. The mean differences between the two transect zones are statistically significant (*$p<0.05$*). This confirm results by Arnold et al (2003); Kituyi (2001); Ghilardi et al (2016) which report decreasing fuelwood consumption with increasing fuelwood scarcity.

6.7.2 Comparison of economic and environmental impact patterns in relation to stove types BETWEEN transect zones

Table 6-19: Comparison of impact differences in relation to stove types between transect zones

	Muranga transect			**Kiambu transect**		
Reference zone	mid-transect	semi-arid	semi-arid	mid-transect	peri-urban	peri-urban
	close-forest	mid-transect	close-forest	close forest	mid-transect	close-forest
Opportunity cost (*unpaid-time use*) (see Table 6-2)						
Traditional biomass stove	28.2%	29.2%	49.2%	32.6%	-43.0%	3.6%
Improved biomass stove	27.3%	27.2%	47.1%	30.8%	-37.4%	4.8%
Opportunity cost (*monetary expenditure*) (see Table 6-2)						
Traditional biomass stove	27.4%	8.3%	33.4%	16.4%	14.2%	28.3%
Improved biomass stove	16.4%	6.4%	21.7%	0.3%	13.8%	14.0%
GHG emissions (see Table 6-2)						
Traditional biomass stove	-29.1%	-24.8%	-61.2%	-26.0%	-26.5%	-59.5%
Improved biomass stove	-34.6%	-33.0%	-79.1%	-45.5%	-53.9%	-124.0%

In Muranga transect, the differences in opportunity cost of unpaid time-use are highest between semi-arid and close-forest zones. The opportunity cost of unpaid time-use for semi-arid zone 49.2% higher for traditional stove users and 47.1% higher for improved stove users as compared to their respective close-forest counterparts. In the Kiambu transect, the differences in opportunity cost of unpaid time use is highest between peri-urban and mid-transect zones. The opportunity cost of unpaid time-use for mid-transect zone 43.0% higher for traditional stove users and 37.4% higher for improved stove users as compared to their respective peri-urban counterparts. These findings confirm previous studies by (Matsika et al., 2013; Egeru, 2014; Murphy 2015) which report that household cooking energy in rural areas is often secured at the expense of productive time, particularly for women.

When it comes to differences in opportunity cost of monetary expenditure for households reliant on market-based fuelwood, Muranga transect exhibits a similar pattern to that observed with the opportunity cost of unpaid time use. However, a different pattern is observed in the Kiambu transect. The observed differences in opportunity cost of unpaid time use is highest between peri-urban and close-forest zones. The opportunity cost of monetary expenditure for peri-urban zone is 28.3% higher for traditional stove users and 14.0% higher for improved stove users as compared to their respective close-forest counterparts. The unveiled pattern suggests that monetary expenditure increase with increasing distance away from the state forest with growing fuelwood scarcity and towards the urban center where fuelwood market prices are highest.

The mean differences for GHG emissions are consistent with per capita fuelwood consumption patterns. In Muranga transect, the differences in GHG emissions is highest between semi-arid and close-forest zones. The GHG emissions for close-forest zone 61.2% higher for traditional stove users and 79.1% higher for improved stove users as compared to their respective semi-arid counterparts. In Kiambu transect, the differences in GHG emissions are highest between peri-urban and close-forest zones. The GHG emissions for close-forest zone is 59.5% higher for traditional stove users and 124.0% higher for improved stove users as compared to their respective peri-urban counterparts. The exhibited pattern suggest that households located at close proximity to the state forest have the highest GHG emissions (highest per capita fuelwood consumption) and tend to decrease with increasing distance away from the state forest, both towards the semi-arid interior and the urban center. Previous studies in Kenya and other parts of SSA (Bailis et al., 2015; Drigo et al., 2015; Uhunamure 2016; Alemayehu and Motuma, 2018) have also associated increasing fuelwood consumption rates with high GHG emissions.

6.7.3 Comparison of impact patterns between stove types (Improved biomass stoves vs. traditional stoves) WITHIN transect zones

The main focus of comparison is between the environmental and economic impacts of adoption of improved biomass relative to traditional stoves between transect zones. A general pattern is observed where the proportion of impacts manifestation is tending to increase by increasing distance away from the state forest and towards the urban center (Table 6-20).

Table 6-20: Impact patterns between stove types within transect zones

	Muranga transect			**Kiambu transect**		
	close-forest	mid-transect	Semi-arid	close-forest	mid-transect	Peri-urban
GHG emission reduction potential	27.6%	30.6%	35.0%	19.9%	30.7%	43.1%
Opportunity cost (unpaid time use)	27.0%	27.9%	29.8%	21.3%	26.3%	25.4%
Opportunity cost (monetary expenditure)	33.6%	42.4%	43.5%	32.4%	43.4%	43.6%

Results in Section 6.3 indicated that in Kiambu transect, the proportion of fuelwood savings tended to increase with increasing distance farther away from the state forest towards the urban center. The mean differences were statistically significant ($p<0.01$) (see Table 6-6). As expected, when this fuelwood consumption is converted to greenhouse gas emission reduction potential, a consistent pattern is observed. Relative to GHG emissions by traditional biomass stoves, improved biomass stoves have a GHG emission reduction potential of 19.9% (1.14 tCO_2e/year) for close-forest zone, 30.7% (1.39 tCO_2e/year) for mid-transect zone and 43.1% (1.155 tCO_2e/year) for the peri-urban zone.

Similarly, in the case of Muranga transect, the proportion of GHG emission reduction potential tend to increase with increasing distance farther away from the state forest toward the semi-arid interior. Relative to GHG emissions by traditional biomass stoves, improved biomass stoves have a GHG emission reduction potential of 27.6% (1.47 tCO_2e/year) for close-forest zone, 30.6% (1.26 tCO_2e/year) for mid-transect zone and 35.0% (1.16 tCO_2e/year) for the semi-arid zone. Other studies in Kenya Bailis et al., 2002) and other SSA countries (Dresden et al., 2014; Adeyemi, 2014; Lee et al, 2013) have found substantial GHG emission reductions with non-traditional bioenergy stoves (although the concept of proximity to resources has not been elicited in past).

When it comes to manifestation of economic impacts, a consistent pattern is observed in Muranga transect reflective of fuelwood scarcity with increasing distance away from the state forest. Adoption of improved biomass stoves for households located at close proximity to the state forest reduce opportunity cost of unpaid time by 27.0% (US$98.20), mid-transect zone by 27.9% (US$141.45) while the semi-arid obtain the highest impact by 29.8% (US$213.66).

However, in the case of Kiambu transect, a slightly different pattern is observed. Adoption of improved biomass stoves reduces opportunity cost of unpaid time investment for households at close proximity to the state forest by 21.3% (US$101.18), mid-transect zone by 26.3% (US$161.34) while the peri-urban obtain the highest impact by 25.4% (US$ 101.17). Reflective of fuelwood scarcity across this transect, this finding is consistent with time expenditure which was found to be highest in the mid-transect zone and lowest in the peri-urban zone. The findings confirm previous cost-benefit analytical studies (Jeuland and Pattanayak, 2012;2016; Nerrini 2017; Toman 2017) which report substantial economic benefits in use improved cookstoves as compared to traditional bioenergy cookstoves.

For the households relying on fuelwood purchased from the market in Kiambu, adoption of improved biomass stoves reduces opportunity cost of monetary expenditure for close-forest households by 33.6% (US$32.27), mid-transect zone by 42.4% (US$ 56.03) while the peri-urban obtain the highest impact by 43.5% (US$ 62.73). From an economic and financial feasibility perspective, this monetary expenditure translate to an investment payback period of 0.83 years, 0.73 years and 0.71 years (close-forest, mid-transect, semi-arid, respectively) (see also Lambe et al., 2015).

On the other hand, for households relying on fuelwood purchased from the market in Muranga transect, adoption of improved biomass stoves reduces opportunity cost of monetary expenditure for close-forest households by 32.4% (US$42.98), mid-transect zone by 43.4% (US$ 68.85) while the peri-urban obtain the highest impact by 43.6% (US$ 80.72). From an economic and financial feasibility perspective, the results further suggest that, with adoption of improved biomass stoves at an investment cost of about US$.15.00, this monetary expenditure translate to an investment payback period of 0.91 years, 0.76 years and 0.74 years (close-forest, mid-transect, peri-urban, respectively).

When it comes to health impacts, adoption and use of improved biomass stoves was found to reduce proportion of prevalence of the self-reported health symptoms by nearly two-fold (see Figure 6-6). Several studies suggest that improved biomass stoves emit lower kitchen concentrations of CO by 40% (Pennise et al., 2009; Smith et al. 2011) and $PM_{2.5}$ by 52% (Masera et al. 2007). In addition, the existence of LPG as a secondary cooking fuel was found to reduce the marginal effects for the overall health symptoms prevalence ($p<0.05$). Laboratory tests to quantify pollutant levels for LPG (Shen et al., 2018) suggest that LPG has significantly large reductions in CO and $PM_{2.5}$ emission levels which are within the recommended WHO guidelines for indoor air quality (WHO, 2014).

The estimation results further indicate that kitchen housing characteristics including the design and ventilation mechanisms have important ramifications on indoor pollution concentration levels. Consequently, the results demonstrate that cooking in a separate room from main house, use of smoke hood/chimney and cooking outdoors have significant protective effect on the prevalence of overall health symptoms ($p<0.05$). Previous experimental studies have suggested that cooking outdoors (Das et al., 2018; Maggio et al., 2013; Langbein et al., 2017) and in kitchens with good ventilation structures can reduce exposure and concentration levels of health damaging pollutants including $PM_{2.5}$ and CO (Johnson and Chiang, 2015; Mutlu et al., 2016; Barnes, 2014; Johnson et al., 2011; Wilkinson et al., 2009).

In closing, during ethnographic surveys, a common behavior was noted where mothers tend to spend time with their young children while cooking by either carrying them on their backs or holding them on their laps. Studies show that children under five are particularly at risk of acute lower respiratory infections attributable to solid biomass fuels (Bruce et al., 2004; Mortimer et al., 2017; WHO, 2014). The estimated model results established that cooks with children below 5 years have a significantly positive association with incidences of eye irritations ($p<0.05$), coughing/phlegm and burns/scalds ($p<0.05$). A survey in rural Kenya by (Ezzati and Kammen, 2002) estimated that improved biomass stoves can reduce acute respiratory infections (ARI) by 24%-64% and acute lower respiratory infections (ALRI) by 21%-44% for children under 5.

6.8 Summary

This chapter has provided a comprehensive outlook about the sustainability impacts of adoption and use of clean bioenergy cooking technologies in rural Kenya. In general, the Chapter has demonstrated strong and consistent impact patterns both between stoves types and across the transect zones (proximity to state forest and urban center). Some discrepancies have also been identified. These mechanisms have important ramifications on household economic welfare (opportunity costs of money and time investment) and health. The emerging general patterns observed identify that:

i.) local fuelwood availability, physical accessibility (walking distance and time consumption) and intra-household factors have a ripple effect on per capita fuelwood consumption.

ii.) Opportunity costs of unpaid time investment in fuelwood procurement activities and cooking tasks increase with increasing distance from state forest towards fuelwood scarce areas (i.e. semi-arid zone of Muranga and mid-transect of Kiambu). This pattern is attributable to: (a) increasing walking distance to physically accessible woodlands (Section 6.2.6); (b) increased application of negative coping mechanisms (Section 6.2.5); (c) increasing fuelwood market prices (Section 6.3.2); and (d) use of inferior fuelwood with poor/slow burning quality (Section 6.2).

iii.) Opportunity costs of monetary expenditure increase with proximity to the urban center (i.e. peri-urban zone of Kiambu transect) and with increasing distance away from the state forest (i.e. semi-arid interior, Muranga). This observation is possibly attributable to: (a) limited open-access areas for fuelwood collection (Section 6.2); (b) high fuelwood market prices (Section 6.3.2); and (c) multiple fuel/stove-use owing to infrastructural and market development for modern cooking technologies (Section 5.2 and Section 6.2.5).

CHAPTER 7

RESEARCH SYNTHESIS AND POLICY IMPLICATIONS

7.1 Introduction

As outlined in Chapter 2, this study assesses the factors of adoption and the impacts of clean bioenergy cooking interventions in Kenya and propose policies that could enable scaling up their adoption. The specific focus is on the dynamics between traditional and modern (i.e. biogas, improved biomass stoves) cooking options in rural settings of the Murang'a and Kiambu counties. The specific objectives include to:

a) identify the drivers, challenges and perceived impacts of clean cooking interventions in Kenya through expert interviews;
b) elicit user preferences and trade-offs inherent to stove choice behavior using household surveys and choice experiments;
c) identify and asses the impacts of cooking energy technologies through a mixed-method approach;
d) suggest policy and practice options to influence sustainable transition pathways for achieving universal access to clean cooking in Kenya.

In line with (d), this Chapter aims to first provide a holistic synthesis of main findings emanating from the individual objectives/chapters (Section 7.2). As outlined in Section 1.2.2, clean cooking is steadily gaining significant traction in Kenya's national policy and its key international commitments for climate change mitigation and sustainable development. The outcomes of this study could enrich current debates about how to facilitate the wide adoption of clean cooking options. In this respect, Section 7.3 highlights some policy-relevant findings and their implications for policy and practice as a means of influencing sustainable transition pathways for scaling up the adoption of clean cookstoves in Kenya. The study considers this information crucial for both policy makers in the government and practitioners including stove producers, promoters and stove programme developers, nationally and internationally.

7.2 Main research findings

7.2.1 Overview of Kenya's clean cooking sector and institutional landscape (Chapter 1)

In Chapter 1, the study provided a synthesis of the current knowledge about clean and improved bioenergy stoves in Kenya through a comprehensive review that brings together the disparate knowledge about the context, status, adoption and impacts of clean bioenergy stoves in Kenya. In addition, the chapter outlined the main national policies, historical development of technological options and stakeholders involved in the clean bioenergy stove value chain.

As outlined in Section 1.2, Kenya prides as one of the leading countries in the development and commercialization of clean bioenergy stoves in Sub-Sahara Africa dating from the 1900s. However, due to a series of interconnected factors, the adoption and sustained use of clean bioenergy stoves remains low in the country. A conceptual framework was developed illustrating the interlinkages between these factors of adoption and impacts in such a way to outline their varying degree of importance (see Figure 1-4). Some of the identified interconnected factors that affect stove adoption including include: (a) stove/fuel characteristics; (b) end-user characteristics; (c) quality assurance; and (d) market structure including innovative financing and distribution models. On the other hand, barriers to adoption/scaling-up persist due to: (a) low affordability of clean cooking solutions; (b) socio-cultural/economic factors; and (c) limited knowledge of the economic, health, and environmental benefits of clean cooking among end users.

Similarly, it was identified that stove adoption and sustained use can have a series of positive impacts related to household energy security (Section 1.4.1), ecosystem conservation (Section 1.4.2), human health (Section 1.4.3), livelihoods (Section 1.4.4), education (Section 1.4.5), and food security (Section 1.4.6). Some of these impacts are gender-differentiated so the adoption of clean bioenergy cookstoves can provide an important impetus to female empowerment and gender equality (Section 1.4.7). However, some negative effects might also manifest due to the loss of local livelihoods (Section 1.4.4).

From policy perspective, one of the most important policies articulating energy policy frameworks has been the Sessional Paper No 4 of 2004, which aims to realize economic growth strategies. A key element has been the promotion of cost-effective, affordable and adequate quality energy services, which need to be made available nationally in the period 2004-2023. The latest Energy Bill, 2015, aligns the powers and functions of the national and devolved structure of the government for establishing regulatory framework in the energy sector (see Table 1-2 for the main relevant government entities and their stipulated responsibilities). Unlike its predecessors, the Energy Bill of 2015 does not include any provisions to promote clean bioenergy stoves, an element that could strengthen the promotion of clean cooking at local level.

An overarching vision of these policies has been to modernize the production, processing, distribution and consumption of energy, and especially biomass energy (see also Owen et al., 2013; Clough, 2012). This entails various interventions and measures necessary to: (a) facilitate clean household energy transitions; (b) promote enabling environment and conditions for investment; (c) expand sustainable biomass supplies; and (d) capitalize on new technological advancement.

Furthermore, it was identified that due to the development of various technological options (see Section 1.2.3), a series of stakeholders are embedded in Kenya's clean cooking sector. These stakeholders possess varying functions, agendas and motives that can curtail the overall sustainability of clean cooking options. (Table 1-5). These include stakeholders directly involved with the development and delivery of cookstoves to final consumers (Figure 1-3). Apart from them, there exists a plethora of other stakeholders with vested interest in clean bioenergy cookstoves (Table 1-5) that are not directly integrated in the cookstove value. These include stakeholders from government institution, NGOs, research organization, donors and international organizations.

7.2.2 Drivers, barriers and perceived impacts of clean cookstoves in Kenya: A multi-stakeholder perception analysis (Objective 1, Chapter 4)

Chapter 4 aimed to understand the perceptions of the diverse stakeholders in order to enrich current debates about how to facilitate the wide adoption of clean cooking options in Kenya. Through expert interviews, perceptions of 28 stakeholders was elicited about the key drivers, barriers, and associated impacts of adoption.

As expected, there is a broad variation between stakeholder groups about specific drivers and barriers, reflecting to some extent their unique interests and role in the clean cooking value chain (see Section 4.3). For instance, private sector stakeholders tended to consistently mention issues related to stove/fuel affordability and business financing, while stakeholders from government, academia/research and NGOs focused more on issues related to awareness and behavioral change (see Table 4-1). Donors and international development organizations strongly highlighted community involvement and participation in stove development (Table 4-1).

However, despite this variation in possible drivers and barriers of clean cooking adoption, there is a large degree of consensus about what stakeholders consider as ***the most important*** of these barriers and drivers of adoption (see Table 4-2). By far, stove affordability (n=10) and awareness (n=9) were identified as the most important factors by practically all stakeholder groups. The other top-ranked barriers/drivers reflect again the specific roles of some stakeholders within the clean cooking sector and include: (a) behavioural change (3 NGO and 1 private sector stakeholders), (b) reliable supply/distribution networks (1 NGO stakeholder), (c) business financing mechanisms (1 private sector stakeholder), (d) stove design (1 academia/research stakeholder), (e) community involvement (1 donor stakeholder), (f) quality assurance (1 government stakeholder) (Section 4.5)

When it comes to impacts of stove adoption, most stakeholders were well-versed with the main sustainability impacts of stove adoption and use in Kenya (see Section 1.4). Practically all stakeholders identified the positive effect of clean cooking interventions on health (Table 4-3). Many stakeholders also evoked the positive effects of clean cooking for (a) women empowerment; (b) energy access; (c) environmental protection; and (d) livelihoods (see Table 4-3). These were also largely identified as the ***most important*** impacts of clean, which can possibly identify major themes to ensure policy coherence and marshal the support of the different stakeholders in clean cooking efforts.

The above suggest that despite the many different perceptions among stakeholders about the drivers/barriers of stove adoption and the subsequent impacts (Tables 4-1, 4-3), there is surprisingly a broad consensus about the most important ones (Tables 4-2, 4-4). This implies both a shared understanding about the main issues in the sector, as well as some consensus about the possible priority areas to target when establishing clean cooking interventions/promotion efforts. The study identifies that such points of convergence can be mobilized to coordinate efforts in the otherwise fragmented institutional landscape.

Apart from establishing stakeholder knowledge about clean cooking impacts (and their importance), interviews were also instrumental in identifying possible trade-offs from the adoption of clean cooking practices (Section 4.5.2). Instances of identified trade-offs include (a) erosion of socio-cultural values; and (b) through the loss of jobs and income from fuelwood value chains that dominate livelihoods in some rural and urban contexts. In this sense it is imperative to understand the inherent sustainability trade-offs in every phase of the adoption process.

7.2.3 Factors affecting adoption of clean bioenergy cooking technologies (Objective 2, Chapter 5)

From households' perspective, Chapter 5 contributes to the fragmented literature about the adoption of clean and efficient cooking technologies, particularly in Kenya and the Sub-Saharan Africa countries (Karanja and Gasparatos, 2019). In this respect, a conceptual framework was developed identifying a range of demographics, socio-economic, ecological and institutional factors believed to affect household decision making for adoption of clean bioenergy cookstoves (see Figure 3-6). For a holistic identification of the inherent drivers of stove adoption, the study employed multiple analytical methods including: Probit regression analysis (Section 5.3), path analysis (Section 5.4), discrete choice experiment (Section 5.5) and ethnographic surveys (Section 5.6). Emerging and cross-cutting patterns are identified both at the household level and in relation to the geographical location (i.e. proximity to the state forest and the urban center) (Section 5.7).

To begin with, household income was identified as a key driver of stove adoption and preference. When it comes to adoption of biogas and improved biomass stoves, the path analysis estimation results rank income among the factors with the highest total effects on adoption (Section 5.4.2). From the discrete choice analysis, it is established that a unit increase in household income increases the likelihood for preference of the modern, LPG alternative (Section 5.5.2.4). This finding is consistent with the energy ladder theory where households tend to switch to modern fuels as their wealth increases (Treiber et al., 2015; Kroon et al., 2013; Masera et al., 2000; ESMAP, 2003).

Second, Chapter 5 relooks at the existing knowledge about role of gender of the household headship which identifies as a cross-cutting theme affecting stove adoption and preference. From the path analysis, the results indicate that male headed household have a significantly higher probability for adoption of the rather expensive and more sophisticated biogas stoves (Section 5.4.2). A similar pattern is observed in the discrete choice analysis where males were found to be more likely to prefer LPG alternative than females (Section 5.5.2.4). This pattern implies that male headed households have higher chances to transition to the modern clean cooking technologies than female-headed households. From a more nuance perspective, the path analysis identifies that women have limited access to productive resources that were established to have significantly positive effect on adoption (Section 5.3.2.1). In addition, female headed households have a negative association with income which reduce their total effects on adoption of improved biomass stoves by 14% (see Table 5-8). This trend implies that in the long-term, reduction in fuel cost and stove prices would have maximum welfare benefit on women.

From the perspective of geographical location (transect zones), households located in the peri-urban zone were found to have a statistically significant positive effect on adoption of improved biomass stoves. This finding is consistent with discrete choice analysis which points out that preference for the modern LPG stoves is significantly positive for households at close vicinity to the urban center. This finding confirm previous studies (Pattanayaket al., 2012; Shen et al., 2015) which present urbanization as a key indicator for greater accessibility to modern fuels (improved market infrastructure) and income diversification. On the other hand, discrete choice analysis revealed that households located in the rural interior have preference for the charcoal alternative. However, based on the magnitude of their coefficients, the charcoal preference for the zone at close proximity to the forest was about 40% higher as compared to that of the semi-arid zone. This is perhaps attributable to the biomass abundance for the households living at the vicinity of the state forest as compared to those farther away where biomass scarcity is high (see also results in Section 6.2.1).

While biomass availability appears to have a significant effect on stove adoption and preference, the physical accessibility (i.e. distance to woodland) is equally important. The estimation results from the probit model indicate that adoption of improved biomass stoves increases by 4.2% ($p<0.05$) with each additional kilometer walked from the homesteads to the most frequent woodland. Conversely, the likelihood for preference of the modern LPG alternative significantly decrease with increasing distance to fuelwood collection area. It can be conveniently argued that while fuelwood scarcity can incentivize household to adopt fuelwood-saving cookstoves, affordability (relative to low income, Section 5.2.2) remain a key barrier for adoption of modern stove alternatives. This would mean that a reduction in stove price and fuel cost will have maximum welfare benefit on households located farther away from the state forest (i.e. in fuelwood scarce zones and low-income groups).

Finally, from ethnographic mapping of user perception, the study established that even though households are positive towards modern cooking technologies, there are other contextual factors beyond the stove-specific and intrahousehold attributes that affect stove acquisition and sustained use (Section 5.6). It was identified that, while some factors are more crucial for catalyzing the initial household decision to adopt clean bioenergy stoves (Section 5.6.1) there exists other factors influence more decisions related to stove maintenance, consistent and sustained use (see Sections 5.6.2, 5.6.3).

In summary, the study identifies that the motivation for sustained use is predicated on: (a) stove technology characteristics (design and performance); (b) intra-household socioeconomic characteristics; (c) geographical location (i.e. proximity to the urban center or the forest); (d) psychosocial factors, peer effects and intergeneration transmission of cooking options; and (e) socio-cultural context within which stoves are used.

7.1.2 Socio-economic and environmental impacts (Objective 3, Chapter 6)

Chapter 6 has provided a comprehensive outlook about the sustainability impacts of adoption and use of clean bioenergy cooking technologies in Kiambu and Muranga counties of Kenya. In section 6.7, a comparative analysis was provided detailing the emerging impact mechanisms and stove use impact patterns, both within and between transect zones. From this output, Table 7-1 provide a visual synthesis of the consistently strong patterns of impact mechanisms and the associated stove impact patterns (Table 7-2) across the transect zones.

Table 7-1: Synthesis of impact mechanisms across enumeration transect zones based on respective estimated quantities

	Muranga transect			**Kiambu transect**		
	Close-forest	Mid-transect	Semi-arid	Close-forest	Mid-transect	Peri-urban
Average walking distance (meters)	877.71	1241.67	2615.71	984.06	1578.33	797.5
Total fuelwood collection time (hours/week)	3.38	7.38	14.96	3.80	10.06	5.14
Total cooking time (hours/week)	12.22	14.07	15.8	12.38	14.14	10.79
Total time investment (hours/week)	15.6	21.45	30.76	16.18	24.20	15.93
Market fuelwood price (KES/kg)	2.13	3.57	5.13	2.56	3.85	4.97
Fuelwood consumption (*collected*) kg/capita/day	3.41	2.54	1.90	3.07	2.15	1.34
Fuelwood consumption (*purchased*) kg/capita/day	2.06	1.67	1.21	2.38	1.77	1.60

[Key: Green (lowest effect); Yellow (medium effect); Red (highest effect)]

Table 7-2: Synthesis of impacts across enumeration transect zones based on magnitude of percentage change (improved biomass stoves vs. traditional stoves)

	Muranga transect			**Kiambu transect**		
	close-forest	mid-transect	Semi-arid	close-forest	mid-transect	Peri-urban
GHG emission reduction potential	27.60%	30.60%	35.00%	19.90%	30.70%	43.10%
Opportunity cost (*unpaid time use*)	27.00%	27.90%	29.80%	21.30%	26.30%	25.40%
Opportunity cost *(monetary expenditure)*	33.60%	42.40%	43.50%	32.40%	43.40%	43.60%

[Key: Green (highest impact); Yellow (medium impact); Red (lowest impact)]

Consistently, the general pattern is that per capita fuelwood consumption (Table 7-1, also see synthesis in Sections 6.71 and 6.7.2) and the associated impacts tend to decrease with increasing fuelwood scarcity (opportunity cost of unpaid time investment, Section 6.4.1; GHG emissions, Section 6.5) and proximity to the urban center (opportunity cost of monetary expenditure, Section 6.4.2).

Table 7-2 (see also Section 6.7.3) illustrate that adoption of improved biomass stoves have significantly positive ramifications on the associated economic impacts (opportunity costs of time investment and money, Section 6.4), environmental impacts (GHG emissions, Sections 6.5) and social impacts (see Section 6.6). However, the manifestation and magnitude of these impacts vary by geographical location (i.e. proximity to the forest and the urban center). As described in Section 6.7, these patterns identify that:

i.) local fuelwood availability, physical accessibility (walking distance and time consumption) and intra-household factors have a ripple effect on per capita fuelwood consumption.

ii.) Opportunity costs of unpaid time investment in fuelwood procurement activities and cooking tasks increase with increasing distance from state forest towards fuel scarce areas (i.e. semi-arid zone of Muranga and mid-transect of Kiambu). This pattern is attributable to: (a) increasing walking distance to physically accessible woodlands (Section 6.2.6); (b) increased application of negative coping mechanisms (Section 6.2.5); (c) increasing fuelwood market prices (Section 6.3.2); and (d) use of inferior fuelwood with poor/slow burning quality (Section 6.2). In addition to consequences of fuelwood inaccessibility, the decrease in opportunity costs of time investment in peri-urban interface is also attributable to: (e) the reported reliance on dry foods e.g. bread and buying ready-made food from street vendors (Section 6.2.5).

iii.) Opportunity costs of monetary expenditure tend to increase with proximity to the urban center (i.e. peri-urban zone of Kiambu transect) and with increasing distance away from the state forest (i.e. semi-arid interior, Muranga). This pattern is attributable to: (a) limited open-access areas for fuelwood collection (Section 6.2); (b) high fuelwood market prices (Section 6.3.2); and (c) multiple fuel/stove-use and fuelwood substitution with alternative fuels such as LPG, kerosene and charcoal owing to infrastructural and market development for modern cooking technologies (Section 5.2 and Section 6.2.5).

Section 6.5 demonstrated that just like in other parts of Kenya and the Sub-Saharan Africa (Drigo et al.,2015), fuelwood harvesting in the study areas is not sustainable. The resultant GHG emissions vary with proximity to resources and by stove use (see also Bailis et al., 2015). With an average of 40% fuelwood saving, the use of improved biomass stove was found to have an average emission reduction potential of 1.97 tCO_2e/year in Kiambu and 1.64 tCO_2e/year in Muranga transects. These results compare with the existing literature which report an estimated range of 1-2 tCO_2e/year for energy-efficient stoves (Johnson et al., 2010; Lambe et al, 2015; Lee et al., 2013). The results further suggest a displacement of 5.03 tCO_2e/year if biogas was to be fully adopted by traditional stove users to displace their equivalent per capita fuelwood consumption (3.29 tons household^{-1} year^{-1}).

Table 7-2 illustrate that, despite the fact that the close-forest residents have the highest per capita fuelwood consumption (Section 6.3), the resultant impact on GHG emissions (Section 6.5) with adoption of improved biomass stoves is largest in the fuelwood scarce areas. In the Muranga transect, the stove impact on GHG emissions is highest in the semi-arid zone (35%) where both the opportunity cost of time investment and monetary expenditure are highest. On the other hand, stove adoption has the highest impact on GHG emissions in the peri-urban interface (43.1%) of Kiambu transect where the opportunity cost of monetary expenditure is highest. This pattern implies that the environmental impacts of adoption of clean bioenergy stoves is highest in the regions experiencing highest opportunity costs of monetary expenditure and time investment.

Section 6.6. presented findings from the health impact analysis where prevalence of eye irritations and coughing/phlegm were found as not only the most common self-reported symptoms but also had significant associations with majority of the assessed predictors. Adoption of improved biomass stoves was found to reduce proportion of prevalence of the probed health symptoms by nearly two-fold. This confirm previous studies which report that improved biomass stoves emit lower kitchen concentrations of CO by 40% (Pennise et al., 2009; Smith et al. 2011) and $PM_{2.5}$ by 52% (Masera et al. 2007). A previous epidemiological survey in rural Kenya by Ezzati and Kammen (2002) estimated that improved biomass stoves can reduce acute respiratory infections (ARI) by 24%-64% and acute lower respiratory infections (ALRI) by 21%-44% for in children under five years of age.

The study further established that the prevalence of health symptoms is also affected by geographical location. For instance, semi-arid interior transect zone was found to significantly increase the probability of prevalence of eyes irritation, coughing/phlegm and nose throat irritations. This could be attributed to inferior biomass use sourced from the shrubs and roadside (see Sections 6.2.1 and 6.2.5) as a result of local fuelwood scarcity. Ethnographic surveys observed that use of twigs, green and wet fuelwood have poor burning qualities and require more tending time. These results confirm previous findings by (Holdren et al., 2000; Das et al, 2018) which associate inferior biomass with increased concentration levels of health damaging pollutants as compared to high quality fuelwood e.g. stems, stumps and large branches.

In addition to stove use and quality of biomass, housing characteristics including: (a) design (smoke hood/chimney); (b) ventilation mechanisms (windows and eave spaces) in the cooking area; and (c) cooking outdoors were found to reduce the prevalence of most of the probed health symptoms. This confirms previous epidemiological studies which have demonstrated that cooking outdoors (Das et al., 2018; Maggio et al., 2013;

Langbein et al., 2017) and in kitchens with good ventilation structures (Johnson and Chiang, 2015; Mutlu et al., 2016; Barnes, 2014; Johnson et al., 2011; Wilkinson et al., 2009) can reduce exposure and concentration levels of health damaging pollutants including $PM_{2.5}$ and CO.

From a gendered perspective (Section 6.2.2), women and girls are often disproportionately involved in fuelwood collection duties (see also Kelly et al. 2018; Waris and Antahal 2014; UNDP 2017). This gender disparity also exists not only for households relying on the free-range off-farm fuelwood, but also for households practicing agroforestry where men decide about what trees species are planted and when to harvest (see also Kiptot and Franzel, 2012; Liyama et al., 2014). The gender gap in unpaid time use was found to have significant implications by restricting women's engagement in beneficial ventures and opportunities to improve their wellbeing (see also Stiglitz et al., 200; Karlsson, 2012; Blackden and Wodon, 2006; UNDP, 2017).

The overall message emanating from the main findings of this chapter is that, adoption of clean bioenergy cooking technologies provides substantial socio-economic benefits at the local scale but also cost-effective interventions with significant environmental global benefits in the form of GHG emission reductions. However, the ramifications of these impacts vary by: (a) households' proximity to resources (i.e. urban center and forest); (b) local biomass availability and physical accessibility; (c) intra-household socio-economic factors; and (d) intra-household demographic and behavioral aspects.

7.2 Policy/practice-relevant findings and implications

As outlined in Sections 1.2.2 and 4.5, there exists significant policy and practice challenges curtailing large-scale and sustained adoption of clean cooking solutions in Kenya. This would undoubtedly require a combination of different interventions (Section 4.4), as there is most certainly not a silver-bullet approach (ESMAP, 2013). Based on the synthesis of findings outlined in Section 7.2, five (5) priority areas are identified that can be suggested to policy makers and practitioners in the clean cooking sector. These implications can be targeted to facilitate adoption and sustainability impacts of clean cookstoves in rural settings of Kenya and other parts of Sub-Saharan Africa. The suggested policy/practice-relevant implications include:

a) enhancement of multi-stakeholder and cross-sectoral collaboration (Section 7.2.1);
b) appropriate financing mechanisms and economic incentives (Section 7.2.2);
c) local-specific policy approaches and stove dissemination activities; (Section 7.2.3)
d) facilitate awareness and behavioral change among stove users (Section 7.2.4); and
e) strategize clean cooking options as cost-effective catalysts to deliver impact and interlinkages across multiple Sustainable Development Goals (Section 7.2.5).

7.2.1 Enhance multi-stakeholder collaboration and cross-sectoral approaches

Adoption and sustenance of clean cooking technologies in Kenya spans multiple policies (Section 1.2.2, Table 1-1) and stakeholders (Section 1.3). Despite the fact that various policies and interventions addressing energy issues in Kenya have been created for both the national and devolved county level, there are clear policy gaps that hinder stakeholder collaboration especially between different government levels. Unification of enabling multi-stakeholder policy and regulatory environment can actively scale-up stove adoption rates, support innovation and investments, and enforce systems for non-compliance in Kenya.

In Section 1.6, it was identified that a lack of synergies, overlap of mandates and uncoordinated interactions may lead to the suboptimal utilization of available resources and hamper stove production, financing, quality control, and scaling up strategies (see also Johnson et al., 2016a; Karanja and Gasparatos, 2019).

Due to the radically different roles of the interviewed stakeholders within the sector there is some variations in their perspectives. The multi-stakeholder perception analysis (Section 4.3) confirmed that there exists a broad variation between stakeholder groups about specific drivers and barriers, reflecting to some extent their unique interests and role in the clean cooking value chain (Tables 4-1 and 4-3). However, despite this disparity, there is a large degree of consensus (Table 4-2 and 4-4) that forge a shared understanding between stakeholders about the priority areas to target when establishing clean cooking interventions and promotion efforts.

Despite this variation, a good level of consensus was identified about the main drivers and impacts of clean cooking options in Kenya (Section 4.5, Table 4-2). In particular, there is a good shared understanding about the need for establishing solid funding mechanisms, not only to facilitate consumer affordability but also to ensure financial sustainability of the entire clean cooking system. At the same time there is a shared understanding about the benefits of clean cooking. Practically all stakeholders identified the positive effect of clean cooking interventions on health (Table 4-3). Many stakeholders also evoked the positive effects of clean cooking for women empowerment, energy access, environmental protection and livelihoods (see Table 4-3). These offer a good base to explore appropriate financial instruments in a coordinated fashion.

A deeper comparative analysis of stakeholder perspectives allowed the identification and mapping of both the main interactions between stakeholders, as well as the possible policy and practice options to strengthen the Kenyan clean cooking sector (Figure 7-2). This comprehensive map is uniquely derived from the consistent interview protocol (Section 4.4) and shows the linkages between various strategic policy and practice priorities

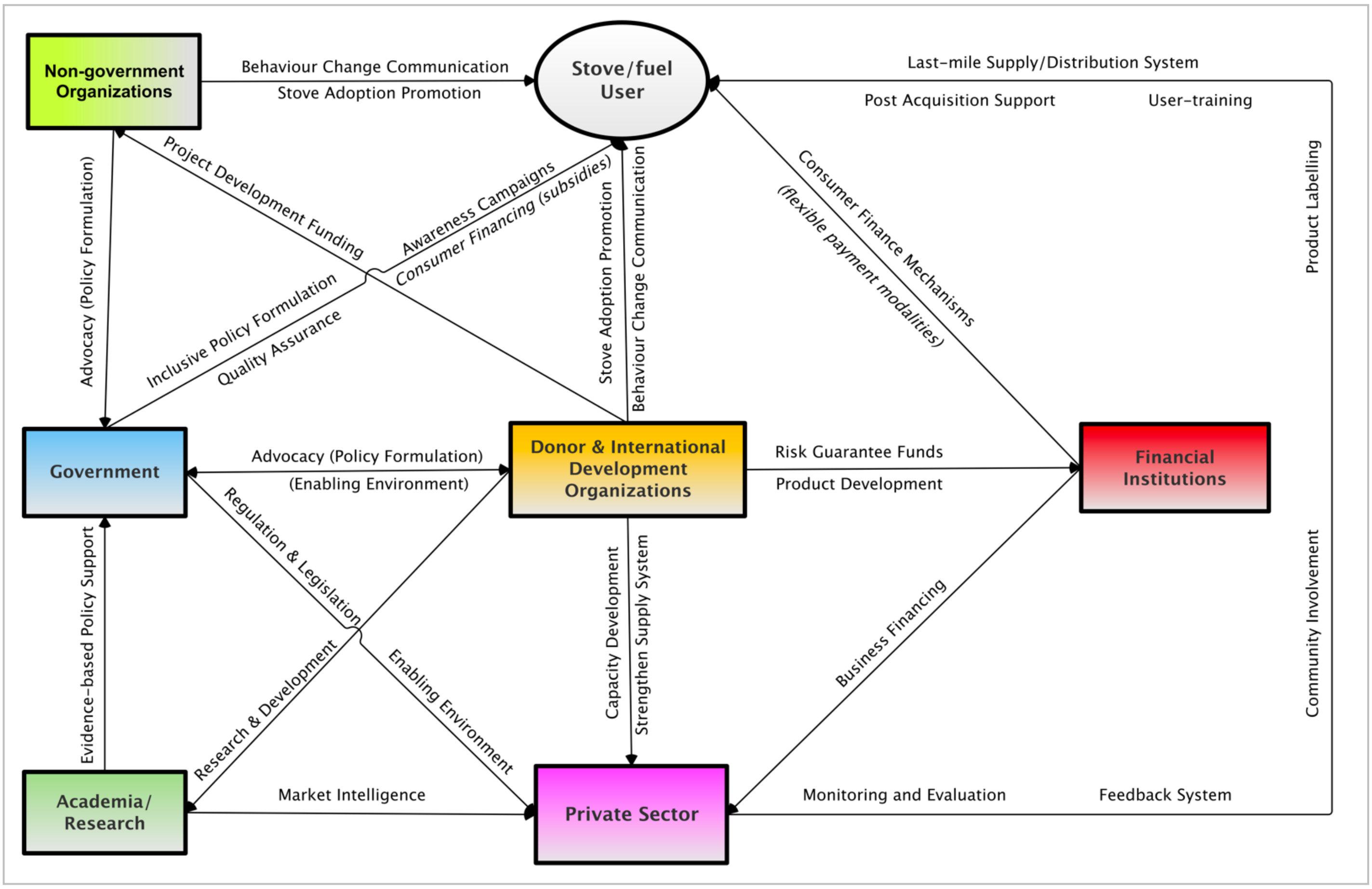

Figure 7-1: Stakeholders interactions and possible interventions emanating from these interactions

Chapter 6 outlined that adoption of clean bioenergy stoves has important positive ramifications for economic (opportunity costs of unpaid time investment and money, Section 6.4), environmental (greenhouse gases, Section 6.5), and social aspects (health, Section 6.6). In this respect, it is imperative for stove-related policies and interventions, to the extent possible, follow a cross-sectoral approach integrating the perspective and interests of different national and local government departments related to energy, gender, health, industry and the environment (see also IEA et al., 2019). For instance, local health services and clinics can raise awareness during clinic/hospital visits about both the health implications of clean cookstoves and good cooking practices (e.g. kitchen ventilation, cooking outdoor, keeping little children away from cooking areas etc.).

Since Kenya operates in a devolved governance structure, county (regional) governments will be particularly important players. To ensure the adoption and sustained use of clean cookstoves, local governments can be the connective institution between local users and national/international stakeholders. This is because, local needs and socio-cultural characteristics of the targeted users need to be considered seriously (Sections 4.2.1.3, 5.6.2 and 5.6.3). In this respect, local governments can provide consumer education to catalyze behavior change, expand clean cooking infrastructure to remote areas, and support pro-poor energy investments through appropriate economic incentives and favorable loan mechanisms.

Finally, the inherent socio-economic impacts are gender-differentiated including effects on stove adoption (Sections 6.2.2, 5.4.1, 5.4.2 and 5.5.2.4). In this respect, stove dissemination activities and programs can provide an important impetus to women empowerment and gender equality (Section 4.3.7). Special emphasis can be given to forming social capital among rural women by various development actors to increase their access and control of key productive resources identified in Section 5.3.2.

7.2.2 Facilitate appropriate financing mechanisms to offset affordability constraints

Through ethnographic surveys (Section 5.6.3) and stakeholder interviews (Section 4.5), affordability emerged as the most important barrier deterring adoption of clean bioenergy cookstoves. In addition, the discrete choice analysis (Section 5.4.2.1, Table 5-10) identified respondents' significant sensitivity to recurring monthly fuel usage costs which affect their decision making 3 times more than the stove price does. This signifies serious implications for the long-term stove use and sustenance which could curtail manifestation of intended sustainability impacts (Sections 1.4, 4.3, 6.4 - 6.6). In order to improve consumer affordability and sustenance of stove use, strategic financing mechanisms are needed particularly for scaling up the adoption of technologies such as LPG and biogas.

Such provisions could be established in form of subsidies and economic incentives (see also Section 4.4.5). However, caution should be taken since evidence from other countries such as Ghana (Asante et al., 2018; Dalaba et al., 2018; Linda Ahunu, 2015), Senegal (Kojima, 2011) and Indonesia (Andadari et al., 2014; Toft et al., 2016) suggest that such subsidies tend to only benefit high-income and middle-income households that can afford the recurring monthly costs and high upfront costs. Furthermore, as suggested by stakeholders in Section 4.2.3.5, possible financing strategies for lifting liquidity constraints on the supply side (i.e. private sector) include engagement with financial institutions and small-and-medium enterprises (SMEs) by the government and donors. In this sense, direct subsidies linked to micro-finance options or reduction of stove VAT and tax-rebates could help enhance user affordability of clean cooking options and increase the reliability of fuel delivery and availability in rural areas.

By acknowledging that clean cooking options provide multiple benefits (Sections 1.4, 4.3, 6.4 -6.6), it might be possible to capitalize on the synergies that exist between household cooking energy, health and climate mitigation, including their financing strategies. For instance, the GHG emission reduction potential (Section 6.5) of clean bioenergy cookstoves opens up possibilities for carbon finance revenues. Following approved estimation methodologies, the estimated emission reductions (Section 6.5) could be traded in the carbon markets (e.g. Clean Development Mechanisms, Gold Standard, etc.). For instance, based on the California's greenhouse gas control system 2015 price at US$13.39 per tCO_2e, the estimated GHG reductions in Kiambu would be worth US$26.38/household for improved biomass stoves and US$67.35/household if biogas stoves or other non-solid fuels were integrated into the carbon market to displace emissions by traditional stoves (5.03 tCO_2e/year.). Such a strategy could improve affordability whilst achieving local sustainable development (health and economic benefits) through carbon finance and mitigating climate change (GHG emissions) at a global scale.

7.2.3 Implement local-specific approaches in dissemination of clean cooking technologies

This study has consistently demonstrated that adoption and associated impacts of clean cooking technologies is a multi-faceted and contextual (local-specific) sustainability challenge that would have a no silver-bullet solution. Thus, it is imperative for programmes and projects promoting and disseminating clean cookstoves to first consider local settings dynamics in terms of proximity to biomass resources (Section 6.2), infrastructural/market development (Section 4.2.3) and socio-cultural dimensions (Sections 5.6.2, 5.6.3, 4.2.1.3) in order to expand the scale of adoption.

For instance, Section 5.4.2.3 (Table 5-11) demonstrated that due to the freely accessible and abundant biomass, households located at close proximity to the forest have no incentive to invest in the modern, LPG alternative. On the other hand, peri-urban residents have a significant preference for modern stove alternatives which is attributable to market infrastructural development, improved awareness and income diversification (Section 5.2). A good understanding of targeted consumer preferences and constraints can influence the design of resonating clean cooking products and interventions.

Reflective of fuelwood scarcity and physical accessibility (proximity to state forest and walking distance/time to collection woodland, Section 6.2.6), energy planners can formulate policies to provide the integrated incentives to promote adoption of improved biomass stoves coupled with promotion of sustainable biomass production practices. Possible options include promotion of agroforestry systems, social forestry, household woodlots, and communal forests (see IRENA, 2018). Furthermore, there is a need to involve local communities in order to identify and introduce the appropriate fuelwood species that are desirable by the communities for cooking purposes (Section 6.2.3).

From a practicing perspective, ethnographic mapping (Sections 5.5.2 and 5.5.3) demonstrated that cooking practices are often deeply entrenched in local socio-cultural practices and psychosocial aspects (see also similar findings by Hooper et al., 2018; Johnson et al., 2016; Tamire et al., 2018). In tandem, many stakeholders asserted that central to achieving the objectives of clean cooking interventions is preventing or solving mismatches between capabilities of local communities and the characteristics and functionalities of new technologies (Section 4.4.1). Therefore, despite the placement of subsidies, incentives and campaigns to promote affordability of clean cooking technologies (as outlined in Sections 7.2.1 and 7.2.2), the local socio-cultural dimensions related to traditional bioenergy should not be ignored.

This notion is underscored by stakeholders in Section 4.2.1.3.2 where stakeholders pointed out that the focus of many stove dissemination programs usually rests on the technology itself while not achieving the active participation of targeted users and thus misunderstanding the local context. In response, the stakeholders advocated for active engagement of local communities (particularly women), in order to develop and deliver appropriate interventions tailored to local conditions, cultures, needs and preferences.

7.2.4 Facilitate awareness and behavioral change among stove users.

Stakeholders asserted that, on the demand side, many barriers persist due to the limited knowledge among consumers about the health, environmental and economic benefits of clean cooking (See Chapter 4.2.1.2.2). In this sense, raising awareness by taking into consideration end-user perspectives would be an important element for scaling up the adoption of clean cooking options.

Consumer behavior and behavior change were perceived by stakeholders as complex aspects (Section 4.2.3.6) and that it can be challenging to catalyze new cooking practices and habits. This is because clean cookstoves typically operate differently compared to the traditional biomass stoves, with which most consumers are accustomed to (see Section 5.6.2, 4.2.1.3). In addition, ethnographic surveys revelated that households are often confronted with improved stove options due to the additional fuelwood preparation requirements (e.g. fuelwood chopping into very small pieces) (Section 5.6.2).

Therefore, adoption and sustenance of such cooking options would require a significant shift in cooking practices and overall user behaviour change, until the new stove becomes part of the daily household routine. Another relevant awareness aspect is the critical role of consumer education on stove usability and kitchen management (e.g. kitchen ventilation, fuel management, keeping little children away from cooking areas)

Finally, in order to persuade adoption, it is recommended that innovative messaging techniques can be tailored to educate and persuade households about the substantial benefits of adoption of clean cookstoves (Section 4.2.3.3). For instance, the messaging techniques could incorporate the estimated values for fuelwood consumption savings (Section 6.4.1), reduced opportunity costs of unpaid time investment (Section 6.4.2), monetary expenditures (Section 6.4.3) and health benefits (Section 6.6). However, while the study has demonstrated substantial GHG emission reduction potential, stakeholders highlighted that the aspects of climate change are still abstract for many Kenyans and that they may prefer to hear about direct technological benefits on their economic welfare and livelihoods (see Section 4.2.3.3).

7.2.5 Strategize clean cooking as a catalyst to deliver impact and interlinkages across multiple Sustainable Development Goals (SDGs)

The current international policy landscape and particularly the traction behind the United Nations' Sustainable Development Goals (SDGs), offers important political recognition platform to promote access to clean cooking technologies, particularly for the sub-Saharan African countries. This study makes the case that promoting clean cooking offer an unprecedented cost-effective strategy to contribute positively to the 2030 agenda and play a pivotal role for wider sustainability transitions.

Through literature review (Chapter 1, Section 1.4), multi-stakeholder perception analysis (Chapter 4, Section 4.3) and multi-impact assessment (Chapter 6), the study has demonstrated that adoption and sustained use of clean cooking solutions is not only an energy security (SDG7) imperative but it is also central in catalyzing towards achieving other sustainable development goals pertaining to poverty alleviation (SDG1), health (SDG3), gender (SDG5), climate action (SDG13) and ecosystem conservation (SDG15), among others.

While acknowledging existence of context-specific trade-offs (Section 4.5.2), this establishment suggest that stove promotion and dissemination projects targeting multiple mechanisms could have a greater potential to catalyze positive impacts across multiple SDGs, and thus create significant value addition.

A much deeper perspective identifies that clean cooking intersects with multiple SDGs and the associated specific targets related to energy access, gender equality, health, food security, economic development, environmental conservation, and creation of partnerships (see extended description in Appendix 1).

The main impact mechanisms relate to:

1. SDG 7 - Energy access (Sections 1.4.1; 4.3.2; 5.2; and 6.3): clean bioenergy cookstoves improve access to affordable, safe and reliable cooking energy;
2. SDG 4 - Gender equality (Sections 1.4.7; 4.3.7; 6.2.2; and 6.4): clean cooking reduces drudgery and unpaid time commitments by women and girls for fuelwood collection activities and cooking. The time saved can be invested in pursuing education, family care and income-generating activities
3. SDG -5 Health (Sections 1.4.3; 4.3.3; 6.6): clean cooking options reduces emissions of smoke and other indoor air pollutants, thus improving the health outcomes of cooking, particularly for women and children who are disproportionately exposed
4. SDG 13 & 15 - Environmental conservation and climate action (Sections 1.4.2; 4.3.2; and 6.5): clean cooking options can reduce the demand for (and dependence on) solid biomass fuels such as fuelwood and charcoal. This reduces pressure on forests/woodlands, land degradation, climate-related hazards (e.g. landslides), and emission of greenhouse gases;
5. SDG 2 & 12 - Food security and sustainable consumption (Sections 1.4.6; 4.3.6 and 6.2.5): clean cooking options can improve nutrition, induce dietary transitions, and reduce food waste by changing cooking habits and curbing the effects of fuelwood scarcity;
6. SDG 8 - Economic development (Sections 1.4.4; 4.3.4): clean cooking options can foster industrial innovation, create local employment, develop technical and entrepreneurial skills (including for women) across the stove value chain
7. SDG 17 - Partnerships (Sections 1.5.7; 4.4.3; 7.2.1): advocacy for clean cooking builds dynamic partnerships between a wide range of national and international stakeholders from different sectors to raise awareness, leverage support, influence policy and attract financial investments.

Given the scale of dependence on biomass fuels in Kenya, the first four mechanisms can have the most substantial and direct effects in meeting SDGs at the national scale, while the remaining three can play a less significant (and possibly more indirect) role, but still contribute substantially to national sustainable development efforts. This perspective makes a strong case for further development of coordinated governance structures to steer clean cookstove interventions. This can possibly be in the form of cross-ministerial committees working closely with other national and international stakeholders including civil society, international organizations, academia and the private sector (see also 7.3.1).

However, as suggested in previous studies (Bruce et al., 2017; Rosenthal et al., 2017), it is important to ensure that stove financing mechanisms (Section 7.2.2) are not at odds with policy goals. For example, LPG is a fossil fuel, which can curtail its financial viability under climate funds while subsidies to promote its uptake may (depending on the context) be at odds with the implementation of SDG Target 12c regarding the rationalization of fossil fuel subsidies. In this sense it is imperative for stove promotion programs to understand the inherent sustainability trade-offs in every phase of the adoption process, including financing strategies.

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7.3 Directions for future research

As outlined in Section 3.4, this research faced some limitations in relation to: (a) existence of multiple stove use or "fuel-stacking"; (b) one-off survey; (c) simulation or forecasting stove demand; (d) intra-household gender differences; and (e) identification and quantification of SDGs interlinkages affected by clean cooking.

For (a) while this study capitalized on primary stove use, it acknowledges the existence of multiple stove use, where households use more than one stove, a concept often referred to as "fuel stacking". Although the study was able to obtain an inventory of these secondary stoves (see Table 5-2), it was not possible to obtain deeper information about their usage patterns and associated impacts. For (b), whereas this study was one-off due to logistical reasons, it appreciates the existence of external factors including climatic conditions and seasonal variations. Such factors could have substantial ramifications for fuelwood procurement patterns, per capita fuelwood consumption patterns and the associated socio-economic and environmental impacts. In order to improve the fuller estimates of findings in this study, future studies can consider taking into account: (i) frequency and usage patterns of secondary stoves; and (ii) fuelwood collection and consumption patterns across seasonal variations which would require 3-4 survey rounds in a year.

For (c), as outlined in Section 3.2.2.6 of the choice experimental design, the "none of these options" and the status-quo alternative were not included in this survey. This approach was decided based on the study objective, which was to quantify the impact of the relationships and trade-offs between different stove-attribute levels upon stove preference. However, future studies can consider such options (i.e. "none of these options" and status quo alternative) in order to simulate and forecast demand for modern stove alternatives in Kenya.

For (d), in order to identify the gender effects in stove preferences, this study makes a comparison between male-headed households and female-headed households, of which clear-cut disparities were observed. However, the study appreciates that males and females are affected differently in terms of decision-making (i.e. budget control) for stove investment (Section 5.6.3) and stove sustenance in terms of fuel procurement and cooking tasks (Section 6.2.2). In this respect, to establish a more nuanced gender differentiation perspective and to better understand the male/female interaction effects with stove-specific attributes, future studies can aim carrying out similar choice experiments while targeting to capture stove choice behavior and trade-offs for both female and male within the same households.

For (e), this study has built a case that clean cooking options can catalyze impact and substantial positive interlinkages across multiple SDGs (Section 7.2.5). This study proposes for a deeper and iterative analytical exercise to identify and quantify the mediating interlinkages across the respective SDGs targets (see the extended table in Appendix 1). Such a scrutiny would give further directions for key priority policy and practice areas that must be targeted in order to enhance the development (and eventually strengthen) such interlinkages.

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Appendix 1: Pathways through which clean cooking interventions affect SDG targets

SDG	SDG Target	Impact Pathways (adoption and use of clean cooking technologies)	Thesis reference
SDG2: Zero hunger	2.1. Ensure access to safe, nutritious and sufficient food	– Reduce pressure on forests and woodlands that local communities depend upon for the provision of various ecosystem services including food	Section 6.2
		– Bio-slurry from biogas systems is reportedly a valuable organic fertilizer that can boost food crop productivity and crop diversity	Section 6.2.
	2.2. End all forms of malnutrition	– Due to time and monetary savings, households may shift the saved money and time to allow for improved access to food production	Section 6.4
		– Lack of reliable cooking fuel affects women cooking habits such as (a) eat undercooked food (b) cook food items with low nutritional value that require less cooking time, (c) reduce number of meals cooked. All these can affect diet and nutrition	Section 6.2.5
	2.3. Double the agricultural productivity and incomes of small-scale food producers	– Bio-slurry from biogas systems is reportedly a valuable organic fertilizer that can boost food crop productivity and crop diversity (whether for own consumption or income generation)	Section 5.6.1, Section 4.3.6
		– Fuelwood scarcity force households utilize animal dung and crop residues for cooking rather than as agricultural inputs to improve soil fertility	Section 6.2.5
	2.4. Ensure sustainable food production systems to increase productivity and production	– The unsustainable collection of fuelwood has reportedly contributed to mud-slides, loss of watershed, land degradation and desertification, all of which place further pressure on local/regional agricultural productivity	Section 4.3.2
SDG3: Good health and wellbeing	3.1. Reduce the global maternal mortality ratio 3.2. End preventable deaths of newborns and children under 5 years of age	– Indoor air pollution from solid fuels has been linked with adverse pregnancy outcomes like stillbirth, child survival, low birth weight and pneumonia risks in children under the age of five years – Clean-burning stoves (e.g. ethanol stoves) can reduce hypertension and cardiovascular risk to pregnant women	Section 6.6
	3.4. Reduce by one third premature mortality from non-communicable diseases 3.9. Substantially reduce the number of deaths and illnesses from air contamination	– Clean cooking options can reduce prevalence of smoke-related health symptoms and incidences of injuries (burns and scalds) in cooking area.	Section 4.2.2.3 Section 6.6
SDG 4: Quality Education	4.1. Ensure all boys and girls have access to education	– Fuelwood collection can divert children time from education	Section 6.2.5 Section 4.2.2.5
	4.2. Ensure that all girls and boys have access to quality early childhood development	– Time savings from fuelwood collection and cooking with inefficient stoves can provide children with adequate time to play	Section 6.2.5
	4.4. Increase the number of youth and adults who have relevant skills for employment and entrepreneurship	– Activities within the clean cookstoves industry and value chain can fosters the generation of employment, and technical and entrepreneurial skills	Section 4.2.2.4

	4.5. Eliminate gender disparities in education and ensure equal access to all levels, including children in vulnerable situations	– Young girls are more involved in fuelwood collection and cooking activities, which means that they are more likely to miss education due to the time commitment.	Section 6.2.2 Section 6.2.5 Section 4.2.2.5
SDG 5: Gender equality and women empowerment	5.1. End all forms of discrimination against all women and girls everywhere	– Women and girls bear a disproportionate burden in exposure to indoor air pollution and cooking and fuelwood drudgery.	Section 6.2.2
		– Households relying on biomass for cooking dedicate around 4-6 hours each day collecting firewood, and several hours cooking with inefficient stoves, a burden largely borne by women.	Section 6.2.6
	5.2. End forms of discrimination and violence against women and sexual exploitation	– Women and girls bear great risks of physical injury and sexual violence during fuelwood collection trips	Section 6.2.4.1
	5.4 Recognize value of unpaid work within the household and the family	– Time spent on unpaid work (including cooking and fuelwood collection) is often taking for granted, and is often diverted from other household and personal activities	Section 6.4.1
	5.5. Ensure women's effective participation in economic development and equal opportunities	– Time saved from cooking with traditional fuels can be invested for economic development pursuits related to education or career	Section 6.4.1
	5.b. Enhance the use of enabling technology to promote the empowerment of women	– Clean cooking value chains offer opportunities for gender economic empowerment through entrepreneurial activities and employment along stove/fuel value chain	Section 4.2.2.7
	5.c. Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels	– Adoption of clean cookstoves highlights gender issues related to cooking with traditional fuels/stoves and has contributed to suggestion of policies for closing gender gaps, and greater female inclusion and empowerment.	Section 4.2.2.7 Section 6.4.1 Section 7.3.1
SDG 7: Affordable and clean Energy	7.1. Ensure universal access to affordable, reliable and modern energy services	– The stove industry has increased access to clean cooking in Kenya (14% of population in 2017) – In the study areas, more than 30% of the surveyed populations have adopted improved biomass stove – In Kiambu, other stove types include charcoal stoves (7.2%), LPG (10.0%) and electric stoves (0.6%).	Section 5.2.1
	7.2. Increase substantially the share of renewable energy in the global energy mix	– Clean cooking initiatives have introduced various renewable energy technologies including biogas, and solar cookers.	Section 5.2.1
	7.3. Improvement in energy efficiency	– Fuel efficient biomass stoves progressively reduce fuelwood consumption by 40%. – Biogas adoption displace fuelwood consumption of 5.39 tons/household/year by traditional stoves	Section 6.3
	7.a. Enhance international cooperation to facilitate access to clean energy research and technology, energy efficiency and promote investment in energy infrastructure and clean energy technology	– International cooperation through initiatives such as GACC and SE4All have facilitated and created a thriving infrastructure for clean and efficient household cooking solutions, including diversification of business models and enterprises	Section 1.1, Section 4.4.4
SDG 12: Sustainable Consumption	12.2. Achieve the sustainable management and efficient use of natural resources	– Clean and fuel-efficient stoves either completely divert or reduce fuelwood consumption, reducing pressure on forests, local woodlands and hence contributing to their conservation, – e.g. improved biomass stoves reduce fuelwood consumption by 40%. – Biogas displace fuelwood consumption of 5.39 tons/household/year by traditional stoves	Section 6.3
	12.3. Reduce per capita global food waste at the retail and consumer levels and reduce food losses	– Most clean cooking designs can regulate cooking temperature and heat intensity to cook meals that were either previously not consumed as they required long cooking times (i.e. required large amounts of fuel) or are heat sensitive with high spoilage risk	Section 4.2.2.6 Section 6.2.5

	12.a. Support developing countries to strengthen their scientific and technological capacity	– The clean stove sector engages with investors to raise awareness about the technological opportunities in the sector and broker relevant deals (including the development of cookstove testing centers)	Section 1.3
	12.c. Rationalize inefficient fossil-fuel subsidies minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities	– There have been instances of using economic disincentives or reversing subsidies to reduce the consumption of conventional cooking fuels and promote clean cooking options, – e.g. in 2016, the Government of Kenya increased the cost of kerosene, reduce 16% VAT for LPG in order to influence the adoption of cleaner cooking fuels. This decision was based on evidence of the toxic effects of kerosene on human health, and a desire to promote cleaner cooking fuel at the household level	Section 1.2.2
SDG 13: Climate Action	13.1 Strengthen resilience and adaptive capacity to climate-related hazards	– Clean and fuel-efficient stoves either completely divert or reduce the need for fuelwood consumption, reducing pressure on forests and local woodland. This often contributes to reduced landslides, land degradation and forest restoration	Section 6.3 Section 4.3.2
	13.2. Integrate climate change measures into national policies, strategies and planning	– The adoption and implementation of stove initiatives can increase the ability of country to mitigate and adapt to climate change	Section 6.5
	13.3. Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction	– The clean cooking sector has raised awareness about the negative effects of traditional cooking on the global climate due to deforestation and GHG emissions	Section 6.5
SDG 15: Biodiversity, forests and diversification	15.1. Ensure the conservation, restoration and sustainable use of terrestrial ecosystems and their services 15.2. Promote the implementation of sustainable management of all types of forests 15.3. Combat desertification, restore degraded land and soil 15.4. Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity	– Clean and fuel-efficient stoves either completely divert or reduce the need for fuelwood, reducing pressure on forests and contributing to their conservation – e.g. improved biomass stoves reduce fuelwood consumption by 40%. – Biogas displace fuelwood consumption of 5.39 tons/household/year by traditional stoves	Section 1.4.2 Section 4.3.2 Section 6.2 Section 6.3
SDG 17: Partnerships	17.7. Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries 17.9. Enhance international support for implementing effective and targeted capacity-building in developing countries to support national plans to implement all the Sustainable Development Goals 17.14. Enhance policy coherence for sustainable development 17.16. Enhance the global partnership for sustainable development to support the achievement of the sustainable development goals in all countries	– The Global Alliance of Clean Cookstoves (GACC) has influenced and catalyzed the development of dynamic partnerships of a wide range of partners and stakeholders in developing countries including Kenya. – Section 1.3 identified that there exists a plethora of other stakeholders with vested interest in clean bioenergy cookstoves (Table 1 5). These include stakeholders from government institution, NGOs, research organization, donors and international organizations. – Figure 7-1 has provided a synthesis of possible collaborations and interactions between stakeholders, and what these interactions can provide for strengthening the clean cooking sector. – These partnerships engage with investors to raise awareness about opportunities in the sector and broker relevant deals that can enable scaling up adoption of clean cooking technologies. – This engagement includes attending selected investor fora and highlight profitable investments in the clean cooking sector.	Section 1.1 Section 1.3 Chapter 4

Appendix 2: Multidimensional poverty dimensions, indicators, relative weights and cut-offs

(Source: adapted from Alkires and Santos, 2014)

Dimension	Indicator	Cut-off deprivation	Weight
Education	Years of schooling	No household member has completed 5 years of schooling	1/6
	Child school attendance	If any school-age child is not attending school in years 1-8	1/6
Health	Nutrition	Below the acceptable Food Consumption Score (FCS) i.e. an FCS of 35 or below	1/6
	Child mortality	A child has died within the household in the last 5 years	1/6
Living Standards	Improved drinking water	The household does not have access to improved drinking water or safe drinking water is more than a 30 min walk away from home	1/18
	Improved sanitation	The household's toilet facility is not improved or is improved but shared with other households	1/18
	Clean cooking fuel	The household cooks with dung, charcoal or wood	1/18
	Electricity	The household has no electricity.	1/18
	Flooring material	The flooring material is made of dirt, sand or dung	1/18
	Asset ownership	The household does not own more than one radio, TV, telephone, bike, motorbike or refrigerator; and does not own a car, truck or tractor	1/18

The Adjusted Headcount Ratio (Mo), measures the incidence and intensity of poverty based on Eq. (1):

$$Mo = H \times A \qquad (1)$$

where "H" denotes the incidence of poverty representing the percentage of the population that is poor in a sample (see Eq. 2). and "A" denotes the intensity of deprivation across the poor (see Eq. 3).

$$H = q/n \qquad (2)$$

where q denotes the number of people identified as poor and n the total number of people in the sample.

$$A = \sum_{i=1}^{n} \frac{C_i(k)}{q} \qquad (3)$$

where $C_i(k)$ denotes the censored deprivation score which (k) indicates the share of possible deprivation experienced by the poor person i.

Considering the Equations 1-3, the Adjusted Headcount Ratio (Mo) is expressed as:

$$M_0 = \sum_{i=1}^{n} \frac{C_i(k)}{q} = HxA = \frac{q}{n}\, x \frac{1}{q} \sum_{i=1}^{q} C_i(k) = \frac{1}{n} \sum_{i=1}^{n} C_i(k) \qquad (4)$$

Appendix 3: Multidimensional energy poverty dimensions, indicators, relative weights and cut-offs

(Source: adapted from Nussbaumer et al., 2013)

Dimension	Indicator	Deprivation cut-off (household is energy poor if…)	Weight
Cooking	Modern cooking fuel	use any fuel beside electricity, LPG, kerosene, natural gas, or biogas	0.2
	Indoor pollution	Food cooked on stove or open fire (no hood/chimney) if using any fuel beside electricity, LPG, natural gas, or biogas	0.2
Lighting	Electricity access	Has no access to electricity	0.2
Services provided by means of household appliances	Household appliance ownership	Has no fridge	0.13
Entertainment / education	Entertainment/ education appliance ownership	Has no radio OR television	0.13
Communication	Telecommunication	Has no phone land line OR a mobile phone	0.13

The Adjusted Headcount Ratio (Mo), measures the incidence and intensity of energy poverty based on Eq. (1):

$$Mo = H \times A \tag{5}$$

where "H" denotes the incidence of energy poverty representing the percentage of the population that is energy poor in a sample (see Eq. 2). and "A" denotes the intensity of deprivation across the energy poor (see Eq. 3).

$$H = q/n \tag{6}$$

where q denotes the number of people identified as energy poor and n the total number of people in the sample.

$$A = \sum_{i=1}^{n} \frac{C_i(k)}{q} \tag{7}$$

where $C_i(k)$ denotes the censored deprivation score which (k) indicates the share of possible deprivation experienced by the energy poor person i.

Considering the Equations 1-3, the Adjusted Headcount Ratio (Mo) is expressed as:

$$M_0 = \sum_{i=1}^{n} \frac{C_i(k)}{q} = HxA = \frac{q}{n}\, x \frac{1}{q} \sum_{i=1}^{q} C_i(k) = \frac{1}{n} \sum_{i=1}^{n} C_i(k) \tag{8}$$

Appendix 4: Copyright permissions to reuse stove images

From: Doi Germann <DorsiGermann@web.de>
Date: Thursday, November 15, 2018 17:53
To: ALICE RUGURU KARANJA <alice.karanja@s.k.u-tokyo.ac.jp>
Subject: Aw: Request to reuse stove images in a journal

Dear Alice Karanja,
best regards from Ramallah/Palestine, where I am actually doing workshops for a local NGO. One of the objectives of our publication "Stove Images" was the use of our findings worldwide for spreading information and contributing to a more sustainable world. Therefore, your request is answered positively. As my internet access and electronic devices here are limited, I will give you my permission in the following way, hoping that it may be acceptable too :

As one of the authors and copyrightholders of "Stove Images" I give you the permission to use articles or photos or drawings from the book for use in different ways but only for non-commercial and non-profit purposes- by acknowlodging refrences. My friend and colleague Beatrix Westhoff died 10 years ago.

Would it be possible, to send us a digital version of your publication after finalisation?
With my best wishes for a successful continuation of your work and best regards from Palestine,

Dipl.Soz. Dorsi Doi Germann
Europa Universität Flensburg
Department Energy and Environmental Management / EEM-SESAM
Munketoft 3 B
24937 Flensburg/Germany
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Fax: +49-461-805 2505
Email: germann@uni-flensburg.de ; dorsigermann@web.de
www.uni-flensburg.de/eem
www.doi-germann.eu

From: "Ingwe, Anna GIZ KE" <anna.ingwe@giz.de>
Date: Thursday, November 15, 2018 16:22
To: ALICE RUGURU KARANJA <alice.karanja@s.k.u-tokyo.ac.jp>
Subject: RE: Request to reuse stove Images in a journal

Dear Alice,

Thank you for your mail.

I do agree to your use of the photos on the following preconditions:

- With the new EU Regulation on Data, I only say yes to the photo as long as there is **no face of a person**. This means if it is just photos showing different stove type , it is ok. But if there is someone photo we have to get a Consent from the actual person by signing some sort of agreement with us.
- Acknowledge the GIZ – EnDev Kenya as the source of the photo.

I hope this should be enough to get you going unless you need more clarification.

Kind regards, Anna

Appendix 5: Household Survey Questionnaire

SECTION A: RESPONDENT'S PERSONALPROFILE

To be administered to all respondents (household head or the spouse)

1. Key information on the respondent.

1.1 GPS location		1.2 Gender of respondent	1=Male 2=Female
1.3 Name of respondent			1.5 Age of respondent _________ Years
1.4 Mobile number			
1.6. Are you the head of the household?	1=Yes 2=No	1.7. What is your relationship with the household head	1=Head 2= Husband 3= Wife
1.8. Religion	*1= Christian* *2= Muslim* *3= Traditional* *4= No religion* *5= Other, specify*	1.9. Ethnicity	1= Kikuyu 2= Kamba 3= Luhya 4= Luo 5=Other, specify
2.1 For how many years have you been living in this area? ______________ *Years*			

SECTION B: HOUSEHOLD DEMOGRAPHICS AND SOCIO-ECONOMIC PROFILE

1.1. Do you own this house?	1=Yes 2=No	1.2. If yes, how did you acquire it?	*1= Bought land and built the house* *2= Inherited the house from parents* *3= Inherited the land from parents and built the house* *4=Leased* *5=Other, specify*_________
1.3. Describe the type of material used to construct the house? *(Select relevant options)*	☐ *Iron sheets roof* ☐ *Wooden wall* ☐ *Cemented/concrete Floor* ☐ *Thatch roof* ☐ *Cement/concrete wall* ☐ *Earthen/dung/sand floor* ☐ *Iron sheets wall*	1.4. Does the household own the following assets?	1= *TV* 2=*Mobile phone* 3=*Car.* 4=*Radio* 5=*Refrigerator.* 6=*Bicycle* 7=*Motorbike* 8=*Truck/tractor*
1.5. Is the household connected to the electricity grid? *1= Yes. 2=No*	1.6. From where do you get water for drinking and household use? *1=Tap water* *3= Fetch from river/well* *2= Communal tap* *4=Rain water* *5= Other, Specify*_____	1.7. How far is this source of water from the household? ***(Ask for roundtrip distance)***	_________ *Walking minutes* _________ *kilometres*
1.8 What type of toilet facility do you have in this household?	*1=Pour flash toilet to pit latrine* *2=Open pit latrine* *3=Flush to piped sewer system* *4=Pit latrine with slab*	1.9. Do you share the toilet facility with other households?	*1= Yes* *2= No*

2. **I would like to find out the following information about children below 18 years living in this household:**

2.1. How many children below 18 years live within this household? _________ Number of children

2.1.1. How many of these children have reached school age and are not going to school? _______ Number of children

2.2. How many members of the household have passed away in the past 5 years? _____ persons

2.2.1. Of those, how many were children less than 6 years old? ________ Number of children

3. For each member of your household (*including yourself*), please tell us the following information:

3.1. What is their relation to you? *Insert the response in the relevant column in the table below.*

3.2. What is their age? *Insert age (in years)*

3.3. What is their gender? *Insert (1) if male, (2) if female*

3.4. How many months in a year does this person live in your house? *Insert the number of months per year*

3.5. What is the highest education level he/she has attained?

3.6. What is his/her MAIN occupation? *Insert as appropriate.*

3.7. How many months is he/she employed every year? *Insert number*

3.8. What is her/his monthly salary? *Insert as appropriate.*

	3.1.	3.2.	3.3.	3.4.	3.5.	3.6	3.7.	3.8	3.8.1
	HH-member Relation to respondent *1= Household Head* *2=Wife/husband* *3 = Child* *4 = Brother/ Sister* *5 = Grand Child* *6 = Other (Specify)_______*	Age (years)	Gender *1 = Male* *2 = Female*	Number of Months per year this person lives in the house	Education *1=No formal schooling* *2=Some primary schooling* *3=Completed primary schooling* *4=Some secondary schooling* *5=Completed secondary school* *6=Completed college/university* *7=Completed post-graduate*	The person's main occupation *1=Farmer* *2= Company Employee* *3=Other agricultural labor* *5=Civil Servant,* *6=Self-run business* *7=Unemployed* *8=Retired* *9= Student in Boarding school* *10= Student in day school* *12= Other (specify)_________*	Months per year this person is employed	Monthly salary *(exact amount)*	Monthly salary *(range in local currency)* *1=Below 10,000* *2=10001-15,000* *3=15,001-20,000* *4=20,001-25,000* *5=25,001-30,000* *6=30,001-35,000* *7=35,001-40,000* *8=40,001-45,000* *9=45,000-50,000* *10=Above 50,000*
Respondent									
HHM1									
HHM2									
HHM3									
HHM4									
HHM5									
HHM6									
HHM7									
HHM8									
HHM9									
HHM10									

SECTION C: HOUSEHOLD ENERGY AND ACCESS

To be administered to all respondents

4. I would like to find out information about the fuels you use for cooking food.

4.1. In the past one year, from where does your household get MOST of its to cook with? (Quantity)	1=Collect 2=Purchase from Market 3=Other Sources	4.2. For the past one year, which is the MAIN source where the household collects MOST of its to cook with?	1=Own woodlot 2=Trees on cropland 3=Communal Woodlot 4=Collect from Roadside 5=Hedgerows/farm boundary 6=State Forest 7=Local communal forest 8=Local private forest 9=Shrub/bush area 10=Other, specify
4.3. Do you collect/purchase firewood on daily, weekly, monthly or yearly basis?	1=Daily 2=Weekly 3=Monthly 4=Yearly	4.4. Specify the number of times	
4.5. How far (meters) from the house is this area where you MOSTLY get for cooking?		4.6. How long, does it usually take in a day, to get to the area you collect MOST of the fuelwood and come back?	
4.7. What means of transport do you most frequently use to carry for cooking?	1=Back/head/hand 2=Motorbike/Bicycle 3=Donkey 4=Vehicle 5=Other, select to specify	4.8. Compared to the current area where you collect most of your fuelwood, would you say this distance has increased, decreased or remained the same?	1=Increased Significantly 2=Increased Slightly 3=Remained the same 4=Reduced Slightly 5=Reduced Significantly 0=Do not Know/Cannot tell
4.9. From the moment you reach your main collection area, how long (minutes) does it take you to gather one bundle of		4.10. Approximately how many bundles of (quantity) do you usually gather per collection trip?	
4.11. How much money does it cost you to purchase one bundle of fuelwood?		4.12. What are the specific tree parts you prefer for fuelwood	1=Twigs 2=Branches 3=Roots/trunks 4=Leaves 5=Logs/stem
4.13. Which household member MOSTLY collects fuelwood for cooking in this household?	1=Husband 2=Wife 3=Boy/s 4=Girl/s 5=Other, specify	4.14. Which household member MOSTLY provides money to buy for cooking in this household?	1=Husband 2=Wife 3=Boy/s 4=Girl/s 5=Other, specify
4.15. Which household member is MOSTLY responsible for cooking tasks in the household?	1=Husband 2=Wife 3=Boy/s 4=Girl/s 5=Other, specify	4.16.	

4.17. How many bundles of fuelwood, in TOTAL, does the household usually use for cooking in an average week?		4.18. What type of cooking stove do you MOST FREQUENTLY use for cooking using fuelwood?	1=Traditional 3-stone Fire 2=Improved Firewood Stove 3=Advanced Firewood Stove
4.19. Please tell me ALL of the different types of cooking fuels that are used for cooking in this household?	1=Charcoal 2=Kerosene/Paraffin 3=LP Gas 4=Biogas 5=Ethanol 6=Electricity 7=Briquettes 8=Pellets 9=Animal Dung 10=Crop residues 11=Firewood 12=Sawdust	4.20. Could you please tell me all of the different types of cooking stoves that you have in this household?	1=Traditional three stone fire 2=Improved biomass stove 3=Traditional Charcoal Stove (4=Improved Charcoal Stove 5=Kerosene Stove 5=LPG Stove 6=Ethanol Stove 7=Biogas Stove 8=Electric Stove 9=Briquette Stove 10=Pellet Stove
4.21. What is the most often used stove		4.22. How did you initially get to know/learn about this stove?	1=Campaigns in media 2=Neighboring households 3=Introduced by cooperatives 4=Social groups 5=Stove Promoters 6=My mother used it/it's our culture 7=Other
4.23. When did you acquire or start using this stove in this household?	YYYY	4.24. How much money did it cost you to purchase this stove for cooking?	
4.25. Which household member brought up the idea to acquire this stove in this household?	1=Husband 2=Wife 3=Son 4=Daughter	4.26. Which household member provided the money to purchase this stove?	1=Husband 2=Wife 3=Son 4=Daughter
4.27. Why did you acquire for cooking in this household over other available stove options in the market? (*select all that apply*)	1=Affordable stove cost 2=Reduced fuel usage 3=Lower fuel cost 4=Cooking time savings 5=Reduced fuel procurement time 6=Space heating/warming 7=Attractive appearance 8=Portability 9=Prestige or social status 10=Smoke and soot reduction 11=Kitchen safety 12=Kitchen hygiene and cleanliness 13=It's good for my health 14=Lower stove maintenance cost 15=Fuel availability 16=It was the only option I had 17=Other reasons? Specify	4.28. Out of all the reasons you have mentioned, which one would you say was the most important when you were making the decision to acquire the stove?	1=Affordable stove cost 2=Reduced fuel usage 3=Lower fuel cost 4=Cooking time savings 5=Reduced fuel procurement time 6=Space heating/warming 7=Attractive appearance 8=Portability 9=Prestige or social status 10=Smoke and soot reduction 11=Kitchen safety 12=Kitchen hygiene and cleanliness 13=It's good for my health 14=Lower stove maintenance cost 15=Fuel availability 16=It was the only option I had 17=Other reasons? Specify
4.29. Do you keep/use more than one cooking stove in the household?	1= Yes 2= No	4.30. Why do you keep/use more than one cooking stove in the household?	1= Space heating/warming 2= Social/large gathering 3= Cook traditional dishes 4= Cook some specific meals 5= Technical problems with the main stove 6= Fuel shortage with main stove 7= Other

4.31. Are you aware that there exist better cooking stoves in the market?	1= Yes 2= No	4.32. What can you say prevents you from acquiring one?	1=I cannot afford other stoves 2=I don't control household budget 3=High maintenance cost for other stoves 4=Lack of skills to operate other stoves 5=Fuel types not available 6=I prefer this stove 7=Culture and traditions 8=Other reasons, specify
4.33. Please think of how much time is required to prepare a typical meal with the (from the time you collect or purchase the fuel, light the fire to the time the food is done cooking) compared to the time you were using the former stove(s). How would you say this time has changed?	1= Increased significantly 2= Increased slightly 3= Remained the same 4= Reduced slightly 5= Reduced significantly 6= Do not Know/Cannot tell	4.34. How have you been USUALLY using the time saved?	1= Agricultural/farm activities 2= Helping children with their studies 3= Taking care of children and other members of household 4= Cleaning and other domestic chores 5= Income generating activities 6= Social activities 7= Leisure/resting/recreational activities 8= Saved time too small to use for any specific purpose 9= Other, specify
4.35. What are the positive attributes ("things") you have experienced in your everyday life from the use of	1= Cooks faster 2= Time savings 3= Money savings 4= Smoke reduction 5= Improved food taste 6= Kitchen safety/hygiene 7= Prestige and social status 8= Fuel Savings 9= Other, specify	4.36. What is the MOST IMPORTANT characteristic that an ideal stove for your household should have?	1= Cook faster 2= Use less fuel 3= Reduce smoke 4= Provide prestige and a higher social status 5= Save money 6= Affordable stove cost 7= Offer Kitchen safety and hygiene 8= Other, specify
4.37. I am going to name a health or safety risk, and I want you to tell me how frequently you or the main cook have experienced it while cooking with stove X within the past 30 days?	1= Burns/scalds 2= Eye irritation 3= Coughing/phlegm 4= Breathing difficulties 5= dizziness 6= Irritation of nose and throat 7= Head-ache	4.38. Since the time you started cooking using, would you say you feel more safe, more unsafe compared to the time you had the former stove?	1= Significantly safe 2= Slightly safe 3= About the same 4= Slightly Unsafe 5= Significantly Unsafe 6= Do not Know/Cannot tell
4.39. Do you have young children (less than 5 years old)?	*1= Yes* *2= No*	4.40. Do they stay in the kitchen with you while you are cooking or when food is being cooked?	*1= Yes* *2= No*
4.41. How long (hours) in a day do the young children spend with you in the kitchen while cooking?		4.42. Do you ever experience fuel shortage to cook with in this household?	*1= Yes* *2= No*
4.43. In the past four weeks, did you have to as a result of lack of sufficient fuel to cook with?	1= Cook fewer meals 2= Eat cold food 3= Eat already-cooked meals 4= Omit cooking foods that require longer time to cook 5= Eat dry foods that don't require cooking e.g. bread 6= Cut other household budgets for fuel 7= Cut fruit trees for fuelwood	4.44. Are you or any other person in this household an active member of the following groups?	1= Religious Group 2= Credit or micro-finance group (chama/SACCOs) 3= Mutual help group (sickness or burial societies) 4= Forest user group 5= Water user group 6= Trade and business association 7= Agriculture/livestock producer groups/cooperatives 8= Family-based Group

	8= Walk for longer distance in search of fuel 9=Switch to low quality or less preferred fuel type 10=Cook using wet/green wood 11=Use crop residues/animal dung for cooking		9= Civic groups (improving community) or charitable group (helping others)
4.45. Where is the cooking done?	*1= In same room used for living/sleeping* *2= In a separate room used as kitchen within the living/sleeping building* *3= In separate building used as kitchen* *4= Outdoors* *5= Other, specify*	4.46. Describe the kitchen design and characteristics	*1= Room with Windows* *2= Room with eave spaces* *3= Four walled room with a door* *4=Room with three or fewer walls* *5= Kitchen has hood/chimney* *6= Other feature, specify*

SECTION E: INCOME AND LIVELIHOOD SOURCES

To be administered to all respondents

5. How much **income** did your household **as a whole** receive in the past twelve months from each of the following activities?

Consider activities from all household members. If more than one member of the household is involved in the same activity, please sum incomes and insert the overall household income.

Note: We have already asked in previous parts of the survey about activities (…). Remind the respondents and ask if they want to add more.

		5.1. Monthly income *(exact amount in KES)*	**5.2. Monthly income** *(range in KES)* 1=below 5,000 2=5,001-7,000 3=7,001-10,000 4=10,001-15,000 5=15,001-20,000 6=20,001-25,000 7=25,001-30,000 8=30,001-35000 9=35,001 - 40000 10=Above 40,000
1.	Farming cash crop (tea and/or coffee)		
2.	Farming food crops		
3.	Selling farm trees/timber		
4.	Selling bioslurry		
5.	Goods collected from nature		
6.	Permanent employment		

7.	Seasonal employment/casual labour		
8.	Own business/self-employment		
9.	Remittances *		
10.	Pension		
11.	Social Security Benefit		
12.	Other 1 (Specify)__________________		
Total Annual Household Income			

First ask exact income per month or year. If not known or unwilling to say, ask for a range.
**(ask also if they receive money from family members not living in the household anymore)*

6. How much did your household spend in the past year for each of the following expenditure items? *Insert amount per month OR per year, depending on what is easier for the interviewee.*

Note: Initially ask exact expenditure per month or year. If not known or unwilling to say, ask for a range

	6.1.	6.2.	6.3	6.4
	Monthly expenditure *(exact amount in KES)*	**Monthly expenditure** *(range in KES)* 1= below 1,000 2=1,001-3,000 3=3,001-5,000 4=5,001-7,000 5=7,001-10,000 6= 10,0001-20,000 7=20,001-50,000 8=Above 50,000	**Annual expenditure** *(exact amount in KES)*	**Annual expenditure** *(range in KES)* 1=below 15,000 2=15,001-35,000 3=35,001-60,000 4=60,001-85,000 5=85,001-100,000 8=Above 100,000
1. Food				
2. Land (buy, rent)				
3. Education				
4. Health				
5. Housing				
6. Clothing				
7. Communication (e.g. air-time)				
8. Transport				
9. Fuel				
10. Leisure				
11. Supporting relatives/ friends				
12. Gifts/ Charities/ Ceremonies				
13. Savings				
14. Other_________________				